GEOPRESSURE ANALYSIS OF CRETACEOUS STRATA IN ZAMZAMA GAS FIELD, SOUTHERN INDUS BASIN, PAKISTAN

BY

MOHAMMAD IKRAM AFRIDI
USMAN ASGHAR

Department Of Earth And Environmental Sciences
Bahria University, Islamabad

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A thesis submitted to Bahria university, Islamabad in partial fulfillment of the requirement for the degree of BS in Geophysics

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USMAN ASGHAR

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ABSTRACT

The current research is carried out to identify the subsurface structures, reservoir properties and evaluate their geopressures for safely hydrocarbon production in Zamzama area. For this objective seismic and well data is used to perform Seismic Data Interpretations, Petrophysical Analysis and Geo-pressure evaluations. In seismic data interpretation, structural interpretation is carried out on four dip lines and two strike lines. Five horizons are marked on seismic sections by confirming their position with the help of well to seismic tie. These marked horizons are Kirthar, Laki, Dunghan, Pab and Fort Munro of Zamzama area. The deformation of the anticline structure is marked by two thrust faults named as F1 and F2. Time and depth contour maps are generated for Pab sandstone due to its primary reservoir property in the area. For petrophysical analysis of Zamzama North-01 well's several parameters are evaluated for hydrocarbon bearing zones. The analysis carried out for Pab sandstone concluded the volume of shale as 17.93 %, the average porosity 7%, effective porosity 5.68%, water saturation 61.39 % and hydrocarbon saturation 38.61%. For Geo-pressure evaluation, Hydrostatic pressure, Overburden pressure and Pore pressure of Paleocene and Cretaceous strata of Zamzama area are calculated. The abnormal pressure zones are identified using Eaton's method. The evaluation of pore pressure predicts that there are mainly over pressured zones in the lower formations of Zamzama area. A very few under-pressure zones are also identified during this evaluation.

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CHAPTER 1
INTRODUCTION

Geopressure Analysis is the combine evaluation of hydrostatic pressure, overburden pressure and pore pressure in order to predict the abnormal pressured zones prior to drilling operations. If the abnormal pressure, mainly over pressure, is not predicted accurately before drilling and while drilling, can cause non-productive time taking catastrophic incidents such as well blowouts, pressure kicks and mud volcanos. (Dodson, 2004, Davies et al., 2007). The abnormal pressure occurs when pore pressure is not in equilibrium with hydrostatic pressure. When pore pressure is higher than hydrostatic pressure it creates overpressure zones and when its lower then hydrostatic pressure it creates under pressure zones. Hydrostatic pore pressure is generated by normal compaction, when the rate of sedimentation is in equilibrium increases with reduction of pore fluid volume. When there is high sediment influx, prevents the fluid in pore spaces from expulsion and the overburden compaction increases. This compaction disequilibrium generates abnormal pressure conditions mainly overpressure zones (Mouchet and Mitchell, 1989).

The integration of seismic data with wells and geological data forms a reliable method for illustrating the geological features beneath the Earth's surface. (Moghal et al. 2007; Ghazi et al. 2014). Seismic data interpretation and petrophysical analysis are fundamental disciplines in the field of geosciences, serving as powerful tools for unraveling the mysteries hidden beneath the Earth's surface. The exploration and development of natural resources, such as oil and gas reservoirs, rely heavily on the precise representation of subsurface geological structures and rock properties. Seismic data method relies on the analysis of seismic waves that travel through the subsurface and return valuable information about the composition, layering, and properties of the underlying rock formations. While petrophysical analysis enables the characterization of reservoir rocks and their fluid content. The integration of these two disciplines contributes significantly to the understanding of the Earth's subsurface, guiding efficient resource exploration and extraction strategies.

1.1 Location of Study Area

Zamzama is one of several gas resourses found in the Sindh Province of Pakistan. The Gas field is covering about 120 square kilometers. This field is regarded as the fourth largest gas field in Pakistan. It lies about 200km north of Karachi. The Zamzama field is situated about eight kilometers east of Sui Southern pipeline, which transports gas from the Sui field to Karachi. The Zamzama field is bordered to the southwest by the Bhit gas field and to the northeast by the Kadanwari, Sawan, and Miano fields. (Qureshi et.al,2022).

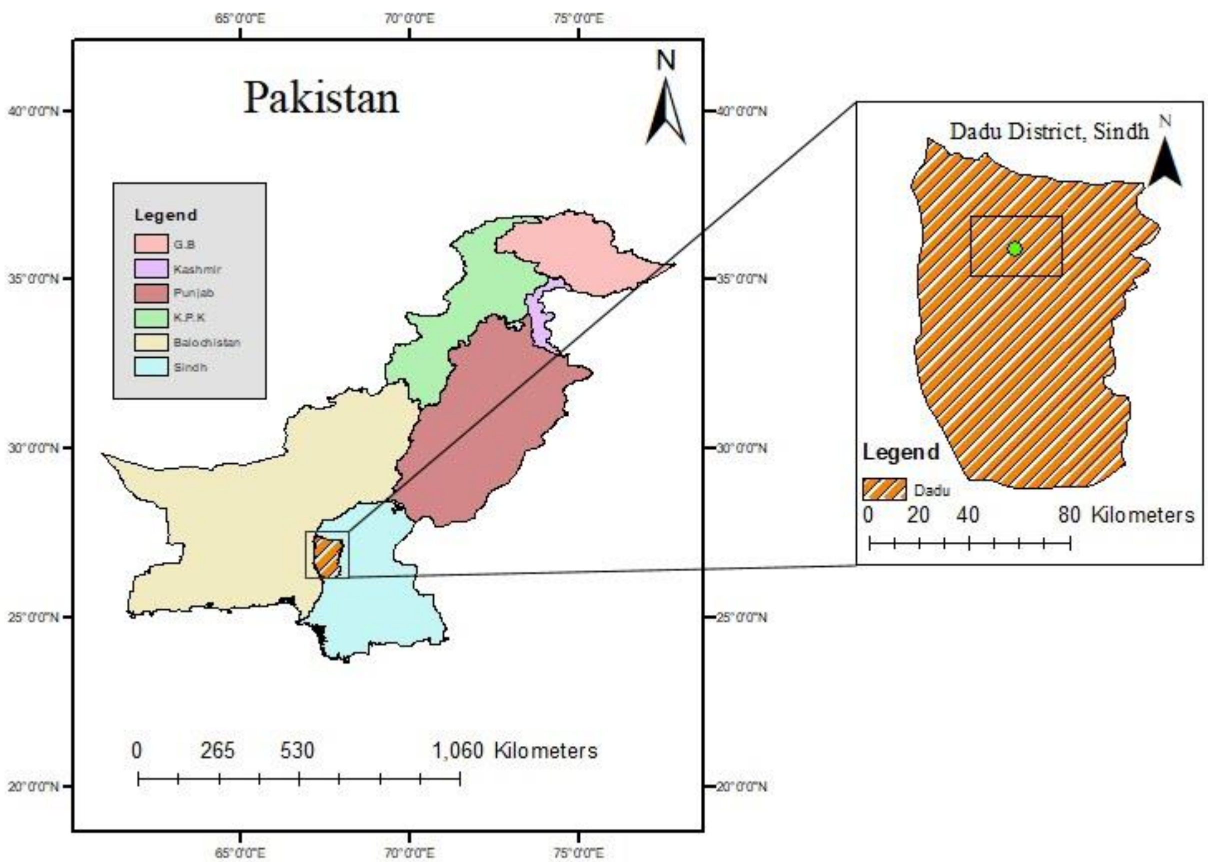

Figure 1.1: Location of study area showing Pakistan provincial map in which Dadu district of Sindh province is highlighted. The Dadu district showing green color location mark of Zamzama gas field (Digitized in GIS).

1.2 Exploration History

The first exploration well on the field, Zamzama-1/ST1, was drilled in 1998. But in late 1950s, the Phulji-1 and Phulji-2 wells were dug in order to find oil-bearing carbonates of the Tertiary strata, was the first attempt to explore the Zamzama gas field (Jackson et al. 2004). Due to the inability to penetrate till the gas carrying the Cretaceous to Paleocene Pab and Khadro reservoir, both wells were declared dry. Additional seismic data was used to investigate the ineffective results, and it was discovered that the Phulji-1 well was abandoned before reaching the Pab reservoir by a few meters (Quadri and Quadri 1998). Petroleum was granted an operating interest in the Dadu Concession (Block 2667-1) in February 1995. The following year, the company recorded 196 kilometers of 2-D seismic data that resulted to the discovery of the Zamzama structure. Later in 1998 the first exploration well on Zamzama field named Zamzama-1/ST-1 drilled up to 3938 meters as hydrocarbon were encountered in Khadro and Pab sandstones of Paleocene and late Cretaceous age respectively. The Zamzama gas field portrays as BHP Billiton's first commercial production in Southern Indus of Pakistan (Garratt et.al,2003).

1.3 Research Objective

The principal objective of this research is to comprehensively study of the subsurface geological formations within the study area and acquire the hydrocarbon potential, as well as the engineering properties. To accomplish our goal and objectives, we have to perform certain steps

(1) To gain insights into the subsurface geological structures and formations.

(2) To characterize key properties of the subsurface rocks for evaluating reservoir potential.

(3) Identification of abnormal pressure zones using log data.

1.4 Data Required

The data used to interpret the Subsurface structure of Zamzama area, has been obtained from Directorate General of Petroleum Concessions (DGPC), Ministry of Petroleum and Natural Resources, Islamabad, Pakistan. The data sets are as followed

(1) Navigation file

(2) Seismic lines

(3) Well data

1.4.1 Seismic data

Seismic data (seg-y format) provided by DGPC contains 2 strike lines along with 4 dip lines used for interpretation of subsurface structures of Zamzama Area.

Table 1.1 List of the seismic lines their type and orientation

Seismic lines	Line type	Orientation
GPHK 96-08.ext	Strike line	Northeast-Southwest
GPHK 98A-33	Strike line	Northeast-Southwest
GPHK 98A-32	Dip line	East-West Trending
GPHK 98A-34	Dip line	East-West Trending
GPHK 98A-36	Dip line	East-West Trending
GPHK 98A-38	Dip line	East-West Trending

1.4.2 Well Data

Following well logs were provided by DGPC in form of las file to perform petrophysical interpretation and pore pressure calculation of Zamzama North-01 well;

(1) Sonic Log (SPHI)

(2) Caliper Log (CAL)

(3) Gamma Ray log (GR)

(4) Litho-Density Log (PEF)

(5) Resistivity Logs (MSFL, LLS, LLD)

(6) Neutron Log (NPHI)

(7) Spontaneous Log (SP)

1.5 Methodology

Seismic and well data were interpreted through Gverse Geographix 2019.4. This software is used for time-depth chart, horizon marking, fault marking. For structural as well as stratigraphic interpretation, five prominent reflectors (top of the Kirthar, Laki, Dunghan, Pab and Fort Munro formations) were marked on the seismic lines. These marked reflectors were correlated with well tops to confirm their position on seismic lines. Moreover, a time and depth contour maps were created on top of the Pab Sandstone to identify the structural trend and deformation style.

While in petrophysical analysis involves the creation of log curves from log trends and well data. Then, these log curves are examined to derive and analyze a wide range of petrophysical properties of the geological formation under investigation. For this process, we used GeoGrphix Discovery to calculate porosity, velocity, shale content, hydrocarbon saturation etc. to conclude our petrophysical analysis.

The sequence of methodology for this research is given as follow:

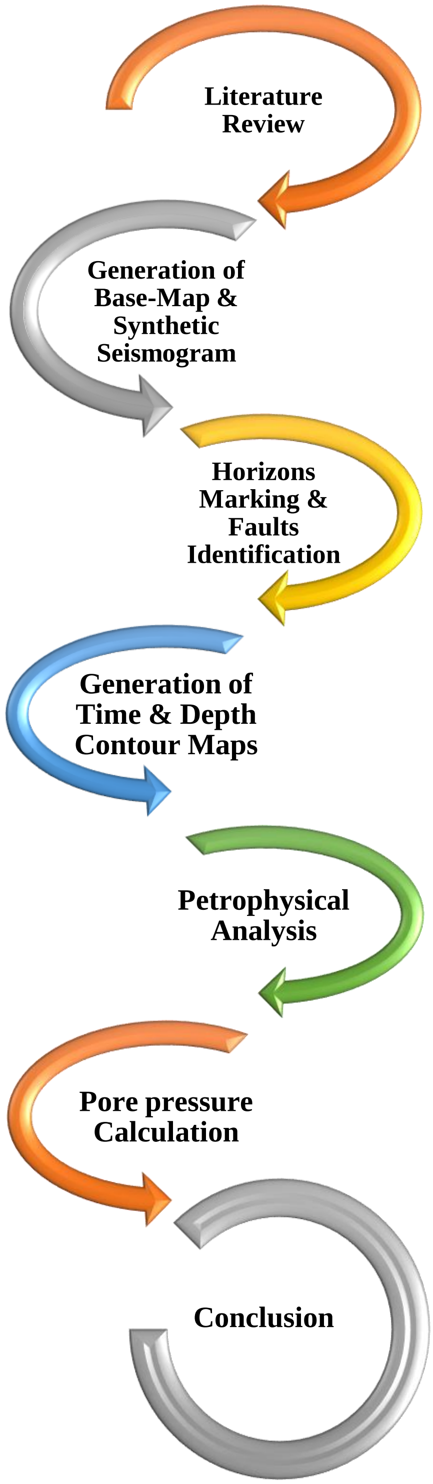

Figure 1.2 Methodology Sequence used in this Research.

CHAPTER 2
GEOLOGICAL SETTINGS

2.1 Basic Geology

Pakistan is situated on two plates known as the Indian and Eurasian plateaus. The portion of the Indian plate is known as the Gondwanian domain, while the portion of the Eurasian plate is known as the Tethyian domain (Kazmi and Jan, 1997). During the Permian period, both were part of a supercontinent known as Pangaea, which was surrounded by a body of water known as Panthalasa (Weganer,1600). Pangaea split into two pieces during the late Triassic period, Gondwanaland and Laurasia. Laurasia went to the north, while Gondwanaland shifted to the south. During the Cretaceous period, Gondwanaland divided into five geological plates, one of which being the Indian plate (Weganer,1600). The Indian plate drifted northward towards Laurasia as it separated from Gondwanaland. During this journey, intra-oceanic subduction occurred in the Late Cretaceous, resulting in the formation of the Kohistan Island Arc (KIA). This activity lasted until the Eocene, when the Tethys closed completely and the Indian plate collided with KIA, at which point KIA was accumulated with the Eurasian plate. As a result, the Himalayas were formed. In Pakistan, the Main Mantel Thrust (MMT) indicates the collision zone in the north, while the Chamman fault refers to the collisional border between the Indian and Eurasian plates in the south-west. (Kazmi and Jan, 1997)

2.2 Geology and tectonics of lower Indus Basin

The southern Indus basin ranges roughly from Latitude 24 N - 28 N and Longitude 66 E to Pakistan's eastern border and features the Thar Platform, Karachi Trough, Kirthar Foredeep, Kirthar Fold Belt, and Indus offshore (Asim et al, 2014). The Zamzama field is located in the Southern Indus Basin and is surrounded to the north by the Central Indus Basin, to the northwest by the Suleiman Fold Belt Basin, and to the southwest by the Kirthar Fold Belt Basin (Kazmi and Jan, 1997). The Lower Indus Basin is located south of 3 out of 155,000 square miles of West Pakistan, and its sediments are Jurassic, Cretaceous, and Tertiary in age. Structure characteristics comprise tilted fault blocks, thrusted faults, anticlines, and so on. These anticlines in the Indus Basin's foreland formed as a result of the compressional activity of the two plates indicated above. This tectonic activity affected the Lower Indus plate form basin's structures and sedimentology, involving rifting of the Indian plate from its mother plate, Gondwanaland, which likely formed NE-SW rift systems and isostatic uplift at margins. (Kazmi and Jan, 1997; Abbasi et al., 2016).

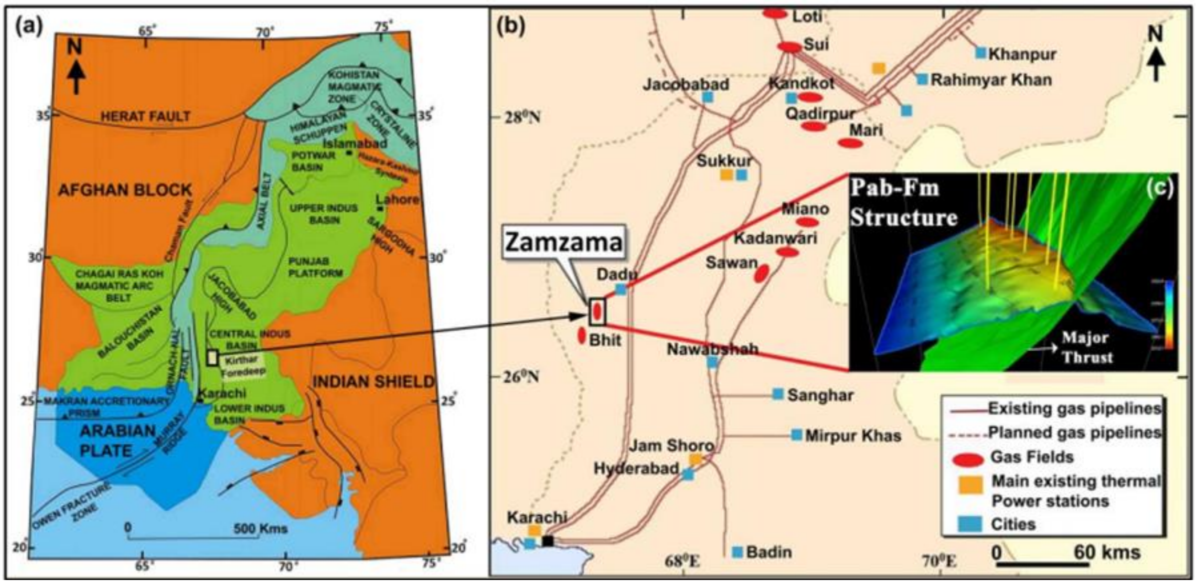

Figure 2.1 (a) Regional map indicating the Zamzama field site and defining significant structural features; (b) The Zamzama region is bordered by major gas fields; and (c) The Pab Formation's anticline is penetrated by a major thrust fault, through which several wells are drilled. (Khan et.al)

2.3 Tectonics and structure of the study area

The Zamzama Gas Field is located in a compressional tectonic regime, as evidenced by the existence of the Sulaiman and Kirthar fold belts (Kadri 1995). The collision of Indian and Eurasian plates resulted in the formation of the Kirthar Fold Belt (KBF) in the Southern Indus Basin (Scotese et al. 1988). The basin is composed of five structural components: the Kirthar Fold Belt, the Kirthar Foredeep, the Karachi Trough, the Thar Platform, and the Offshore Indus (Raza et al., 1989). The gas field is bounded to the east by the Indian Shield and to the west by the Indian plate's marginal zone. It is also restricted to the north by the Sukkur rift and to the south by the offshore Indus.

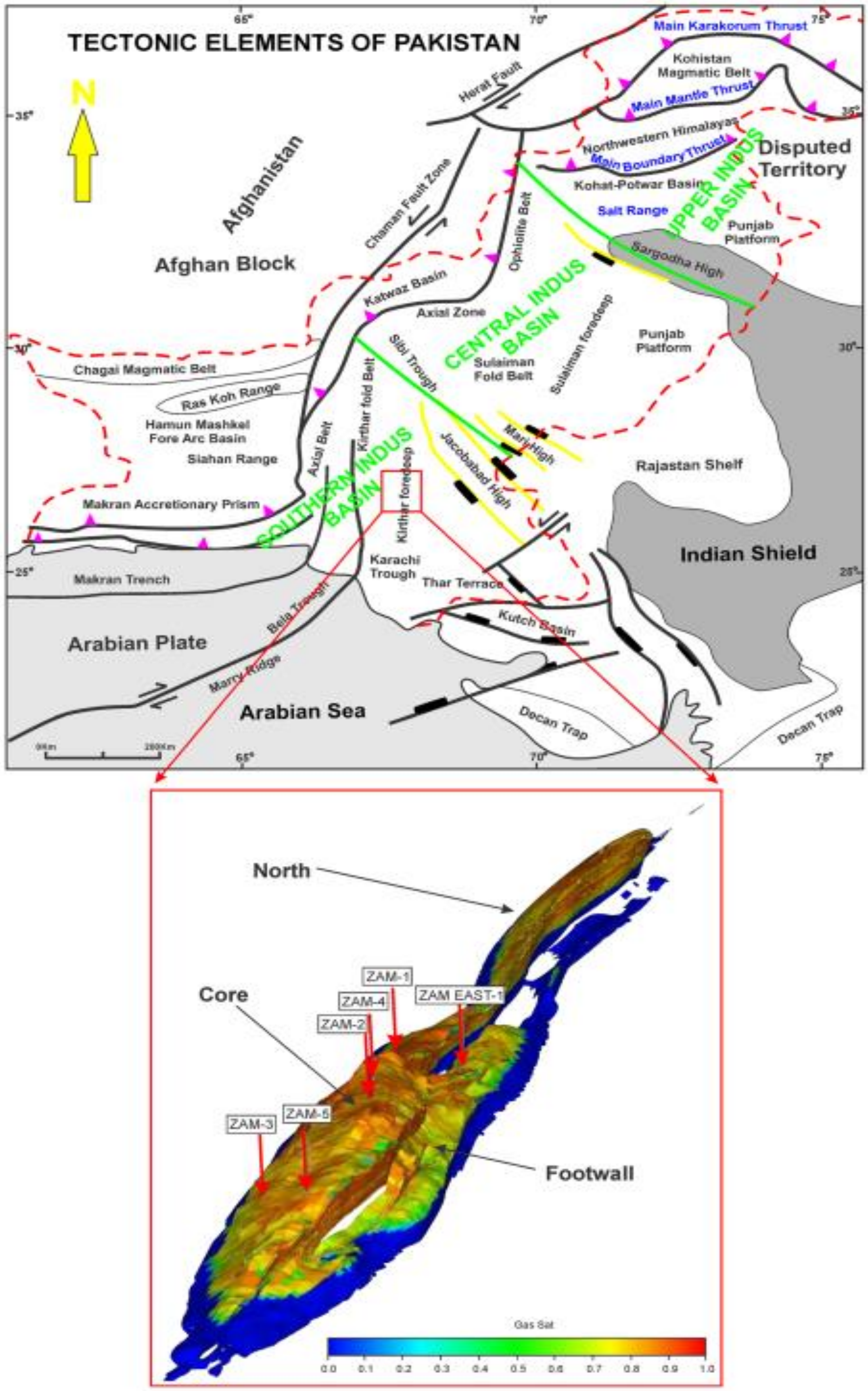

Figure 2.2 Tectonic map of Pakistan representing the major faults and division of basins (modified after Kadri 1995). The inset figure shows its actual location on Pakistan map and the complete Zamzama structure (modified after Jackson et al. 2004).

The Zamzama area belong to the western portion of the Kirthar Fore deep, which is bounded to the north by the Jacobabad Mari Kandhkot high, to the south by the Hyderabad high, and to the east by the Nabisar Slope and Tharparkar high and by KBF Bela Ophiolite in the west (Raza et al., 1989). The Zamzama structure is a north-south anticline formed by the collision of the Indian and Eurasian plates with a large thrust fault in same direction (Khan et al., 2021). The hanging wall is separated from the footwall structure by a significant thrust fault, which is bounded to the east by the anticlinal structure. This thrust was previously believed to extend for around 40 km across the area, separating the principal hanging wall structure from a less developed footwall anticline (Zafar et al., 2018).

2.4 Stratigraphy of the area

The study area's sedimentary rocks are mostly Jurassic to Holocene in age (Fig. 3). Mesozoic sediments were deposited on the northern passive margin of the Indian continent during its rifting from Gondwana in the Kirthar Fold Belt (Hedley, 2001). The overlying of Ferozabad Group, Jurassic, Sembar Formation mark an unconformity by the presence of an oxidation zone as well as laterite deposits. The Goru and Parh formations, on the other hand, took shape within carbonate shelf environments. The siliciclastic rocks of the Pab Formation, in contrast, underwent deposition along the western Indian inactive margin. This occurred within an intra-slope basin during the Cretaceous period, coinciding with the Indian Plate's traverse over the Reunion hotspot (Umar et al., 2011).

2.5 Borehole stratigraphy of Zamzama North -01 Well

The total depth of the drilling of Zamzama North -01 Well is approximately 3996.00 metres. As we progress through the geological layers, we come across the Siwalik formation, which is quite young in age. As we descend farther, we reach the last formation top Fort Manro, which dates from the early Cretaceous period. The next table will provide extensive information, such as the age and thickness of the top of each formation.

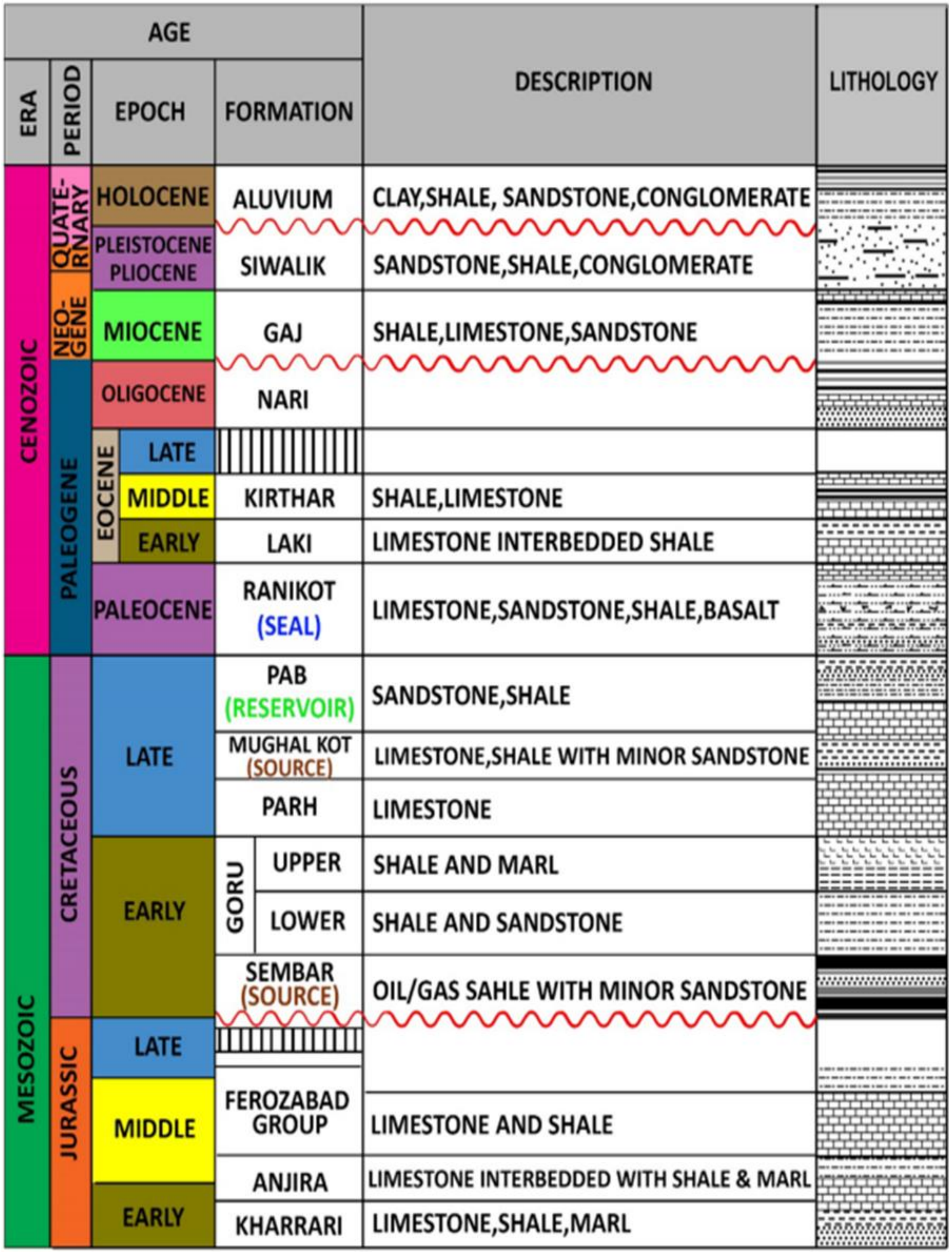

Figure 2.3 Generalized stratigraphy of the Kirthar Fold Belt, Lower Indus Basin, Pakistan, indicating the source, reservoir and seal rocks in the region modified after. (Umer et.all)

Table 2.1 Formation tops, age, depth and thickness of Zamzama North-01 well formations.

Formation top	Age	Formation top (m)	Thickness (m)
Alluvium	Recent	0.00	64.00
Siwalik	Miocene	64.00	1,453.00
Gaj	Miocene	15,17.00	95.50
Nari	Oligocene	1,612.50	651.50
Kirthar	Eocene	2,264.00	176.50
Ghazij	Eocene	2,440.50	140.00
Laki	Eocene	2,580.50	394.50
Dunghan	Paleocene	2,975.00	380.50
Girdo	Paleocene	3,355.00	302.50
Khadro	Paleocene	3,658.00	54.50
Pab	Late cretaceous	3,712.50	195.00
Fort Munro	Early Cretaceous	3907.50	88.50

2.6 Petroleum system

The Lower Indus basin has been an abundant supplier of oil and gas. The late cretaceous formation of the lower Indus basin, known as Pab sandstone, is a large gas producing reservoir of the Zamzama block, with a capacity of approximately 1.7 trillion cubic feet, however lateral ramps connecting the hanging and footwall caused differential water invasion and pressure depletion in producing fields. As a result, while drilling new wells, it is critical to isolate the gas-sand facies from the rest of the water sand and shales (Khan et al,2021).

The Pab sandstone of Zamzama Gas field was deposited in fluvio-tidal to shallow marine environments making it best reservoir for the hydrocarbon accumulation. (Umar et al.). This formation is composed of braided delta/coastal plain depositional systems that are particularly sand-rich. In the Kirthar Fold Belt, the Pab Formation is well-developed, however there is truncation east of the Zamzama Gas Field. It creates an extensive reservoir unit across the Kirthar area to the west (Jackson et al., 2004). The principal source rocks of the Zamzama Gas Field are Cretaceous Mughal Kot shale strata, which were deposited in shallow marine and deltaic environments (Shah et al.). The Ranikot Group's overlying Paleocene shales feature an excellent basal muddy horizon, that offers top seals to the Pab and Khadro formations. These shale strata act as efficient seals in a variety of wells, including those in the Bhit, Zamzama, Hallel, and Mehar fields. (Jackson et al., 2004). The majority of traps are fault-bounded structures with thrust/reverse faults (Smewing, 2002).

2.6.1 Source rock

The organic matter when converted into Kerogen and later accumulated into the formation is called source rock. Shale and limestone act as a source rocks which under certain temperature and pressure conditions covert organic matter into hydrocarbons. In case of Zamzama field, we have Sembar and Goru of late Cretaceous age, acting as a source rock (Ghazi et.al, 2021).

2.6.2 Reservoir rock

When hydrocarbon moves or migrated into porous and permeable formation, probably sandstone, the formation is said to be reservoir. Their Pab act as primary while Khadro as Secondary hydrocarbon reservoir which contain addditional gas (Qureshi et.al,2022).

2.6.3 Top seal and cap rock

The formation which restrict the further migration of hydrocarbon due to its impermeable nature is called seal. Their Girdo (Ranikot) formation, marine shale act as a seal on Pab and Khadro gas accumulation reservoirs (Ahmad et. Al,2022).

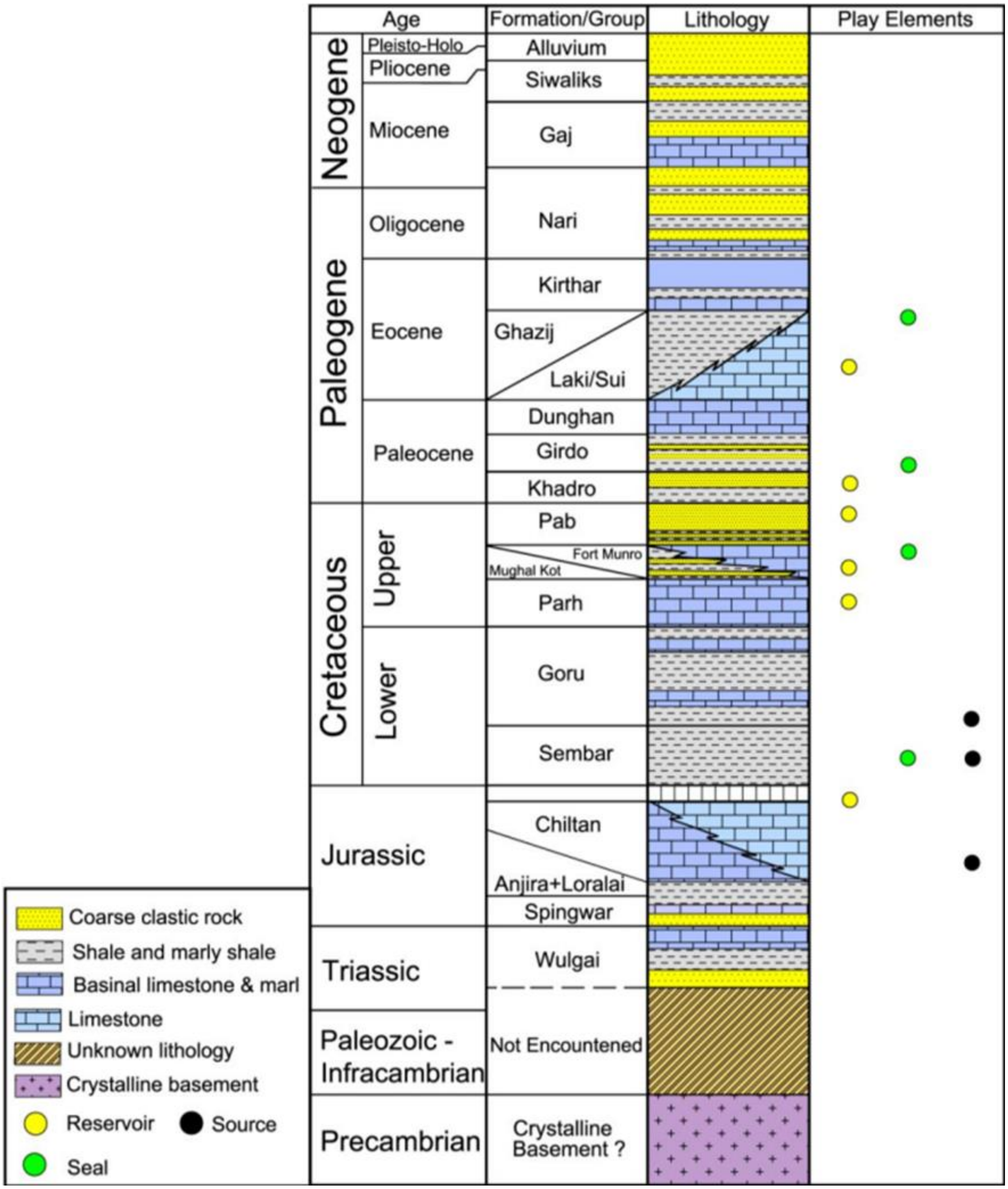

Figure 2.4 Stratigraphic Column showing the Petroleum Play Elements of Zamzama Area, Southern Indus Basin, Pakistan (modified after Abbasi et al. 2016; Zafar et al. 2018).

CHAPTER 3
SEISMIC DATA INTERPRETATION

3.1 Introduction

Seismic data interpretation is the process of analyzing and deriving geological and geophysical information about the Earth's subsurface by interpreting the signals recorded from seismic surveys. By analyzing the waves generated from seismic sources and recorded by sensors, geoscientists can create detailed images of the subsurface structures, helping in various applications such as oil and gas exploration, geological mapping, and understanding tectonic processes. Seismic interpretation helps us understand subsurface structures through the following key steps and mechanisms:

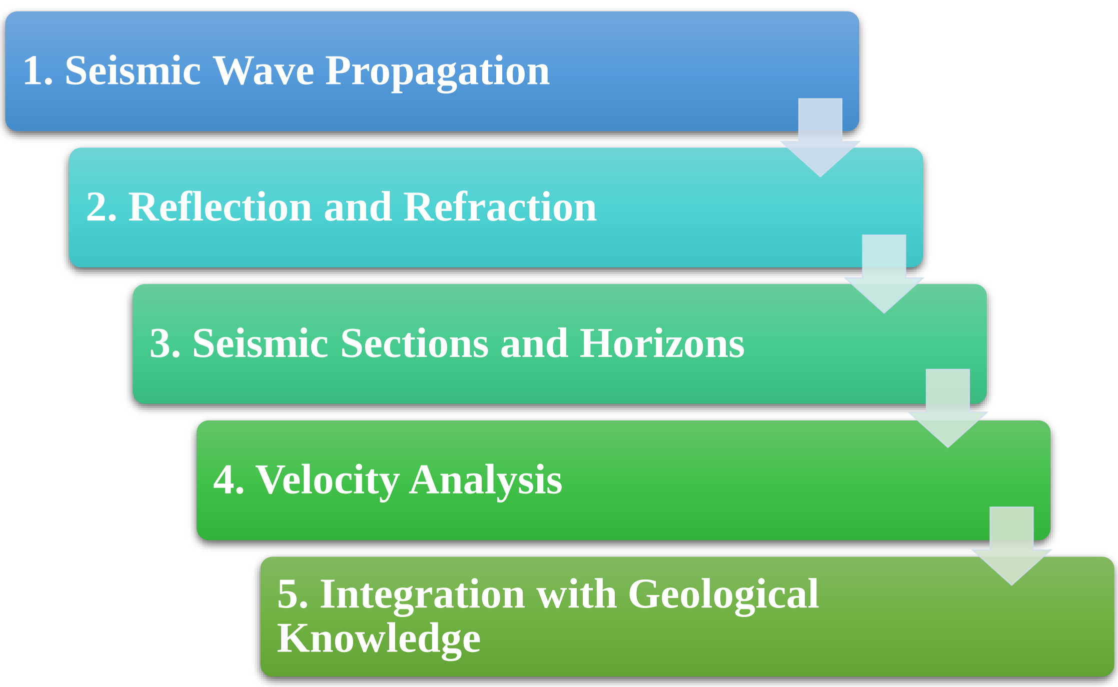

Figure 3.1 Key Steps taken for Seismic Interpretation.

Seismic interpretation is divided into two categories: structural interpretation and stratigraphic interpretation. These two techniques focus on different areas of the subsurface and use different methodologies.

3.1.1 Structural Interpretation

Structural interpretation involves analyzing seismic data to understand the three-dimensional geometries of subsurface features, such as faults, folds, and other tectonic structures. The primary goal of structural interpretation is to map the spatial distribution and geometry of these features. This type of interpretation is particularly relevant in fields like oil and gas exploration, where the location and orientation of subsurface structures can significantly impact the presence and movement of hydrocarbons.

Key aspects of structural interpretation include:

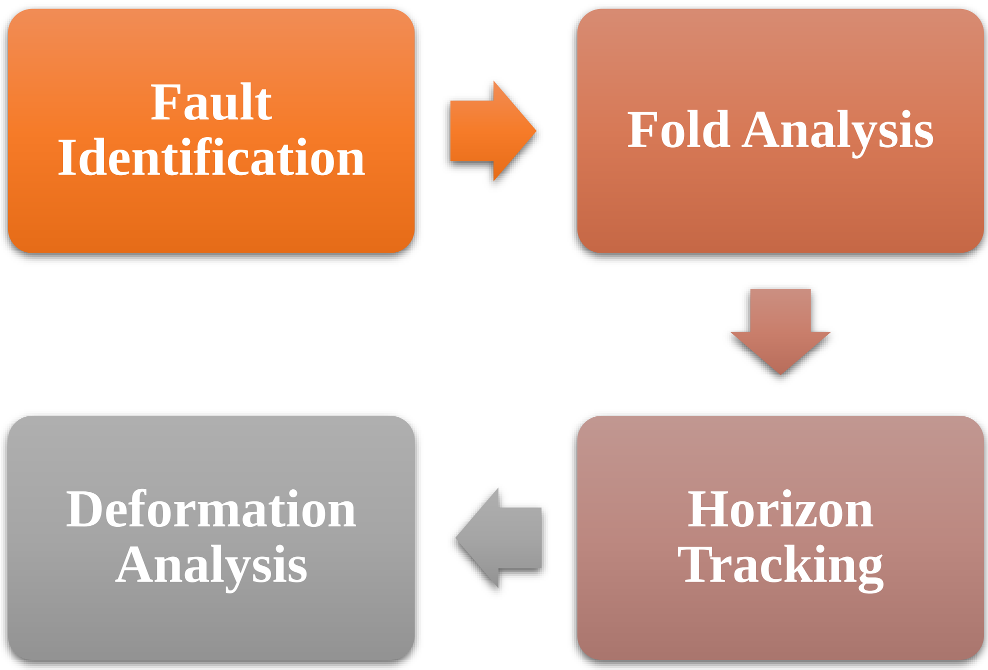

Figure 3.2 Key aspects for subsurface structural interpretation.

3.1.2 Stratigraphic Interpretation

Stratigraphic interpretation focuses on understanding the depositional history and arrangement of sedimentary layers within the Earth's subsurface. This type of interpretation is essential for reconstructing the geological history of an area, identifying potential reservoir rocks for resource exploration, and studying paleoenvironments. Key aspects of stratigraphic interpretation include:

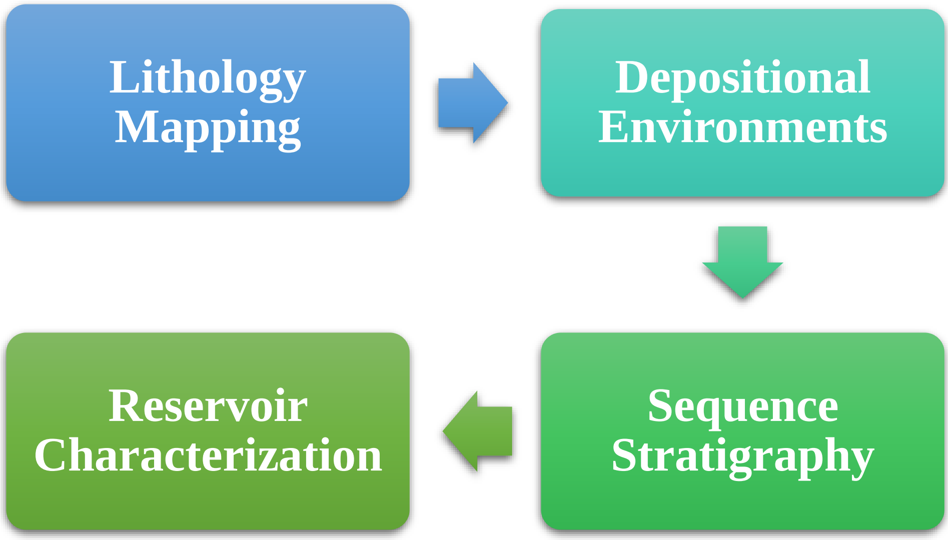

Figure 3.3 Key aspects for subsurface stratigraphic interpretation.

3.2 Structural Interpretation of Study Area

The Zamzama structure is a massive north-south thrusted anticline with an eastward trending thrust. The Primary hydrocarbon reservoir in the Zamzama gas field is Late Cretaceous Pab sandstone. The thickness of the Pab sandstones is consistent throughout the Zamzama structure (Abbasi et.al). The marine shale Girdo (Ranikot) Formation provides the top seal for the Pab sandstone reservoir. The North-South anticline structure is deformed by westward dipping thrust faults having a throw of more than hundred meters. These faults are marked and named as F1 and F2 in the interpreted section of dip lines given below. The structural interpretation of Zamzma area is done on the Gverse Geographix 2019.4 with following steps taken:

3.2.1 Base map

Base map is graphical representation of seismic lines and well locations on the area under investigation. It allows interpreters to align seismic data with the actual subsurface conditions as indicated by well data. The base map is a fundamental tool for interpreting and understanding subsurface structural features. Interpreters can precisely detect and identify numerous subsurface structures such as faults, folds, and anticlines by superimposing seismic lines onto the base map. The seismic data provided by Directorate General of Petroleum

Concessions (DGPC) of Zamzama Area is used for 2-D seismic structural interpretation. The data include two strike lines and four dip lines while have Zamzama North-01 well on GHPK98A-34 seismic dip line.

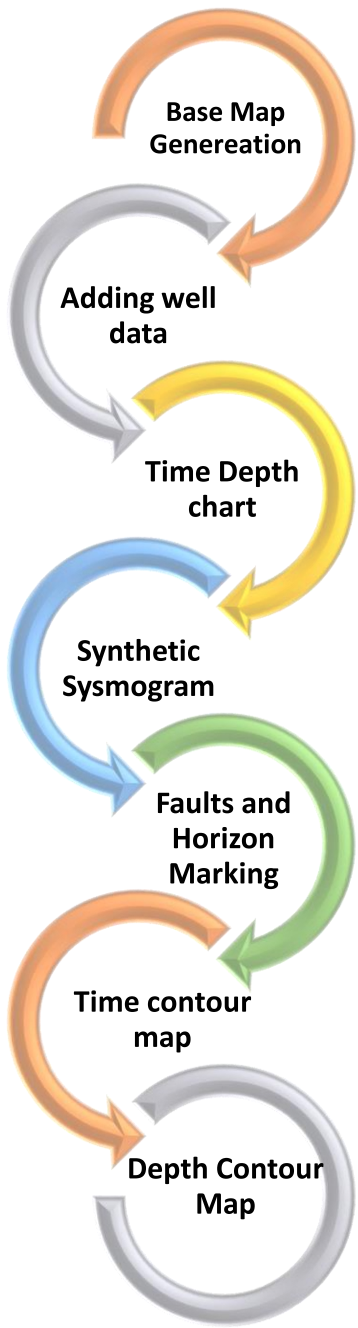

Figure 3.4 Steps taken for structural interpretation.

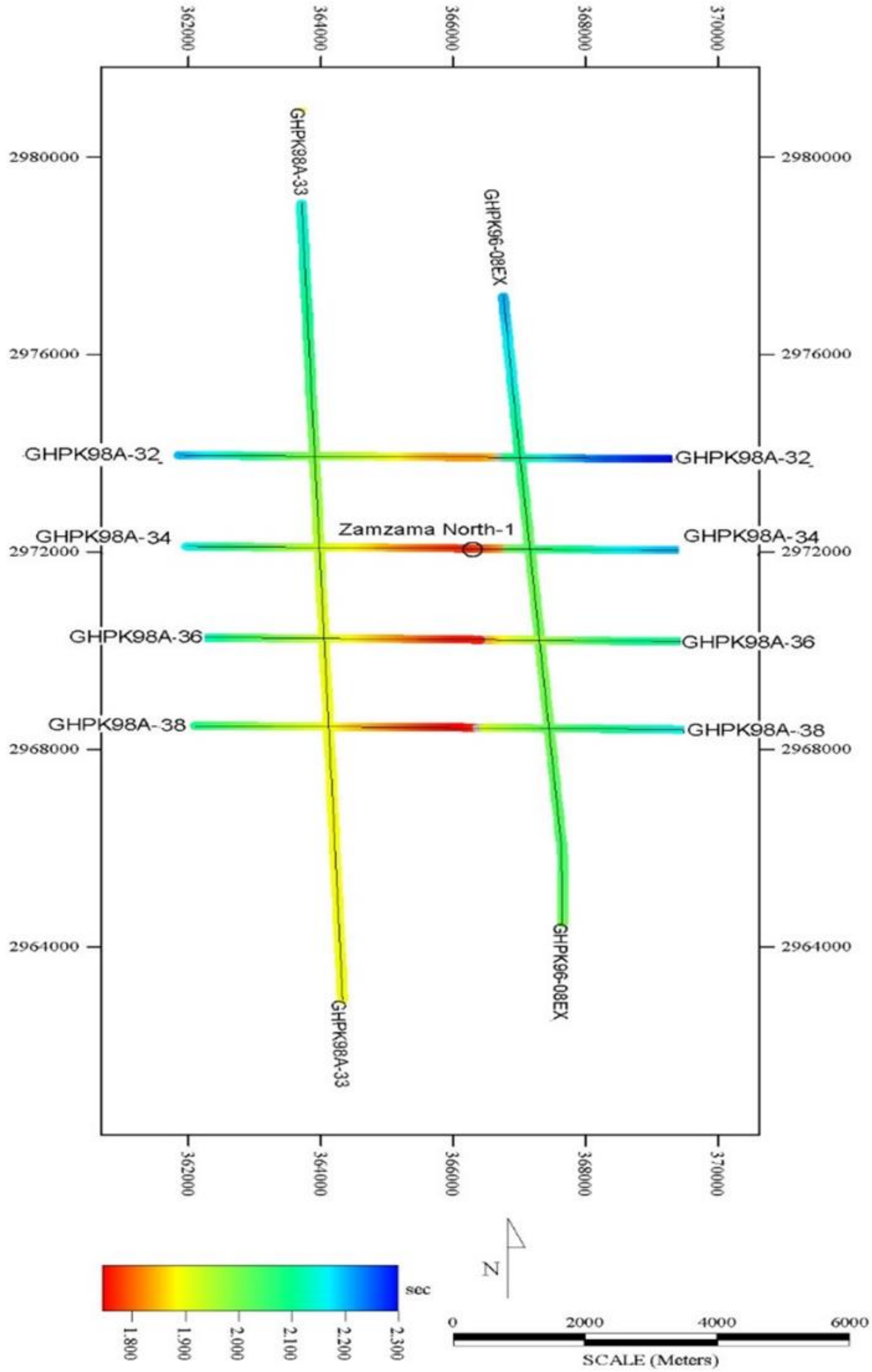

Figure 3.5 Base map of study area showing four dip line and two strike line with the location of well.

3.2.2 Control Line

In seismic interpretation, a control line on a base map refers to a line or series of lines that are used as a reference for correlating seismic data. These lines contain well data or other forms of direct geological information. They are superimposed onto other seismic lines for accurate interpretation and analysis. GHPK98A-34 is control line of our area of investigation having Zamzama North-01 well on shot point 1173.

3.2.3 Time Depth Chart

The time-depth chart is a crucial tool for seismic interpretation to bridge the gap between the time-based seismic data and the actual depth information of the Earth's subsurface. For calculation of depth values the velocity information is taken from the header file HPK98A-34 provided by Directorate General of Petroleum Concessions (DGPC).

The following formula was used to convert time domain to depth domain:

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

Table 3.1 Time and depth table of seismic line GHPK98A-34 at shot point of 1173.

Time (ms)	Time(sec)	Velocity	Depth (m)
6	0.006	1909	5.727
261	0.261	1979	258.2595
378	0.378	2034	384.426
478	0.478	2118	506.202
565	0.565	2193	619.5225
662	0.662	2361	781.491
749	0.749	2441	914.1545

896	0.896	2535	1135.68
1096	1.096	2758	1511.384
1228	1.228	2917	1791.038
1374	1.374	3001	2061.687
1530	1.53	3119	2386.035
1675	1.675	3228	2703.45
1824	1.824	3293	3003.216
2108	2.108	3460	3646.84
2409	2.409	3621	4361.4945
2864	2.864	3942	5644.944
3854	3.854	4366	8413.282
4461	4.461	4553	10155.467
5963	5.963	4839	14427.479

3.2.4 Jump Correlation

Jump correlation refers to a technique used to match and correlate seismic reflections from one seismic section to another. It is often employed in areas where geological structures, such as faults or erosional surfaces, have caused abrupt changes in the position of seismic reflectors between adjacent seismic lines or sections. When seismic data is acquired over different lines or sections, these lines may not be perfectly aligned due to factors like topography, seismic acquisition geometry, or subsurface geological complexities. As a result, seismic reflections that should be continuous might appear as discontinuous or misaligned. Jump correlation aims to rectify these misalignments by identifying and adjusting for the vertical displacements, or "jumps," in seismic reflectors.

As Zamzama area has two major faults and few minor faults, jump correlation is necessary to corelate the reflectors of different horizons in order to acquire accurate interpretation. For this purpose, we used our control line GHPK98A-34 jump correlation with the two strike lines GHPK96-08Ex and GHPK98A-33. After acquiring the reflectors of the strike lines, we correlated these with the remaining three dip lines by matching their reflectors.

3.2.5 Fault Identification

Basically, faults are the disturbance in the continuity of seismic horizons. The abrupt change in seismic amplitudes, and disruptions in the regular pattern of horizons to identify potential fault locations. Once potential faults are identified, we analyze the seismic data to determine the nature and characteristics of the fault. This includes estimating the amount of displacement, the orientation of the fault plane, and the potential impact on the surrounding geological formations.

There are two major westward dipping thrust faults in Zamzama area, which deform the North-South anticline structure. Due to thrusting in Zamzama area the hanging wall moved upward relative to the footwall and the Zamzama North-01 well is drilled into hanging wall. These two thrust faults are marked as F1 and F2 faults on the seismic section.

3.3 Horizon Marking

Horizon marking in seismic data interpretation refers to the process of identifying and delineating specific seismic reflectors that represent the subsurface geological formations. These identified reflections are known as "horizons," and marking them involves highlighting them on seismic sections. Horizon marking is a fundamental step in seismic interpretation because it helps geoscientists understand the subsurface geology and geological structures more accurately.

The Gverse Geographix 2019.4 is used to mark the five horizons Kirthar, Laki, Dunghan, Pab and Fort Munro of Zamzama area. After the faults identification and marking, the displacement in horizons is marked and matched accurately through jump correlation. The formation top values of marked horizons of Zamzama Area are given below:

Table 3.2 List of five marked horizons with their formation top and thickness values.

Formation top	Formation top age	Formation top (m)	Thickness
Kirthar	Eocene	2,264.00	176.50
Laki	Eocene	2,580.50	394.50
Dunghan	Paleocene	2,975.00	380.50
Pab	Late cretaceous	3,712.50	195.00
Fort Munro	Early Cretaceous	3907.50	88.50

3.3.1 Seismic Line GHPK98A-34

The seismic line GHPK98A-34 is control line having well location of Zamzama North-01 on shot point 1173. So, we used the well information and imposed the Synthetic Seismogram to mark the formations on the seismic line along the well. The control line has shot points from 1010 – 1270 in a line in east-west trending.

Five prominent reflectors have been marked on the control line with a thrust major fault F1 along a minor thrust fault F2. These five prominent reflectors are Kirthar, Laki, Dunghan, Pab and Fort Munro formations of Zamzama area. The major thrust fault deforms the anticline structure and all formations, while the minor fault deforms only two marked formations Pab and Fort Munro. As having the well data, we used this seismic line for jump correlation to mark accurately the seismic reflectors on other seismic lines.

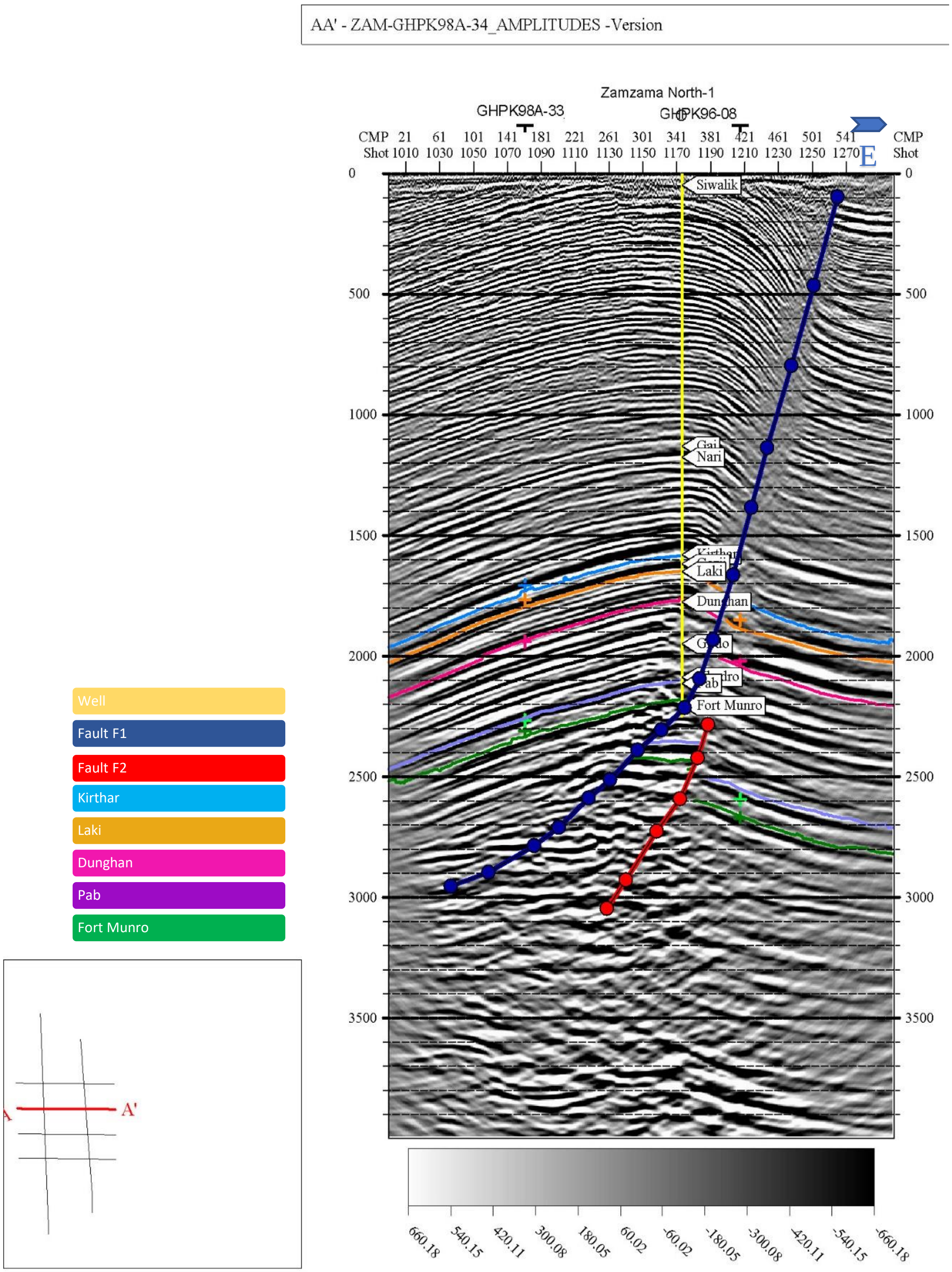

Figure 3.6 Interpreted seismic line GHPK98A-34.

3.3.2 Seismic Line GHPK98A-32

Seismic line GHPK98A-32 is a dip line trending in East-west direction. On the seismic line five prominent reflector are marked along with two faults. The fault F1 is major fault cause the deformation of the anticline structure and movement of footwall prominently.

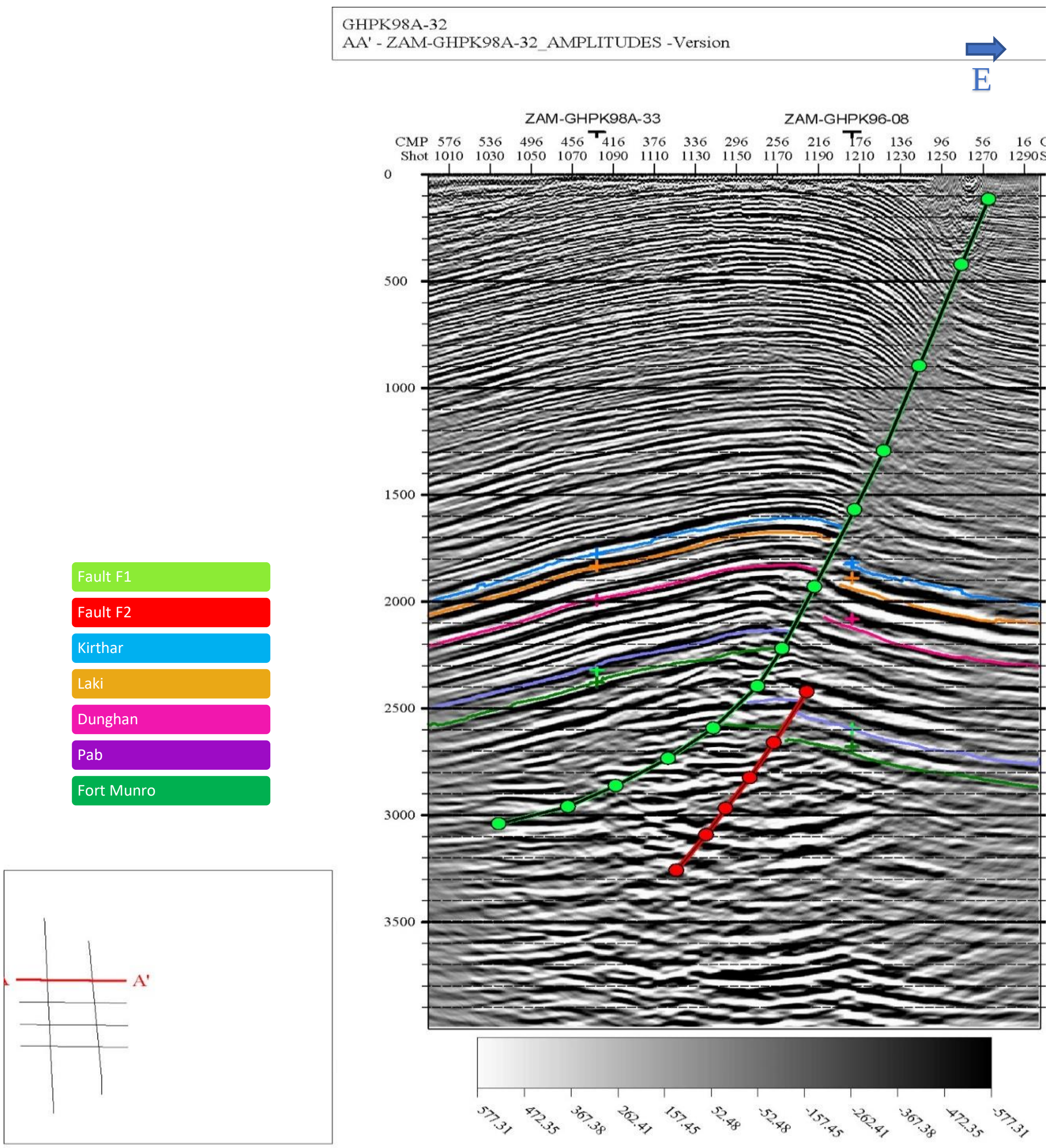

Figure 3.7 Interpreted seismic line GHPK98A-32.

3.3.3 Seismic Line GHPK98A-36

The Seismic Line GHPK98A-36 is also a dip line in east-west trending direction. The dip line is showing the anticline structure with a deformation caused by a major thrust fault F1. The marked five horizons also show displacement along this fault.

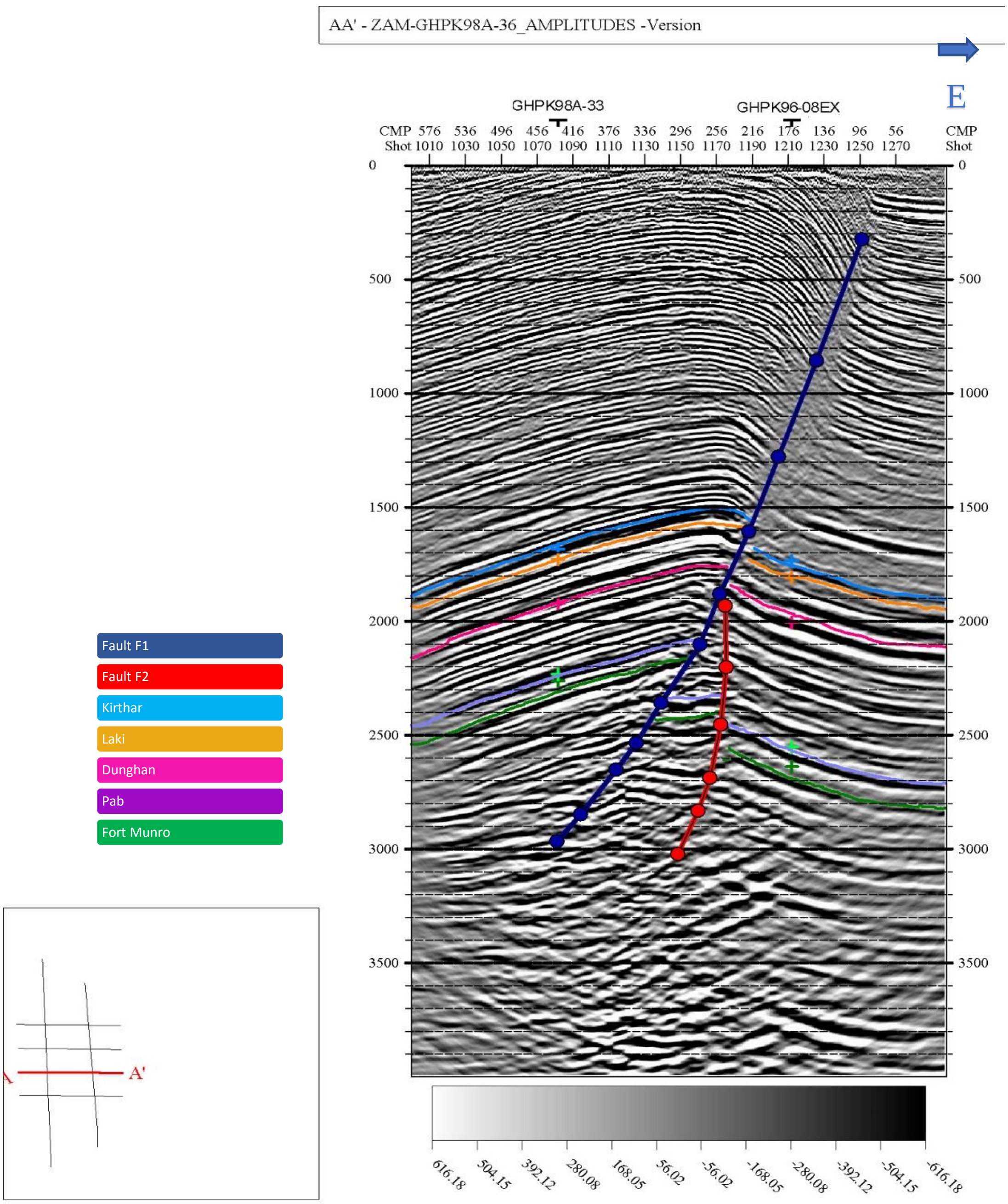

Figure 3.8 Interpreted seismic line GHPK98A-36.

3.3.4 Seismic Line GHPK98A-38

The seismic line GHPK98A-38 is last dip line of the base map having same east-west trending direction. Five reflectors with two thrust faults are marked in which the minor fault F2 displace only two reflectors Pab sandstone and Fort Munro.

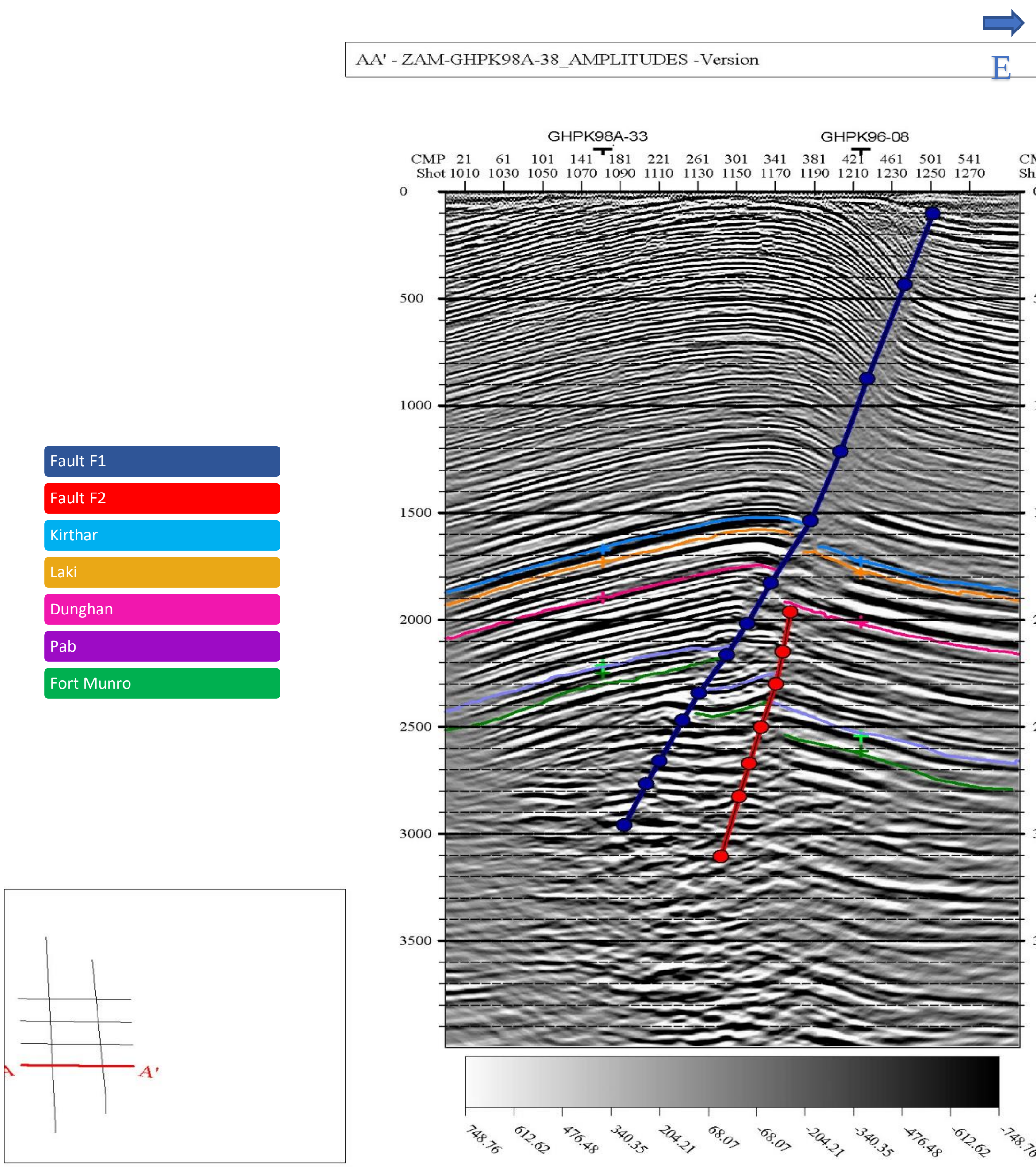

Figure 3.9 Interpreted seismic line GHPK98A-38.

3.3.5 Seismic Line GHPK96-08 Ex

The seismic line GHPK96-08 Ex the strike line trending in North East – South west direction. The gentle dipping horizons towards west are marked with no fault deformation. The strike line has shot points from 2170 – 2620 in east – west direction.

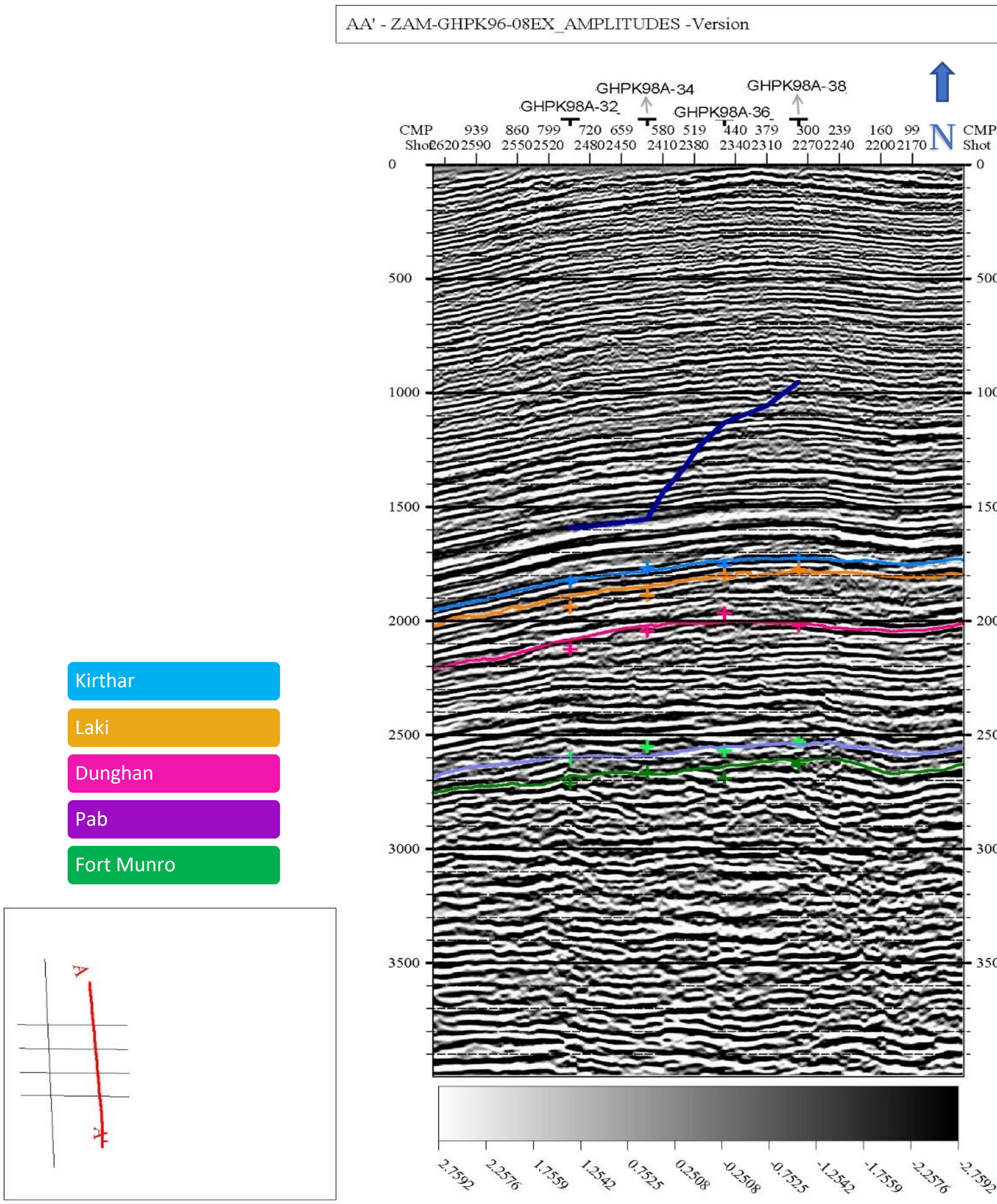

Figure 3.10 Interpreted seismic line GHPK96-08 Ex.

3.3.6 Seismic Line GHPK98A-33

The Seismic Line GHPK98A-33 is also the strike line having shot points from 1030 – 1630. The seismic line orientation is in Northwest – Southeast direction. The five marked reflectors show gentle dipping towards west direction.

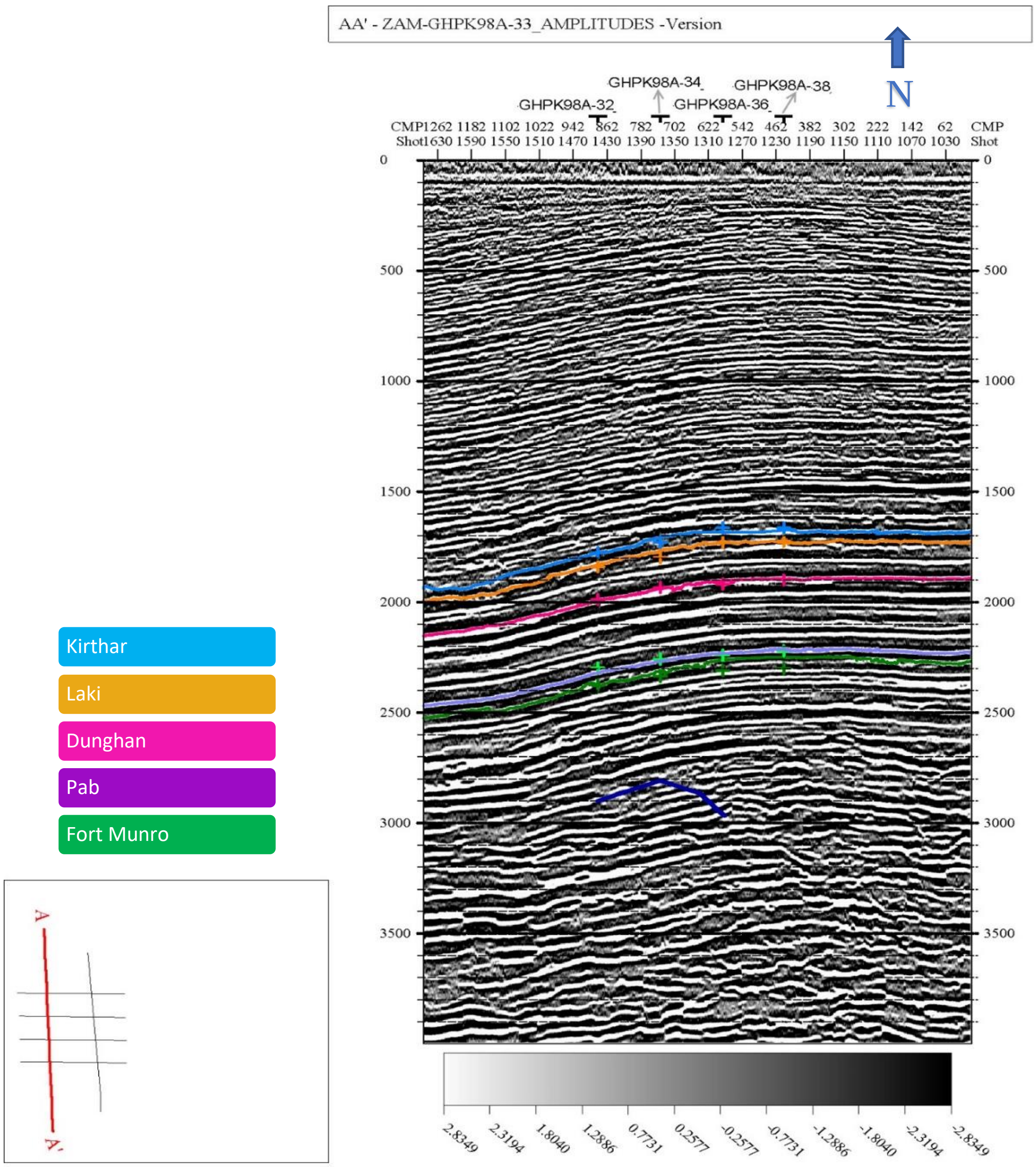

Figure 3.11 Interpreted seismic line GHPK98A-33.

3.4 Contour Map

Once the seismic horizons are picked, contour lines are generated to represent the elevations or depths of these horizons across the study area. Contour lines connect points of equal seismic reflection time or depth. These maps provide a visual representation of subsurface geological features, fault lines, unconformities, and potential hydrocarbon reservoirs. Due to reservoir properties of Late Cretaceous Pab sandstone in the Zamzama gas field it is selected for the contour mapping of both time and depth values. Gverse Geographix 2019.4 software is used for time picking values and gridding on the base map. These maps of Pab sandstone are crafted using two critical tools: Travel Time (TWT) maps and Depth Contour maps.

3.4.1 TWT Contour Map

Two-Way Travel time (TWT) contour maps are generated by joining the same time values of seismic waves in subsurface. They show how long it takes for seismic waves to travel to different depths in the Earth and bounce back. These maps are like a snapshot of the subsurface, giving us a picture of the time, it takes for waves to reach various layers. This information is crucial because different rock layers and geological features affect the speed of seismic waves. TWT maps help us pinpoint where these features exist in subsurface.

Figure 3.12 is showing the TWT contour map of Pab Sandstone with minimum value of 2077 milliseconds (2.0 sec) and maximum value of 2754 milliseconds (2.7 sec). Blue color shows minimum time duration of seismic waves while green indicates the moderate value and red color shows maximum time taken by the waves. In TWT contour map, the blue color is in middle of the base map showing the shallow depth and red and green color on the flanks confirming the anticline structure of Pab sandstone. The location of Zamzama North-01 well and the thrust faults in the structure are also shown on the map.

3.4.2 Depth Contour Map

Once we have the data from TWT maps, we can create depth contour maps. These are like topographical maps but for what's hidden beneath us and helpful to understand visually faults, anticlines, and folds. Contour lines are drawn to connect points with equal depths. The closer the lines are, the steeper the slope or the faster seismic waves travel. On the other hand, lines that are further apart indicate flatter areas or slower wave travel. Depth contour map is almost similar to TWT contour map portraying the anticline structure and the role of thrust faults in Pab sandstone. This map showing minimum depth value of 3635 meters in subsurface and maximum values is 4819 meters.

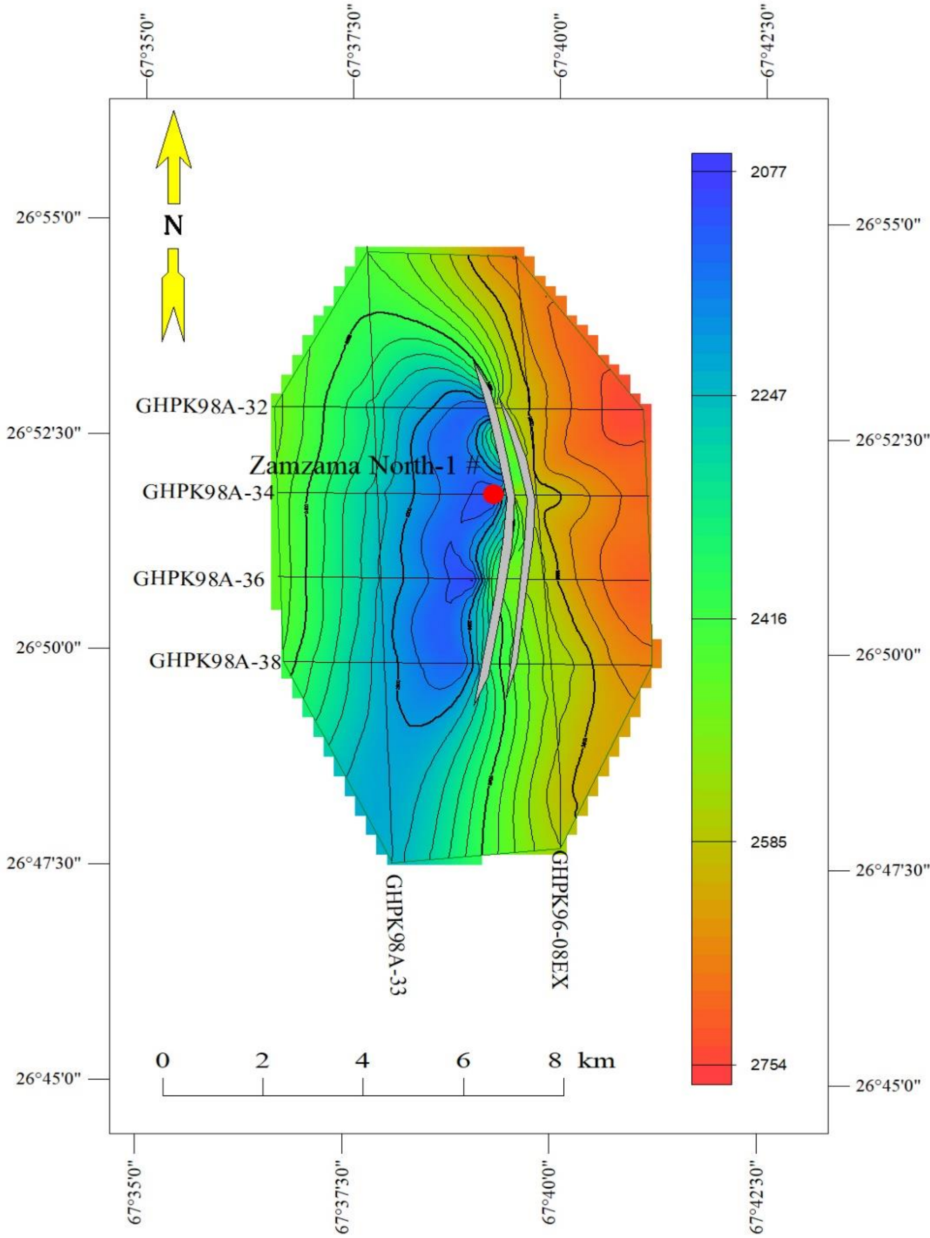

Figure 3.12 Time contour map of Pab sandstone.

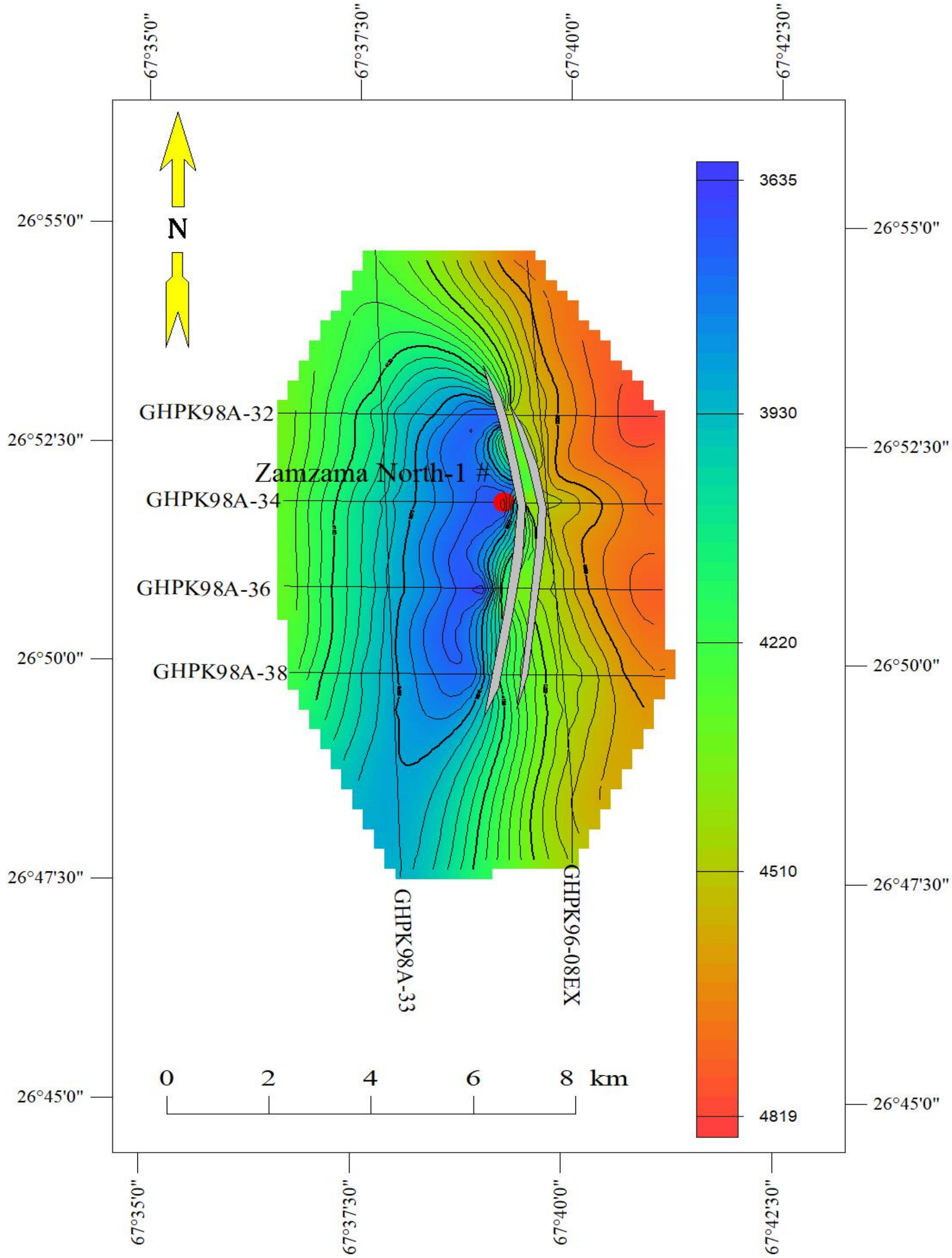

Figure 3.13 Depth contour map of Pab sandstone.

CHAPTER 4
PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics is the study of the physical and chemical properties of rocks and their interactions with fluids, especially hydrocarbons. It involves the measurement, analysis, and interpretation of various rock and fluid properties to understand subsurface reservoirs, assess their potential for hydrocarbon production, and optimize the recovery of oil and gas resources. Petrophysical analysis is carried out for Pab Sandstone of late cretaceous age utilizing wireline logs (density, neutron, self-potential, and resistivity). The analyses were carried out to calculate porosity, water resistivity, water saturation, and oil saturation, which are used to determine the reservoir's hydrocarbon potential.

4.2 Well Logs Data

DGPC has also supplied well log data in the form of a LAS file. This file encompasses essential data, including caliper logs, gamma ray logs, density logs, neutron logs, sonic logs, and resistivity logs. The table below presents the specific well log data employed in the petrophysical analysis for this current research project.

Table 4.1 Wireline logs used for petrophysical interpretation of reservoir zone.

Lithological Logs	Porosity Logs	Resistivity Logs
Gamma Ray Log (GR)	Neutron Log (NPHI)	Latero-log Deep (LLD)
Self-Potential Log (SP)	Density Log (RHOB)	Latero-log Shallow (LLS)
-	Sonic Log (DT)	Micro-spherically Latero-log (MSFL)

4.2.1 Uninterpreted Log Curves

In the above Raw log curves, we have total four tracks of logs which are Lithology, Resistivity, Porosity and last track is Sonic and Litho-Density (PEF) (Track 4) logs. The petrophysical values are taken of Pab sandstone from measured depth of 3712.50 meters to 3907.50 meters.

In track 01, we observe two log curves one is Gama Ray and other is Caliper log. Gama ray log is represented by red line having a scale of 0 to 150 API values. Basically, Gama ray log measure the radioactive material values which emit Gama rays. By comparing these API values, we can predict the lithology. In the above raw log curves, we have three peaks of maximum Gama ray at depth of 3725, 3744 and 3841 meters. The black dotted curve on track 01 represent Caliper log data. Caliper log measures the thickness of borehole. There are two maximum peaks in caliper values during the Pab sandstone at the depth of 3745 and 3767 meters. These peaks represent the phenomenon of caving in boreholes, where the borehole wall breaks due to subsurface lithology erosion. The process of caving cause wellbore instability and addition of debris in drilling fluid.

On track 02, we have three curves of resistivity logs which are LLS (Res S), LLD (Res D) and MSFL (Res M). the LLS is represented by blue dotted line, MSFL by black dotted line and LLD by red color line having a same scale from 0.2 to 2000 OHMs. The basic principle of resistivity logs is that in good porous rock high resistivity value means there is presence of hydrocarbon which is resistive in nature. On track 02 these three curves show almost same behavior and stays in middle of graph while there are few peaks showing high resistivity in LLD shows maximum value then LLS and MSFL.

Third track has two curves which are Formation Density (RHOB) and Neutron Porosity (NPHI) log. RHOB is represented by red color curve having scale from 1.95 to 2.95 $g/(cm^3)$ while NPHI by light blue color having scale from -0.15 to 0.45 v/v. Both logs give information about the porosity in subsurface lithology. Neutron log measure the Hydrogen index, high NPHI value means high concentration of hydrogen indicating the presence of fluid which shows high porosity. While in case of Formation density high RHOB value means less porosity in subsurface lithology. During the 3767 meters depth RHOB values show a negative peak means presence of high porosity.

On track four we also have two curves which are Litho-Density (PEF) and Sonic (DT) logs. Sonic has green color curve with a scale of 40/140 US/FT and PEF curve is black dotted having scale of 0 to 10 B/E. In PEF we measure the lithology type by the rate of absorption of waves while in sonic log we measure porosity by the transit time of waves. High value of sonic log (DT) means high porosity. The PEF log has two maximum peaks during the depth of 3745 and 3767 meters. While sonic log curve remains in middle with few little peaks of maximum value.

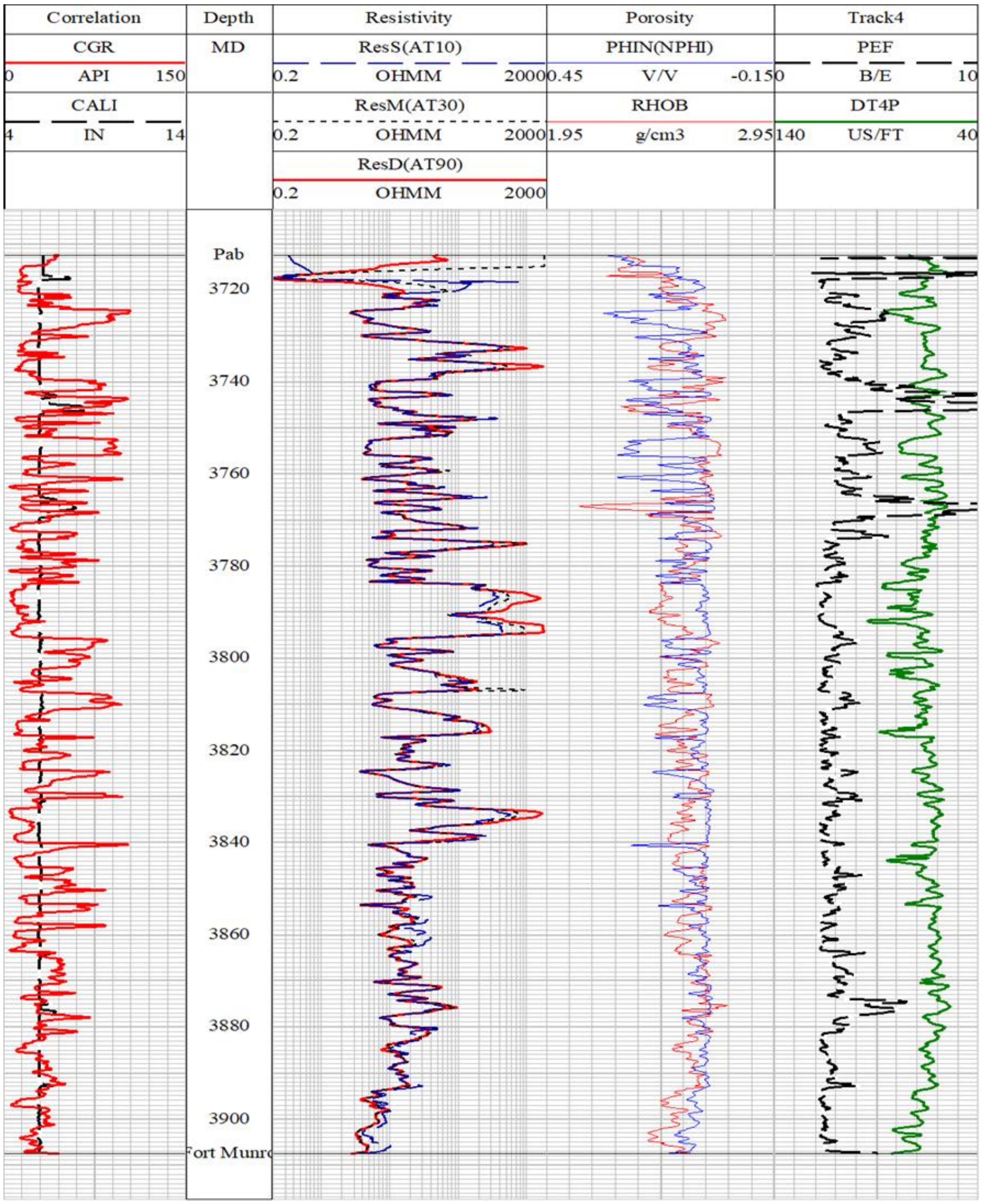

Figure 4.1 Uninterpreted and Raw log curves of Zamzama North-01 well.

4.3 Logging Objectives

The key objective of petrophysical interpretation is to determine the amount of fluid in a reservoir that is hydrocarbon saturated (Sh). Petro-physicists use data from well logs and perform various measurement techniques to determine parameters such as porosity, permeability, water resistivity, oil saturation, and fluid saturations in subsurface formations. This information helps in:

(1) Identifying potential hydrocarbon-rich zones.

(2) Distinguishing between hydrocarbon-bearing zones and non-bearing zones.

4.4 Petrophysical Properties Evaluation

For the petrophysical analysis of wireline logs, we calculated several essential parameters are given below:

(1) Determination of Shale Content

a) Calculation of the volume of shale (Vsh)

The volume of shale is estimated using Gamma Ray Log (GR).

Linear response (Vshale = IGR) :

$$V_{sh} = I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}}$$

where:

IGR = the gamma ray index

GRlog = the gamma ray reading at the depth of interest

GRmin = the minimum gamma ray reading. (Usually the mean minimum through a clean sandstone or carbonate formation.)

GRmax = the maximum gamma ray reading. (Usually the mean maximum through a shale or clay formation.)

b) Calculation of the volume of clean (Vclean)

The volume clean lithology can be calculated as the voume of shale values subtracted from 1. Their formula is given below:

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

(2) Porosities Calculation

Porosity is estimated using wireline logs and several mathematical relationships. Porosity and rock type have an impact on formation density. Porosity can thus be determined if the type of rock is known (Krygowski et.al).

a) Calculation of density porosity (DPHI)

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

Where,

ρm = matrix density,

ρb = bulk density

ρ f = density of fluid

b) Calculation of neutron porosity (NPHI)

The value of neutron porosity φN is directly calculated fron Neutron log.

c) Calculation of average / total porosity (APHI)

$$\phi_T = \frac{\phi N + \phi D}{2}$$

Where,

φD = density porosity

φN = neutron porosity

d) Calculation of effective porosity (EPHI)

$$\phi_e = \phi_T \ x \ (1 - V_{sh})$$

Where,

φT = Total Porosity

Vsh = Volume of shale

If Density and Neutron data is not reliable then we use sonic porosity values for effective porosity calculation

$$\phi_e = \phi_s \ x \ (1 - V_{sh})$$

Φs = sonic porosity

e) Calculation of sonic porosity (SPHI)

The sonic log formula can be used in porosity calculation to evaluate consolidated strata (Wyllie et al.). Acoustic waves move at a slower rate through porous strata.

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_p - \Delta t_{ma}}$$

Where,

φS = porosity estimated from sonic log (µs/ft),

Δ t = interval transit time,

Δ t *ma* = time values for matrix,

Δ t *p* = time value from fluid,

(3) Resistivity of Water (Rw)

To determine the water saturation the values of Rw is required which can be calculated by different methods

- SP method

➢ Picket plot method

➢ Apparent water resistivity method

(4) Fluid Saturation

a) Calculation of Water Saturation (Sw)

The Indonesian equation was used to calculate the water saturation and represent the relationship between formation characteristics that impact resistivity and true resistivity (Rt) (Poupon et al.).

$$\mathrm{SwI} = \left[\frac{\sqrt{\frac{1}{\mathrm{Rt}}}}{\frac{\mathrm{Vshl}^{1-0.5\mathrm{Vshl}}}{\sqrt{\mathrm{Rsh}}} + \sqrt{\frac{\phi_e^m}{a \cdot \mathrm{Rw}}}} \right]^{\frac{2}{n}}$$

Where,

(Sw) = water saturation,

(Rw) = water resistivity,

(Rsh) = shale resistivity,

(Rt) = true resistivity,

(φe) = porosity and

(Vsh) = shale volume

b) Calculation of Hydrocarbon Saturation (Sh)

Hydrocarbon saturation is the remaining value when Saturation of water is subtracted from 1.

$$\mathrm{Sh} = 1 - \mathrm{Sw}$$

4.5 Specification of Zamzama North-01 well

The Zamzama North-01 well is situated within the Zamzama Field, Sindh. BHP Billiton initiated the Zamzama Phase 1 Development and successfully commenced contractual gas deliveries from the newly established facilities to its customers on July 17, 2003. The specification of Zamzama North-01 Well is given in the table:

Table 4.2 Specification of Zamzama North-01 Well, Zamzama Gas Field, Sindh, Pakistan.

Well Name	**Zamzama North-01**
Company	BHP BILLITON
Province	Sindh
Completion Date	01 JUN 2003
Well Bore Status	Gas
Depth Reference Elevation (m)	48.62
Total Depth	3,996.00
Depth Reference	KB
Well Type	Development
Latitude	26 51 50.02
Longitude	67 39 14.70
Concession	Zamzama

4.6 Pickett Plot Construction

The Pickett plot typically involves plotting two well log measurements against each other on a graph, creating a scatterplot. The two most common measurements used in Pickett plots are resistivity (Rt) and porosity (Φ). The primary goal of creating a Pickett plot is to visually identify trends or relationships between these two measurements.

The Pickett plot is an illustration of the Archie equation making it a useful tool to calculate Sw range within a reservoir. The Archie equation is given below:

$$S_w{}^n = \frac{R_w}{(\Phi^m \times R_t)}$$

Where,

- Sw = water saturation,
- n = saturation exponent,
- Rw = formation water resistivity,

- Φ = porosity,
- m = cementation exponent,
- Rt = true resistivity

Different rock types and fluid saturations often exhibit characteristic patterns on Pickett plot. The diagonal blue color line representing 100% water resistivity while the above red diagonal lines representing 75%, 50%, 25% and 0% water resistivity respectively. The average water resistivity (Rw) calculated is 0.023 Ohm-metre (Ωm).

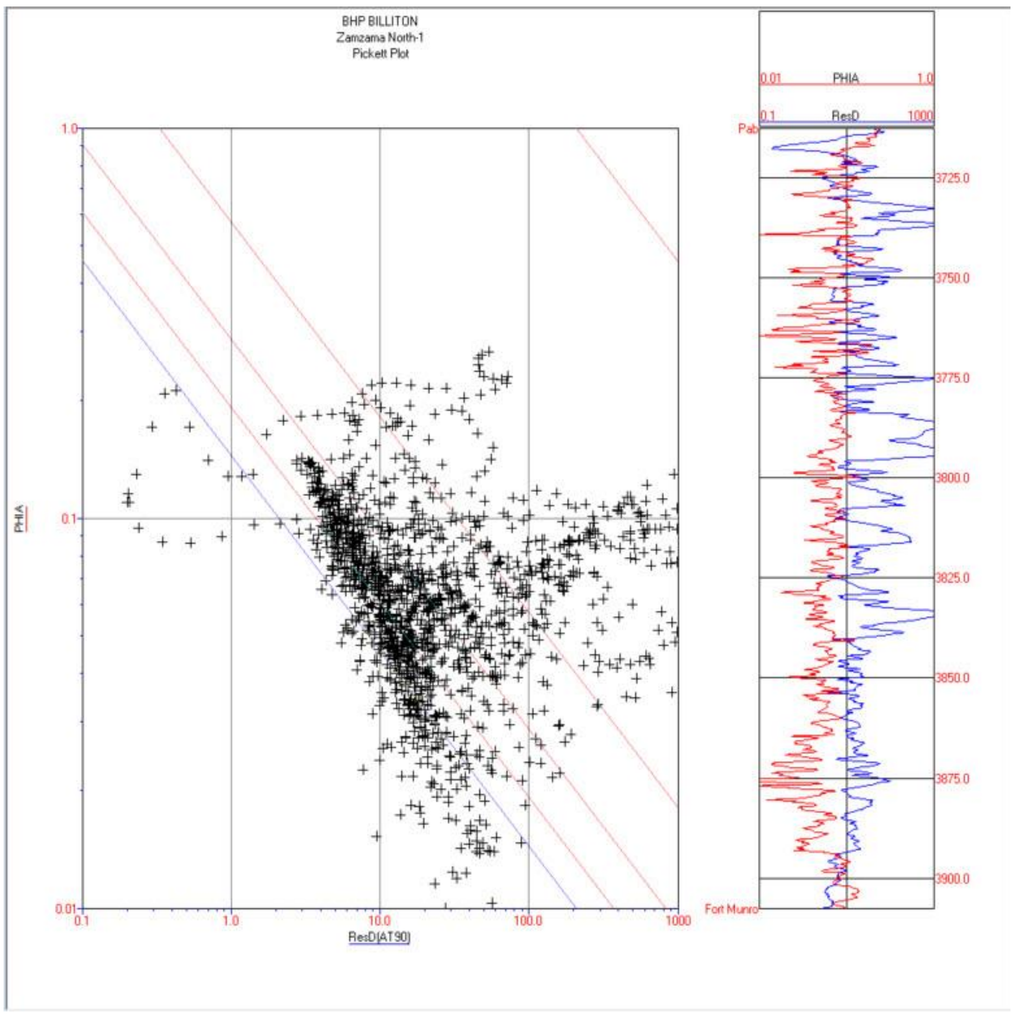

Figure 4.2 Pickett Plot of Zamzama North-1 well.

4.7 Petro-physical Interpretation of Pab Sandstone

In petrophysical interpretation firstly caving and gas effect filters on Track 01 and Track 03 were applied, then four tracks were created. These tracks have values of Volume of shale, PHID, PHIS, PHIA, PHIE, water saturation and hydrocarbon saturation calculations. Formulas used for these calculations are already given in section 4.4.

In caving, the base line created for Caliper log curve and all the peaks having more values then base line are highlighted with light green color. Gas effect can be seen in track 03 highlighted with red color. This effect is created by the inverse behavior of Formation density and Neutron logs. Volume of shale is calculated in track 5 and the rest of space in the track is highlighted with sandstone filter. The scale used for representation of these values is 0 to 1. The volume of shale value decreasing with depth because it has more maximum peaks from 3720 to 3780 meters depth as compare to lower depths of this formation. The average value calculated for volume of shale is 0.1793 and its 17.93 % along the given track. While on track 5 and track 6 PHID, PHIS, PHIA and PHIE values are represented with purple, cream, pink and light green colors respectively. The scale for these values is kept same as from 0 to 1. These porosity calculation values are very small and show little peak values at some depths. PHID has average value of 0.017 (1.7%), PHIS has average value 0.0973 (9.73%) while PHIA has 0.707 (7%) and PHIE has 0.0568 (5.68%) values.

The last track represents the water saturation value on the same scale from 0 to1. While the water saturation shows high average value of 0.6139 (61.39 %) and many numbers of maximum peaks during the track. The space left by water saturation is filtered with black color representing the hydrocarbon column. The hydrocarbon saturation value increase where the water saturation decreases. At 3730, 3790, 3810, and 3830 meters depth the maximum peaks of hydrocarbon saturation is observed. The average value for hydrocarbon saturation is 0.3861 which is 38.61 %.

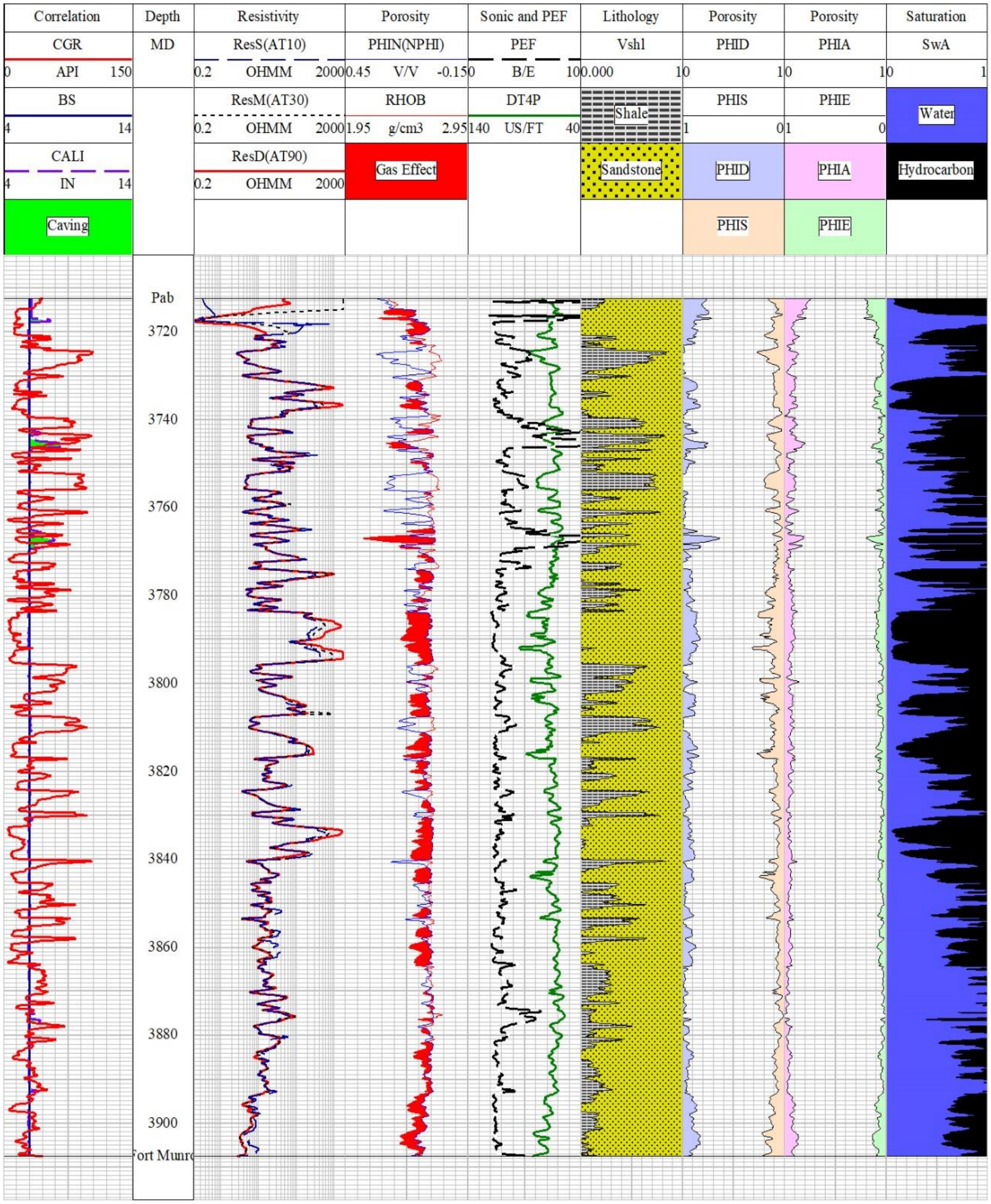

Figure 4.3 Interpreted Well logs of Zamzama North-01 for Petrophysical Analysis.

Table 4.3 Results of Petrophysical Analysis of Pab Sandstone, through Zamzama North-01 log data.

Pab Sandstone	Average Value	Average %
Volume of Shale (Vsh)	0.1793	17.93 %
Density Porosity (PHID)	0.017	1.7 %
Effective Porosity (PHIE)	0.0568	5.68 %
Sonic Porosity (PHIS)	0.0973	9.73 %
Average Porosity (PHIA)	0.0707	7 %
Water Saturation (Sw)	0.6139	61.39 %
Hydrocarbon Saturation (Sh)	0.3861	38.61 %

CHAPTER 5
GEOPRESSURE ANALYSIS

5.1 Introduction

Geopressure analysis, also known as pore pressure analysis or formation pressure evaluation, is a critical aspect of subsurface geology and drilling operations in the field of petroleum exploration and production. It involves the study and assessment of the pressure within geological formations beneath the Earth's surface. In practice, accurately characterizing pore pressure and its classification is critical for drilling operations. Various methods, including well logs, seismic data, and drilling measurements, are used to assess pore pressure conditions in real-time. Understanding whether pore pressure is normal, abnormal, or subnormal helps drilling engineers make informed decisions about well design, mud weight selection, and drilling practices to ensure the safety and success of the drilling operation.

Pressure is the measure of force exerted per unit area, and in the context of the oil industry, it is typically expressed in pounds per square inch (psi). These pressures include:

5.2 Hydrostatic Pressure

This is the pressure exerted by the column of drilling fluid in the wellbore and is vital for maintaining well stability during drilling. The pressure is a function of the average fluid density and the vertical height or depth of the fluid column.

Mathematically, hydrostatic pressure is expressed as:

$$\mathbf{HP\ (psi) = 0.052 \times \rho f\ (ppg) \times D\ (ft)}$$

Where,

HP = Hydrostatic pressure

0.052 = Conversion factor

ρf = Average fluid density

D = True vertical depth or height of the column

It is generally more convenient to refer to hydrostatic pressures in terms of a pressure gradient while planning or drilling a well.

5.2.1 Hydrostatic Pressure Gradient

A pressure gradient is the rate at which pressure increases per unit vertical depth, i.e., psi per foot (psi/ft). Hydrostatic pressures and pressure gradients can be readily converted to equivalent mud weights and pressure gradients.

The gradient of hydrostatic pressure is given by:

$$\mathbf{HG = HP / D} \ \ldots \text{(psi/ft)}$$

Where,

HG = Hydrostatic Pressure Gradient

HP = Hydrostatic Pressure

D = Vertical Depth

5.3 Overburden Pressure

Overburden pressure is the stress caused by the weight of overlying rock and sediments above the point of interest. Understanding this pressure is essential to assess the structural integrity of the wellbore. The total weight is the sum of the weights of the formation solids (rock matrix) and fluids in the pore space. The combined weight's density is referred to as the bulk density (ρb).

As a result, the overburden pressure can be represented as the hydrostatic pressure exerted by all materials above the depth of interest:

$$\boldsymbol{\sigma ov = 0.052 \times \rho b \times D}$$

where:

σov = overburden pressure (psi)

ρb = formation bulk density (ppg)

D = true vertical depth (ft)

5.3.1 Overburden Gradient

Similar to Hydrostatic pressure gradient the overburden gradient can be calculated as,

$$\boldsymbol{\sigma ovg = (0.433 \times \rho b) / 0.052}$$

Where,

σovg = overburden gradient (ppg)

ρb = formation bulk density (gm/cc)

factor 0.433 converts bulk density from gm/cc to psi/ft

Because of changes in formation density, the overburden gradient is not constant with depth. Variations in lithology and pore fluid densities cause instability. Furthermore, due to increased overburden, the degree of compaction also increases and hence formation density increases with depth. The following equation is used to calculate the overburden gradient under such conditions of changing lithological and pore fluid density:

$$\sigma ovg = 0.433 \times [(1 - \varphi)\ \rho ma + (\varphi \times \rho f)]$$

where:

σovg = overburden gradient (psi/ft)

Φ = porosity

ρf = formation fluid density, gm/cc

ρma = matrix density, gm/cc

5.4 Pore Pressure

Pore pressure is the pressure exerted by fluids within the pores of subsurface rocks. The term "formation (pore) pressure" has a scientific meaning that is similar to this. Accurate pore pressure prediction is critical for preventing wellbore blowouts and maintaining drilling safety. The classification of pore pressure is either normal, abnormal, or subnormal, depending on its magnitude.

5.4.1 Normal Pore Pressure

Normal pore pressure refers to a subsurface pressure condition where the actual pore pressure is relatively close to or in equilibrium with the hydrostatic pressure.

5.4.2 Abnormal pore pressure

Abnormal pore pressure, often referred to as overpressure arises when the pore pressure surpasses the hydrostatic pressure exerted by the formation water within the pore spaces. This condition can occur at various depths, ranging from shallow to ultra-deep, and is attributed to a complex interplay of geological, geochemical, geothermal, and mechanical factors.

Causes of abnormal pore pressure may be summarized under:

(1) Depositional Effects
(2) Diagenetic Processes
(3) Tectonic Effects
(4) Structural Causes
(5) Thermodynamic Effects

5.4.3 Subnormal pore pressure

Subnormal pore pressure mostly referred as under-pressure occur when pore pressure is less then hydrostatic pressure at a specific depth. Subnormal pressures are encountered less frequently than abnormal pressures.

5.4.4 Pore Pressure Calculation

In 1975, Eaton proposed an empirical relationship for predicting pore pressure gradients using the sonic transit time of compressional wave:

$$Ppg = OBG - (OBG - P\_ng)\ (\Delta t\_n/\Delta t)\hat{}3$$

Where,

Ppg = formation pore pressure gradient

OBG = overburden stress gradient

P_ng = hydrostatic pressure gradient

Δt_n = sonic transit time in shales at the normal pressure

Δt = sonic transit time in shales

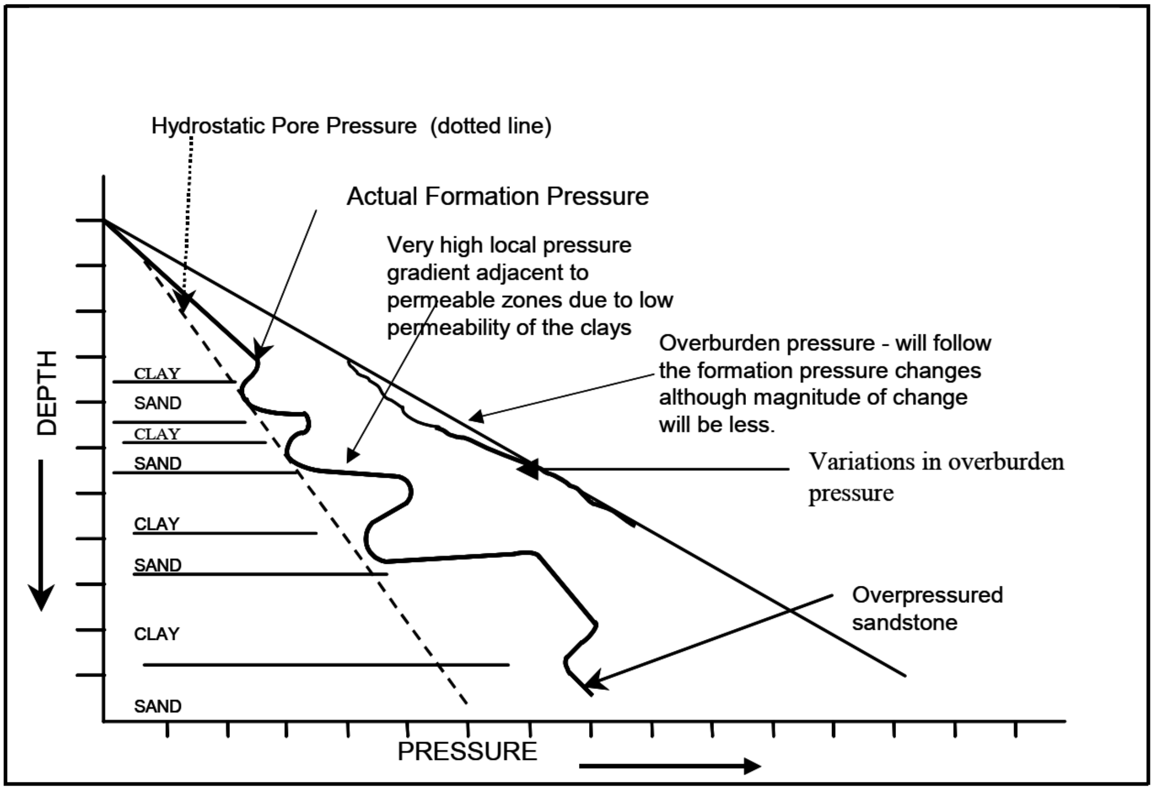

Figure 5.1 Trend lines of Hydrostatic pressure, Pore pressure and Overpressure variation with depth and in different lithologies (Rabia, 2002).

5.5 Pore Pressure prediction

The pore pressure of Zamzama North-01 well is analyzed using Eaton's approach based on acoustic well logs. Lower formations of the well has been analyzed from depth of 3355.5 meters to 4500 meters with intervals of 50 meters. These formations include lower part of Girdo, Khadro, Pab and Fort Munro formations. For geo-pressure calculation four tracks are created which include Gama ray, Caliper, Average porosity, Formations Density, Sonic, Hydrostatic pressure, Overburden pressure and Pore pressure were evaluated. The estimation of geo-pressure of by using well logs is shown in Figure 5.5

First track shows Gamma Ray (NGR), Caliper, Bit Size (BS) and Normal Gamma Ray Trendline (NGRT) curves and lines. The Gamma Ray behavior is represented with green color having scale of 0 – 150 API. For observation of GR curve's behavior, a Normal GR Trendline (NGRT) is generated with red color on 60 API. While in the lower Girdo formation the GR curve shows overall constant behavior towards the right side with little peaks towards left. While in Khadro Formation the curve behavior changed due to change in lithology. In Pab sandstone overall GR curve behavior is towards the left side of NGRT while there are some peaks toward maximum values right side of the trend line. In Fort Munro formation the curve behavior again changed due to change in lithology. While there are maximum peaks are observed towards the maximum values on the right side of the trendline and also towards the minimum values on the left side. The caliper log showing the borehole diameter which is compared with the size of drill bits used. There are two peaks has been observed in Pab sandstone in 3745 and 3768 meters of depths. These peaks representing the phenomenon of caving in the borehole wall.

Track 02 has two curves of Average Porosity (PHIA) and Formation density (RHOB) in only two formations Pab sandstone and Fort Munro. PHIA curve is represented with black color having scale of 0 – 1 and RHOB is with blue color having scale of 1.95 – 2.95 g/cc. The area of Average porosity is shaded with orange color to show the porosity values clearly. Overall both curves have constant behavior with little fluctuations. In track 03 we have Sonic curve (DT4P) with green color and Normal Compaction Trendline (NCT) with red color. DT has a scale of 40 – 140 US/FT in which the NCT id marked on 19 US/FT. Overall the curve behavior is towards the left side (maximum DT values) showing high porosity. However, there two right side behavior of curve around 3400 meters and 3630 meters. The other changes in curve behavior shows the change in lithology.

5.5.1 Geo-pressure Results

Geo-pressure results can be seen in last track having Hydrostatic pressure (HP), Overburden Pressure (OP) and Pore pressure (PP_DT) with two filters Under-pressure and Overpressure. Hydrostatic pressure is represented with blue line having scale from 0 – 5000 psi. The overall behavior of HP is constant with no peaks and fluctuations. HP line starts from 1500psi with a gradual increase with depth extends up to 1700 psi approximately. The average value recorded for HP is 1641.786 psi. Overburden pressure is represented with purple color having same scale from 0 – 5000 psi. The overall nature of OP values is straight line with no peaks while with the line bending with gentle angle towards maximum values shows increase in the pressure with depth. OP line starts from minimum value of 3200 psi and gradually increases with depth till it reaches to its maximum of 3850 psi approximately. The average value recorded of OP is 3587.09 psi.

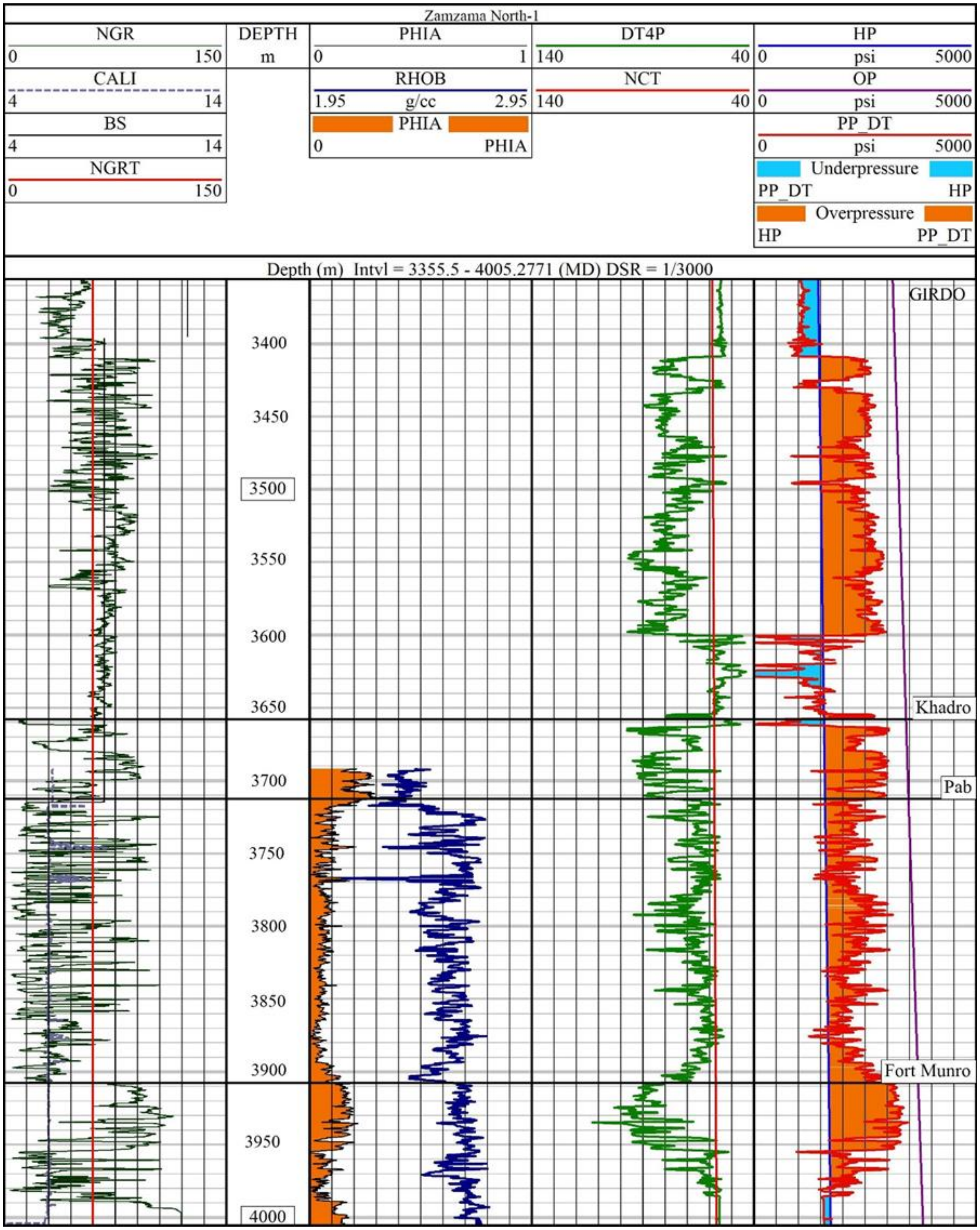

Figure 5.2 Geo-pressure estimation of Zamzama North-01 well lower formations.

The pore pressure is represented with red color curve having scale of 0 – 5000 psi. Unlike to the other two pressures, pore pressure curve shows many peaks and fluctuations. The PP curve maximum peaks are in upper Fort Munro around 3930 meters while the minimum or null values are in lower Girdo and upper Khadro formation with the depth of 3600 – 36550 meters. The average value for PP is 2196.014 psi calculated. Upon comparing the pore pressure values with hydrostatic pressure, the under-pressure and over pressure zone are highlighted. The zones having Pore pressure values lesser then Hydrostatic pressure are marked under-pressure zones. The under-pressure zones are highlighted with light blue color. There are total two under-pressure zones observed in Girdo formation only. Those zones having pore pressure greater then hydrostatic pressure marked as Overpressure zones. The overpressure zones are highlighted with orange color and these zones can be easily observed throughout the depth with many peaks.

Table 5.1 Results of Geo-pressure of Zamzama North-01 well logs.

Parameters	Average Values
Hydrostatic Pressure	1641.786 psi
Overburden Pressure	3587.09 psi
Pore Pressure	2196.014 psi

CONCLUSIONS

After Seismic data interpretation, Petrophysical Analysis and Geopressures assessment we conclude that

(1) The thrusted anticline structure in the Zamzama area supports an effective petroleum system. The structural deformation and thrust faults create suitable geometries for accumulation of hydrocarbons. The cretaceous Pab sandstone having reservoir properties is well trapped by the upper cap rocks of Khadro, and Ranikot formations.

(2) The petrophysical analysis reveals good reservoir properties for Pab sandstone having 5.68% effective porosity and 38.61% hydrocarbon saturation.

(3) The geopressure assessments indicate the overpressure conditions in the Paleocene and Cretaceous strata of Zamzama area. These overpressure zones can lead to challenging well drilling conditions. Accurately pressure evaluation can reduce the risk of blowouts and kicks.

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