2D SEISMIC INTERPRETATION AND PETROPHYSICAL ANALYSIS OF QADIRPUR AREA, CENTRAL INDUS BASIN, PAKISTAN

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

By

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ABSTRACT

This research presents a comprehensive seismic data interpretation and petrophysical analysis of the Qadirpur-03 well located in the Qadirpur area. Focused on both the Habib Rahi Formation as a reservoir and the Ghazij Formation as an unconventional source, the study encompasses an extensive evaluation of five seismic lines: 985-QPR-01, 985-QPR-02, 985-QPR-03, 90-QPR-05, and 90-QPR-06. Through detailed seismic interpretation, key structural and stratigraphic features were identified, providing insights into the subsurface geology. The analysis revealed crucial information regarding the distribution and characteristics of the Habib Rahi and Ghazij formations. Petrophysical analysis of the Habib Rahi Formation included assessing porosity, shale volume, and hydrocarbon saturation, yielding significant findings on the reservoir potential. Similarly, the unconventional Ghazij Formation was thoroughly investigated to understand its hydrocarbon prospects by using Indonesian’s equation and DlogR method to highlight effects and have better understanding. The integration of seismic and petrophysical data offers a deeper understanding of the geological and hydrocarbon potential of the Qadirpur-03 well, contributing to the broader knowledge of hydrocarbon exploration in the region.

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CHAPTER 1

INTRODUCTION

Likewise, the study of petrophysics plays a vital part in our understanding of the physical and chemical attributes of hydrocarbon- bearing jewels within the subsurface. Petrophysical analysis yields vital information, including the identification of fluid and mineral types, and the evaluation of porosity. This analysis is pivotal for estimating the volumes of both fluids and minerals in different zones of interest, encompassing both affected and pristine regions. Also, rock physics examinations are accepted to assess the impact of factors similar as porosity, mineral composition, and fluid saturation on the elastic properties of subsurface materials. These studies are necessary in enhancing our appreciation of the sub surface’s response to seismic examination and in enhancing the precision of hydrocarbon force assessments in regions like the Qadirpur area of the Central Indus Basin, Pakistan. (Asim et al., 2015)

1.1 Location of Study Area

The study area, centered around the Qadirpur- 03 well, is positioned in the Sindh province of Pakistan, within the central Indus Basin. This region, known for its substantial hydrocarbon resources, is a crucial area of interest for geological and petrophysical exploration. The Qadirpur- 03 well is strategically located in a zone famed for its complex subsurface structures and hydrocarbon potential. This well, along with others in the vicinity, contributes to the understanding of the broader geological infrastructure of the Central Indus Basin. The proximity of the Qadirpur field to other significant gas fields in the region underscores the area's importance in the context of Pakistan's energy sector.

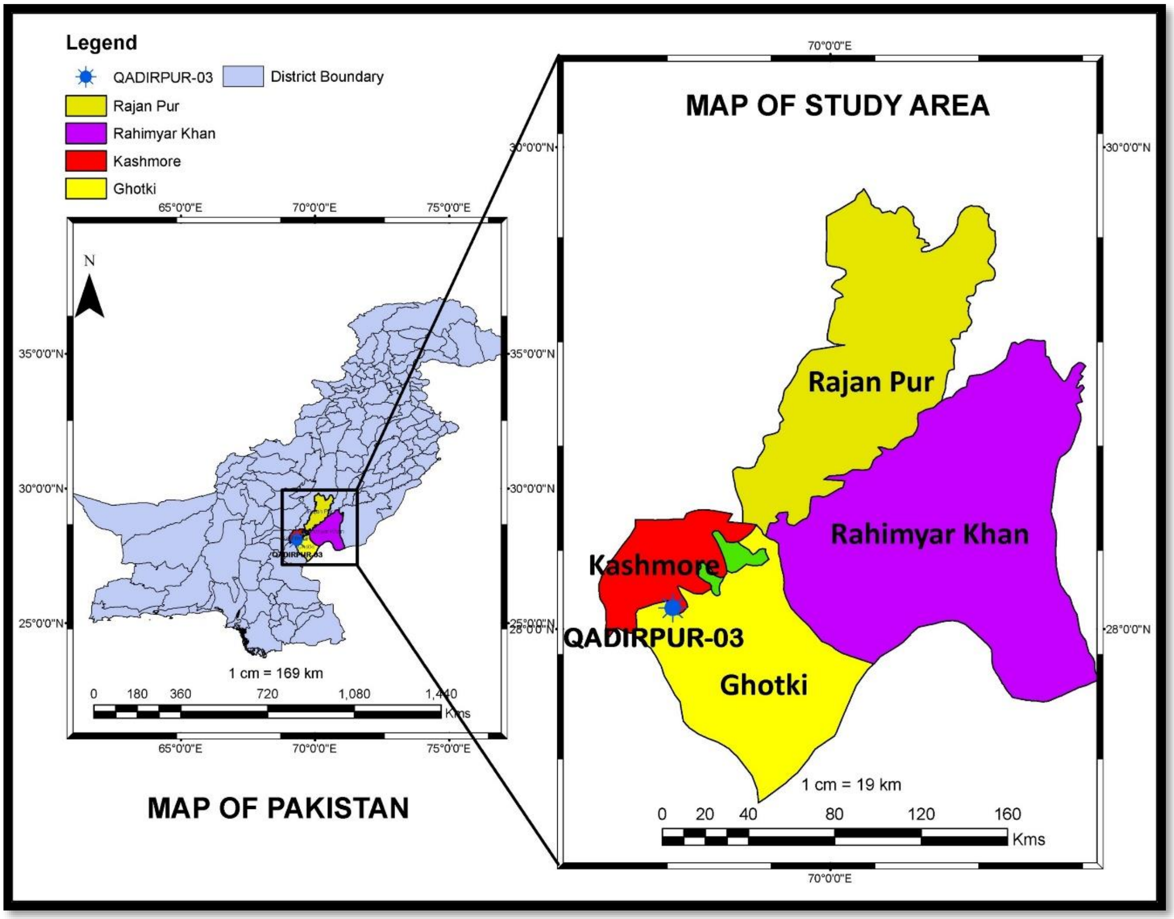

Figure 1.1: Study Area Map of Qadirpur-03 Well in the Central Indus Basin

1.2 Exploration History

The exploration history of the Qadirpur- 03 well in the Qadirpur gas field reflects a journey of significant discoveries and technological advancements in hydrocarbon exploration. Initial exploration in the region dates to the late 20th century, with the Qadirpur- 03 well playing a vital part in unveiling the gas reserves of the area. The breakthrough in the exploration of this well came with the integration of advanced seismic ways, which provided a deeper insight into the subsurface structures. The well's successful drilling led to the discovery of considerable natural gas reserves, marking it as a crucial contributor to Pakistan's natural gas production. Over the years, continued exploration and development around the Qadirpur- 03 well have further solidified the field's status as a major hydrocarbon reservoir in the Central Indus Basin.

1.3 Climate

The Qadirpur area, encompassing the Qadirpur- 03 well, is characterized by a predominantly arid climate, typical of the Lower Indus Basin in Pakistan. This climate has a direct impact on the geological and depositional processes in the region. The hot, dry conditions prevalent in the area impact the sedimentation patterns and preservation of geological formations, pivotal for hydrocarbon exploration. The lithological diversity in formations such as the Goru Formation, encountered in the drilling of the Qadirpur- 03 well, can be attributed to these climatic conditions. Understanding the climatic influence on these formations is essential for accurate modeling and analysis of the reservoir's properties and potential.

1.4 Objective

The basic goal of this thesis is to determine the hydrocarbon potential and engineering characteristics of the rocks in the vicinity. Seismic methods, as well as petro physical examination of well-logs, were employed to achieve this goal.

Following are the main goals to be accomplished:

1) Structural Interpretation of the study area
2) Reservoir evaluation of the Habib Rahi Formation.
3) Unconventional Resource evaluation of Ghazij Formation

1.5 Data Required

Data was obtained from Director General Petroleum Concessions (DGPC). The set data included:

(1) Well logs.

(2) Seismic Lines

(3) Navigation File

Table 1.1: Seismic Lines used in seismic data interpretation.

Line name	**Line type**	**Line orientation**
985-QPR-01	Dip Line	North-East Trending
985-QPR-02	Dip Line	North-East Trending
985-QPR-03	Dip Line	North-East Trending
90-QPR-05	Strike Line	North-West Trending
90-QPR-06	Strike Line	North-West Trending

1.6 Methodology

- **Horizon Identification:** Labeling crucial seismic horizons for stratigraphic analysis.
- **Synthetic Seismogram Generation:** Creating synthetic seismograms to relate well data with seismic reflections.
- **Fault Mapping:** Relating and mapping faults within the seismic data.
- **Contour Mapping:** Developing time and depth contour maps for subsurface structure analysis.
- **Velocity Analysis:** Conducting seismic velocity studies for enhanced data interpretation.
- **Depth Conversion:** Converting seismic time data to depth measurements for precise modeling.
- **Petrophysical Analysis:** Analyzing well log data to determine rock properties.
- **Software Utilization:** Using Geoghraphix Gverse 2019.4 for seismic lines interpretation and petrophysical analysis.

CHAPTER 2

GEOLOGY AND TECTONICS OF THE CENTRAL INDUS BASIN

A basin is generally a low- lying depression on Earth where long- term subsidence facilitates the accumulation of sediments. Over time, these sediments undergo contraction and lithification, transforming into sedimentary rocks. The Indus Basin, notable for its considerable extent in a NE- SW direction, is one of the largest basins and is relatively stable tectonically compared to other regions in Pakistan. Characterized by buried ridges, platform slopes, and varied zones of up-warp and down-warp, the basin extends from the Khairabad- Panjal thrust to the Ornach- Nal & Quetta fault system along the western margin of the axial belt. It encompasses several geological provinces, including the Kohat- Potwar, Sulaiman, Kirthar, and the axial belt. (Malkani, 2010)

Divided into the Upper, Central, and Southern Indus Basins, the Central Indus Basin, where the Qadirpur- 03 well is located, is distinguished by the Punjab Platform, characterized by a broad monocline structure leaning gently towards the Sulaiman Depression and the Sulaiman Fold Belt. The Southern Indus Basin, spanning between latitudes 24 ˚N- 28 ˚N and longitudes 66 ˚E to the eastern boundary of Pakistan, includes features like the Thar Platform, Karachi Trough, Kirthar Foredeep, Kirthar Fold Belt, and the Indus Offshore. The Upper Indus Basin comprises various mountain ranges extending in a west- east direction from the Hindu Kush and Pamirs in the west and north to the main Himalayan chain in the south and east, forming a complex and diverse geological landscape.

2.1 Geology and Tectonic of Central Indus Basin

The Central Indus Basin, locating the Qadirpur- 03 well, is a geologically rich and tectonically active region in Pakistan. Extending over a significant portion of the country's landscape, the basin is characterized by a diverse range of sedimentary deposits, including Jurassic, Cretaceous, and Tertiary sediments. It's strategically positioned, bounded to the north by the Upper Indus Basin, to the northwest by the Suleiman fold belt, and to the southwest by the Kirthar Fold Belt. (Stöcklin,1980) This location places the Central Indus

Basin in a unique historic setting, generally within the "Indus platform and foredeep" zone, encompassing various structural formations.

The basin is marked by a complex array of geological structures, such as tilted fault blocks, thrust- faulted anticlines, and simple anticlines. These structural features, particularly prevalent in the foreland area of the Central Indus Basin, are largely attributed to the tectonic forces resulting from the collision between the Indian and Eurasian plates. This tectonic interaction has shaped the geography, impacting both the structures and sedimentology of the region. The basin's geology includes a wide range of sediment types, from infra- Cambrian to recent, encompassing both clastic and carbonate materials. crucial tectonic events that have influenced the Central Indus Basin include the rifting of the Indian Plate from Gondwanaland, which probably led to the formation of NE- SW to N- S rift systems, and isostatic adjustments at the perimeters of the tectonic plates.

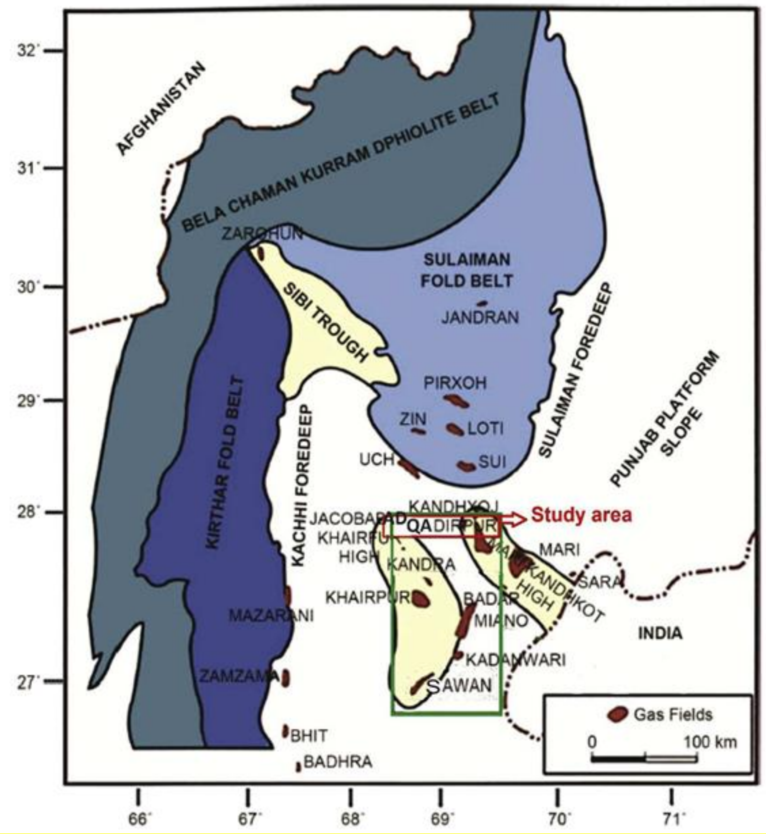

Figure 2.1: Tectonic map showing the location of study area (Ali, 2010; Ahmad etal.,2013)

2.2 Tectonic and structure of study area

The Qadirpur- 03 well is strategically positioned within the Central Indus Basin, near the interface of the Indus platform and the Kirthar Fold Belt. This area is framed by the Indian Shield to the east and the marginal zone of the Indian plate to the west. The Central Indus Basin, encapsulating the Qadirpur gas field, is further delineated by the Sindh Monocline to the north and extends southward towards the offshore Indus region.

The study area is especially part of the Central Indus platform, a region characterized by a complex interplay of tectonic forces and geological structures. To the north, it's bounded by the Jacobabad- Mari- Kandhkot high, to the south by the Hyderabad high, and to the east by the Nabisar Slope and the Tharparkar high. The structural formation of the Qadirpur area, including the Qadirpur- 03 well, is significantly influenced by the collision between the Indian and Eurasian plates, resulting in a distinctive anticlinal structure. This tectonic activity has given rise to a prominent north-south oriented, eastward verging thrusted anticline in the region.

The geological structure of the Qadirpur area is further defined by a major thrust fault, which distinguishes the hanging wall from the footwall structures. This fault, extending over a considerable length, plays a critical part in shaping the subterranean armature of the region. It's characterized by its significant influence on the formation and distribution of potential hydrocarbon reservoirs, making it a focal point for exploration activities in the Central Indus Basin. (Qureshi et al., 2020).

2.3 Stratigraphy of Central Indus Basin

The stratigraphic frame of the Central Indus Basin has been profoundly influenced by major tectonic episodes, especially the rifting of the Indian Plate from Gondwanaland during the Jurassic or Early Cretaceous period. This tectonic activity led to significant uplift and eastward tilting of the basin, initiating at the onset of the Cretaceous. (Murthy et al., 2011). Similar events have shaped the structural and sedimentological characteristics of the basin, resulting in a complex stratigraphic sequence.

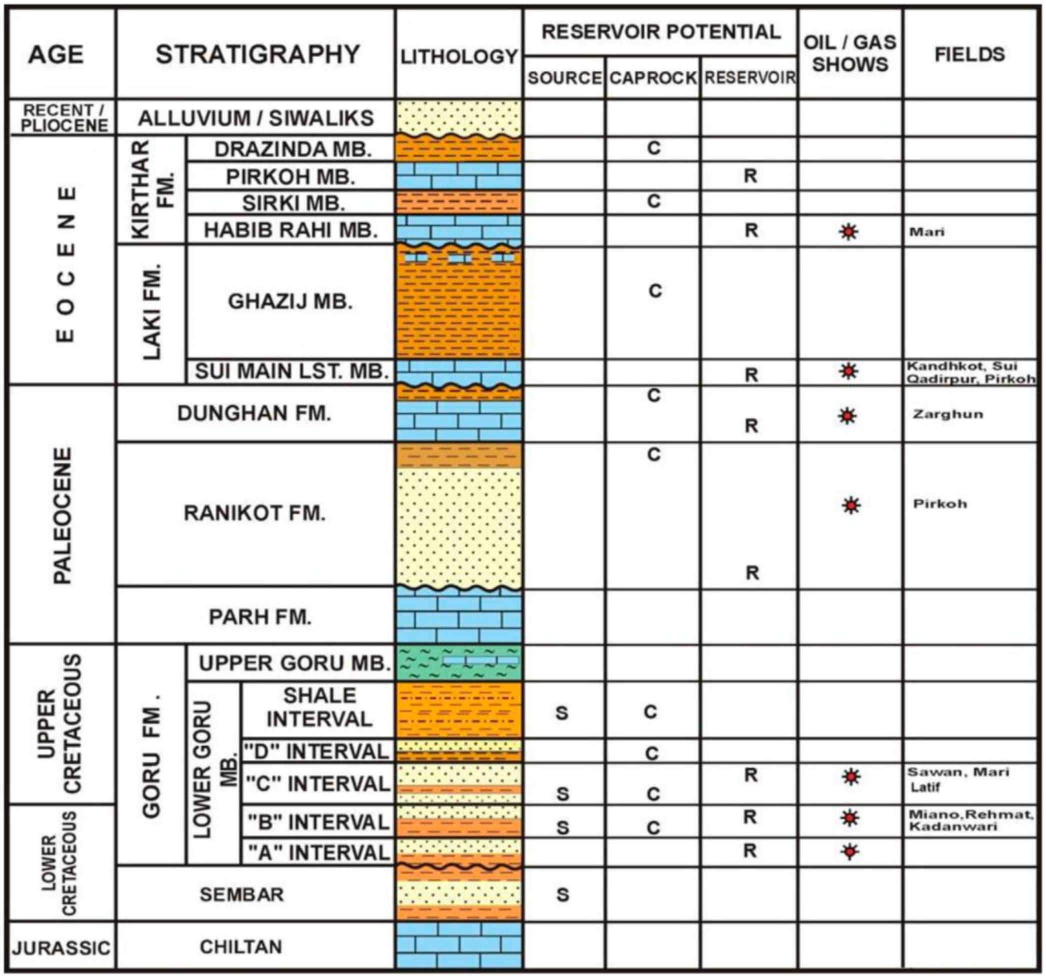

Figure 2.2: Generalized stratigraphy column of the Middle Indus Basin (Azeem et al., 2016)

This sequence encompasses a wide range of sedimentary deposits from various geological ages, each layer providing insights into the environmental conditions and geological processes at the time of deposit. The stratigraphy of the Central Indus Basin is crucial to understanding the hydrocarbon potential of the area, particularly in terms of the distribution and characteristics of potential reservoirs and source rocks. Mahmoud, 2015) The Qadirpur- 03 well, positioned within this stratigraphic context, serves as a crucial site for exploring these aspects and contributes to the broader understanding of the basin's hydrocarbon prospects.

2.4 Borehole Stratigraphy of Qadirpur-03 Well

The Qadirpur- 03 well, a crucial exploratory well in the Central Indus Basin, reached a total drilled depth of roughly 4000 measures. The stratigraphic sequence encountered in these well spans from recent formations to those dating back to the Late Cretaceous period. The uppermost formation encountered is the recent alluvial deposits, indicative of the region's recent geological history. Progressing deeper, the well penetrates through a series of stratigraphic layers, each representing a distinct geological era.

The deepest formation reached in the Qadirpur- 03 well is the Fort Manro formation, a significant geological layer dating back to the Late Cretaceous age. This formation, along with others encountered in the well, provides valuable information about the geological history and hydrocarbon potential of the Central Indus Basin.

Table 2.1: Borehole stratigraphy of Qadirpur-03 Well

Formations	**Depth (m)**
ALLUVIUM	0.0
SIWALIK	96.0
NARI	500.0
DRAZINDA	704.0
PIRKOH	773.0
SIRKI	880.0
HABIB RAHI	930.0
GHAZIJ	1014.0
SUI UPPER LIMESTONE	1220.0
SHALE UNIT	1280.0
SUI MAIN LIMESTONE	1333.0

2.5 Petro Play

The Qadirpur- 03 well, positioned in the Central Indus Basin, is part of a significant petro play area with a history of substantial hydrocarbon discoveries. The exploration in this region has been guided by the potential in formations similar to the Late Cretaceous clastics of the Lower Goru Formation, which have shown promising results for oil and gas production. (Dar et al., 2021)

Table 2.2: Petroleum Elements of Study Area

Source Rock	**Ghazij Formation** - Contains significant organic content for potential hydrocarbon generation. - Known for its unconventional hydrocarbon prospects.
Reservoir	**Habib Rahi Formation** - Characterized by properties suitable for hydrocarbon accumulation. - Potentially high porosity and permeability.

2.5.1 Source Rock

The Central Indus Basin, encompassing the Qadirpur- 03 well, is characterized by the presence of crucial source rocks, especially the Sembar and Goru formations' Cretaceous shales. These formations, rich in organic content, have experienced significant thermal development, making them capable of generating oil and gas. (Wandrey, Law, & Shah, n.d.) The burial and development of these source rocks have been critical in the hydrocarbon generation process, contributing significantly to the basin's overall hydrocarbon potential.

2.5.2 Reservoir

Near the Qadirpur- 03 well, the primary hydrocarbon reservoirs are characterized by rocks with high porosity and permeability. The Lower Goru Formation has been identified as a primary reservoir rock, holding substantial hydrocarbon reserves. The capability of these formations to accumulate and retain hydrocarbons has been central to the success of exploration and production activities in the region. (Ali et al., 2019)

2.5.3 Top Seal and Cap Rock

The effectiveness of hydrocarbon trapping in the Central Indus Basin, including the area around the Qadirpur- 03 well, is largely attributed to the presence of competent top seals. The marine shales of formations such as the Girdo (Ranikot) Formation deliver the ultimate top seal for hydrocarbon accumulations. These shales are critical in ensuring the hydrocarbons remain trapped within the reservoir rocks, preventing their escape and conserving their concentrations for extraction.

CHAPTER 3

SEISMIC DATA INTERPRETATION

In this chapter, we delve into the seismic interpretation for the Qadirpur-03 well, located in the Central Indus Basin. Seismic data processing is the first step in this endeavor, providing a window into the subsurface geological structures. The interpretation primarily revolves around analyzing phase, amplitude, and frequency components of the seismic data, which are critical for understanding the subsurface characteristics. The main goal of seismic interpretation in the context of the Qadirpur-03 well is to accurately identify horizons and reflectors associated with various geological formations. This technique is instrumental in gathering both structural and stratigraphic information, essential for hydrocarbon exploration. (Qureshi et al., 2020) A crucial part of this process is the detailed marking of horizons and faults. Such precision enhances the effectiveness of seismic interpretation, leading to a clearer understanding of subsurface geology. This is particularly important for the Qadirpur-03 well, as it aids in the identification of potential hydrocarbon-bearing formations and structures.

Through seismic interpretation, we aim to thoroughly analyze and comprehend the geological formations around the Qadirpur-03 well. This understanding is vital for guiding exploration strategies and optimizing hydrocarbon extraction in this region. (Hasany & Saleem, n.d.)

3.1 Seismic Interpretation

Seismic interpretation for the Qadirpur-03 well involves an in-depth analysis of the subsurface geology, which is categorized into two primary domains:

Stratigraphic interpretation is concerned with the history, composition, geological ages, and distribution of strata. (Khan et al., 2022) Stratigraphic analysis interprets the layering and sequencing of geological strata, providing insights into the depositional environment and historical geology of the region.

Structural interpretation involves the identification and mapping of faults, folds, and other structural features within subsurface geology. The main objective of structural analysis is to locate potential structural traps, which are crucial for hydrocarbon exploration. (Chandrasheker, n.d.) The types of structural traps identified are significantly influenced by the tectonic setting of the area surrounding the Qadirpur-03 well. (Hussain et al., 2015)

Both stratigraphic and structural interpretations are integral to understanding the geological framework of the Qadirpur-03 well. This understanding is essential for identifying potential hydrocarbon-bearing formations and optimizing exploration and extraction strategies in the Central Indus Basin. (Hasany & Saleem, n.d.)

3.1.1 Stratigraphical Seismic Interpretation

Seismic stratigraphy is an approach that employs seismic data to interpret the stratigraphy of geological formations. This technique is particularly valuable in basins like the one surrounding the Qadirpur-03 well, where there may be limited well data. For areas with sparse well control, seismic stratigraphic interpretation has become a crucial part of exploration. This approach places new responsibilities and requires specialized skills from both geologists and geophysicists. To meet exploration demands, two primary methods have been developed: a physical approach, which involves processing and synthetic modelling, and a seismic-stratigraphic approach that applies traditional facies geology in novel ways.

The interpretation of seismic stratigraphy primarily focuses on changes in reflection waveforms, rather than just the travel-time of the reflections. It has been observed that waveform changes can provide key insights, although they can be obscured by noise, particularly in land seismic survey data. (Mitchum, Vail, & Sangree, n.d.) Marine seismic data often offers better resolution for detecting stratigraphic changes. (Vail, Todd, & Sangree, n.d.)

The extraction of stratigraphic information from seismic data relies on a set of principles and techniques that constitute a branch of applied science known as seismic stratigraphy. The primary aim of this approach in the context of the Qadirpur-03 well is to identify various stratigraphic features visible in seismic sections. These features can include facies changes, sand lenses, reefs, and unconformities, each offering valuable insights into the subsurface geological history of the area.

3.1.2 Structural Seismic Interpretation

The objective of structural seismic interpretation, particularly relevant to the Qadirpur-03 well, is to construct detailed structural maps of the subsurface. This involves analyzing the three-dimensional configuration of seismic wave arrival times to understand the geological structures below the surface. (Alridha, Daim, & Jassim, n.d.) Structural interpretation in seismic sequence stratigraphy connects the patterns observed in seismic reflections to models of cyclic depositional episodes. This process is crucial in mapping the subsurface geological features that are significant for hydrocarbon exploration.

In Qadirpur-03 well, the identification of faults, folds, and fractures is a key aspect of structural interpretation. These features are essential in pinpointing potential hydrocarbon leads and developing exploration plays. The interpretation process places considerable emphasis on geometric attributes, which are instrumental in detecting faults, folds, and fractures. Some of the primary geometric attributes used in structural interpretation include dip magnitude and azimuth, coherence, and curvature. Each attribute provides unique insights into the subsurface structural geometry, aiding in the accurate mapping of geological structures that could contain hydrocarbon deposits.

3.2 Subsurface Structural Interpretation of Study Area

For the subsurface structural interpretation in the area encompassing the Qadirpur-03 well, a 2D seismic dataset has been utilized. This seismic data is instrumental in delineating the structural trends of the subsurface formations. The dataset includes a total of six seismic lines, comprising four dip lines and two strike lines, which provide a comprehensive view of the geological structures in the study area. The well log data from the Qadirpur-03 well serves as a critical control point for determining the depth of various subsurface horizons. This well, strategically positioned along one of the interpreted seismic dip lines, offers essential data that aids in correlating seismic information with actual subsurface conditions. The interpretation of these seismic lines and integration with well log data allow for a detailed understanding of the subsurface structural features in the Qadirpur-03 area. This understanding is vital for identifying potential hydrocarbon reservoirs and guiding further exploration and drilling activities in the Central Indus Basin. (Munir et al., 2014)

3.3 Seismic Interpretation Steps

The workflow utilized for seismic data interpretation specific to the Qadirpur-03 well area is outlined in the flowchart presented in the following section.

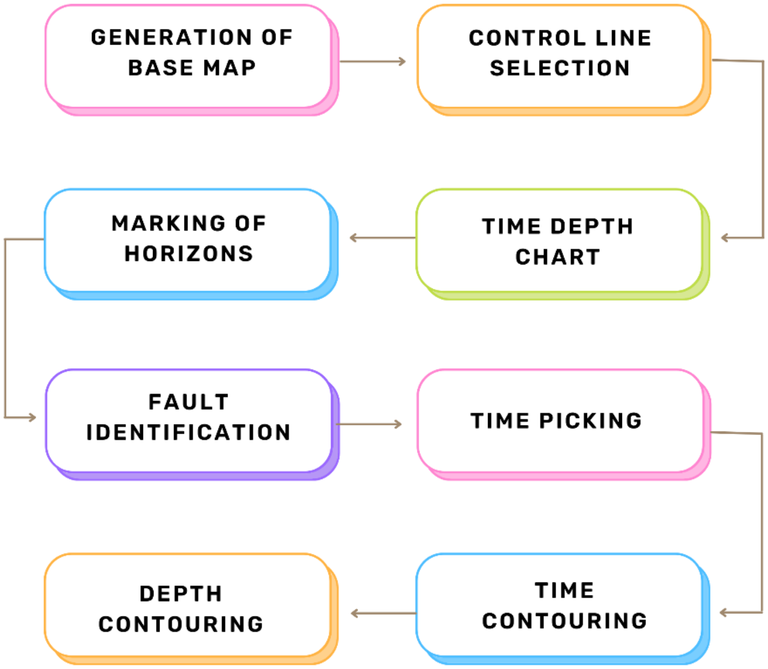

Figure 3.1: Seismic Data Interpretation Hierarchy.

3.3.1 Base Map

The base map delineates the positioning of the Qadirpur-03 well site along with the associated seismic lines and seismic survey shot points, which are plotted with precise geographic coordinates of longitude and latitude. This map has been generated by employing the navigation data furnished by the Director General of Petroleum Concessions. Three dip lines (985-QPR-01, 985-QPR-02, 985-QPR-03) trending in North-East direction and two strike lines (90-QPR-05 and 90-QPR-06) trending in North-West direction.

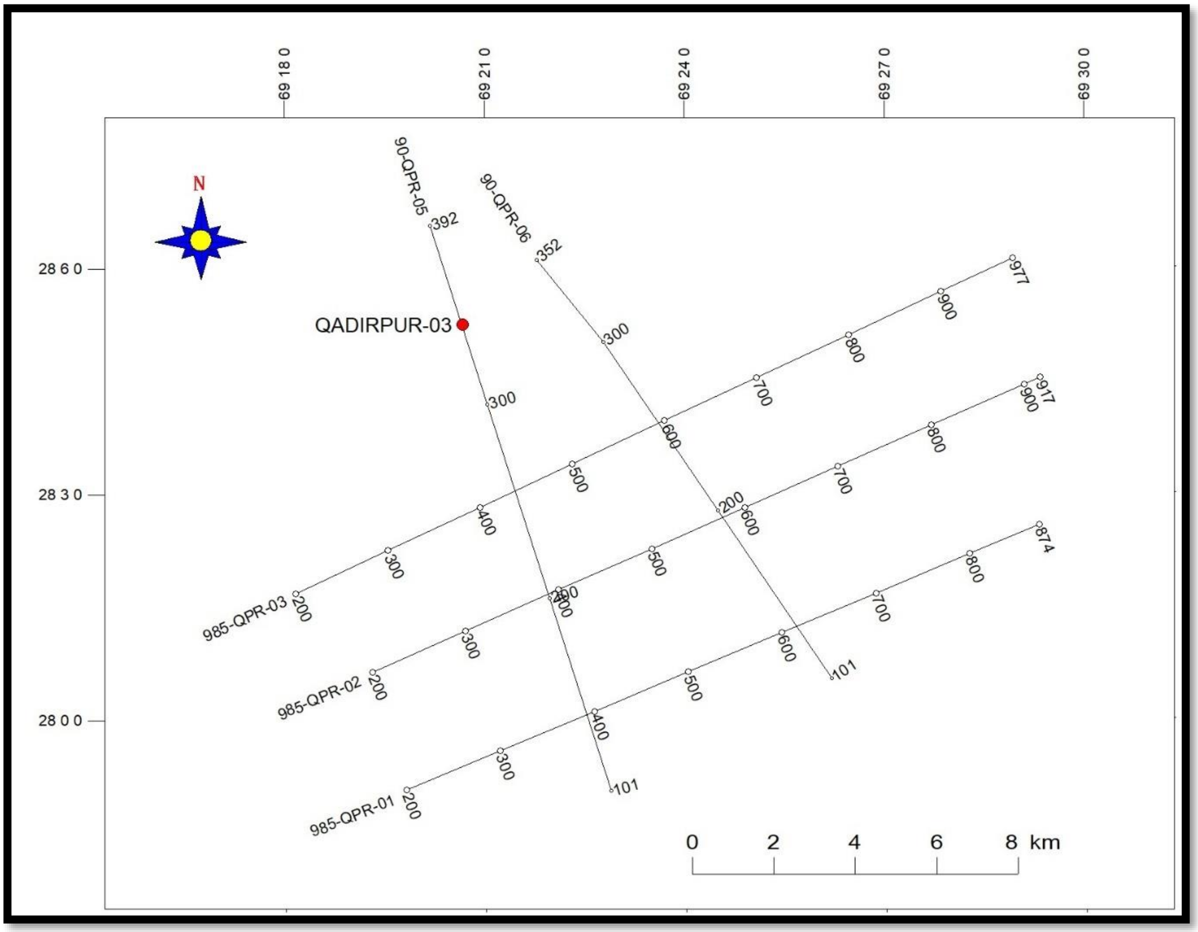

Figure 3.2: Strike and Dip Lines along with the location of well plotted on the base map.

3.3.2 Data Quality

The success of seismic interpretation is heavily reliant on the quality of the seismic data. Achieving accurate and reliable results is contingent upon the clarity and resolution of the data at hand. The data's quality is a pivotal factor in determining the feasibility of an accurate interpretation. Despite the age of the seismic data provided for the Qadirpur-03 well, its integrity has been upheld, ensuring that it remains of good quality. (Liang et al., 2015) High-resolution and clear data are indispensable for error-free outcomes in seismic analysis. The historical data used in this study has proven to be sufficiently detailed, allowing for a comprehensive interpretation of the subsurface structures.

3.3.3 Selection of Control Line

The seismic line designated as 90-QPR-05 (Strike Line) is of particular importance. The selection of control line is done generally where the well lies, in our case, Qadirpur-03 well lies on 90-QPR-05 (Strike Line). This line acts as the control line for accurately marking horizons and faults. Additionally, it serves as the reference for correlating and tying the seismic data (for generating synthetic) from other lines within the study area.

The backend parameters are:

Formation Depth = Formation Top + Seismic reference datum – Kelly bushing

Seismic reference datum = 0 Kelly Bushing = 79.00 m

3.3.4 Time-Depth Chart of Qadirpur-03 Well

Upon establishing the control line, the subsequent phase involves creating a Time-Depth (TD) chart. This chart is developed by compiling velocity, time, and depth data extracted from the seismic section. An Excel spreadsheet is utilized to input these values and to construct a graph that correlates time with depth. The TD graph is essential for aligning time values with corresponding depths and for extrapolating horizons as needed. In the seismic section, time is represented as two-way travel time, which is the duration it takes for the seismic wave to encounter an impedance contrast and return to the receiver, such as geophones.

However, for depth estimation, the one-way travel time is required—this is the duration for the wave to travel from the source to the reflective boundary. To convert the two-way travel time into one-way travel time for depth calculation, the recorded time is divided by 2 and for the conversion of time from milliseconds to seconds is divided by 1000. Depth measurement is then determined using the method developed by Sigismund (2018), which allows for the accurate interpretation of subsurface features.

$$S=V*t/2000$$

Here, S= Depth, V= RMS Velocity and t= Time (TWT_t).

Table 3.1: Time-Depth Chart Calculations

Time (ms)	(RMS) Velocity (m/s)	S=V*T/2000 (m)
0	1443	0
300	1739	260.85
600	1985	595.5
900	2196	988.2
1200	2406	1443.6
1500	2750	2062.5
1800	3064	2757.6
2100	3195	3354.75
2400	3269	3922.8
2700	3370	4549.5
3000	3496	5244
3300	3708	6118.2
3600	3944	7099.2
3900	4211	8211.45
4200	4523	9498.3
4500	4879	10977.75
4800	5176	12422.4

The synthetic seismogram has now been constructed, and any misalignments within the data, referred to as mis ties, have been thoroughly examined.

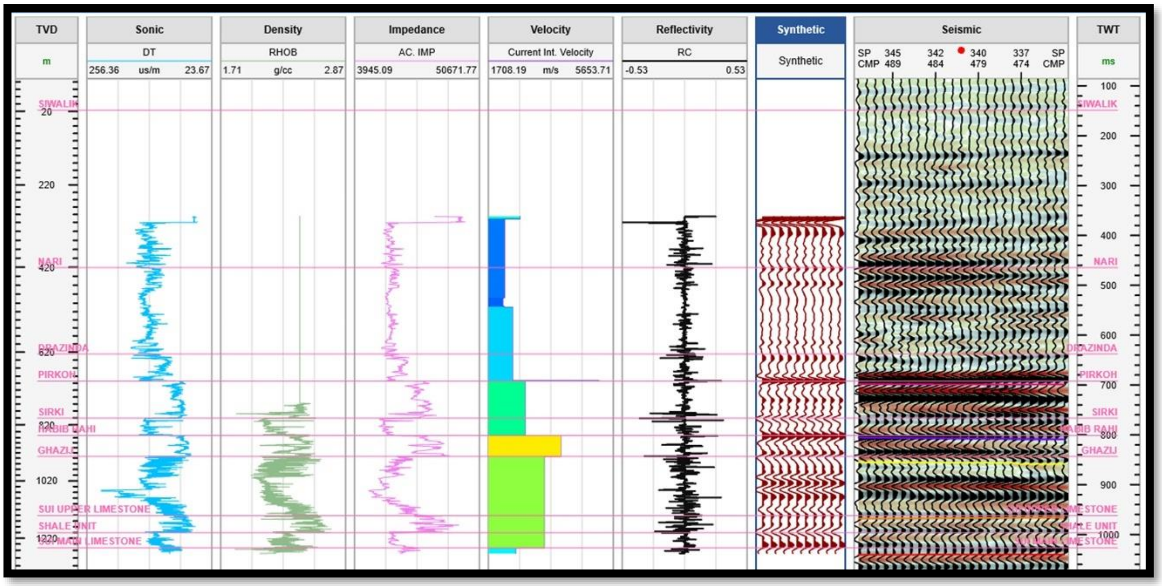

Figure 3.3: Synthetic Seismogram of the Seismic Control Line having well.

3.3.5 Marking of Horizons

The initial phase of seismic data interpretation involves scrutinizing reflection patterns to detect any unconformities on the seismic section. Continuous reflectors are easier to trace. Horizons are marked by following the sequence of wavelet traces across consecutive traces. Challenges in marking horizon continuity may arise due to various factors. Structural disturbances, lithological changes, and background noise can merge, terminate, or distort wavelet traces, resulting in weakened seismic signals. We marked Five key horizons using distinct colors to facilitate easy identification: the Pirkoh Formation is marked in pink, the Habib Rahi Formation in purple, the Ghazij Formation in yellow, the Sui Upper Limestone in orange, and the Sui Main Limestone in red. These horizons were identified on seismic lines 985-QPR-01, 985-QPR-02, 985-QPR-03, 90-QPR-05, and 90-QPR-06.

The validity of these formations was confirmed by well top data from LMKR, ensuring the accuracy and reliability of our seismic interpretation.

3.3.6 Fault identification Process

Following the marking of the horizons, the subsequent phase in seismic interpretation involves the identification and marking of faults. The faults were identified and marked based on interruptions in the continuity of seismic reflections. Specifically, six normal faults were identified on seismic line 985-QPR-01. Additionally, seven normal faults were marked on seismic lines 985-QPR-02 and 985-QPR-03. These faults contribute to the formation of horst and graben structures, which are significant in understanding the subsurface geology of the area.

3.3.7 Interpreted Seismic Sections

90-QPR-05 is a strike line and selected as a control line. Synthetic Seismogram is imposed on this line. It is evaluated with the help of Geoghraphix Gverse 2019.3 Software by providing the Time and Depth values of formation which were calculated previously.

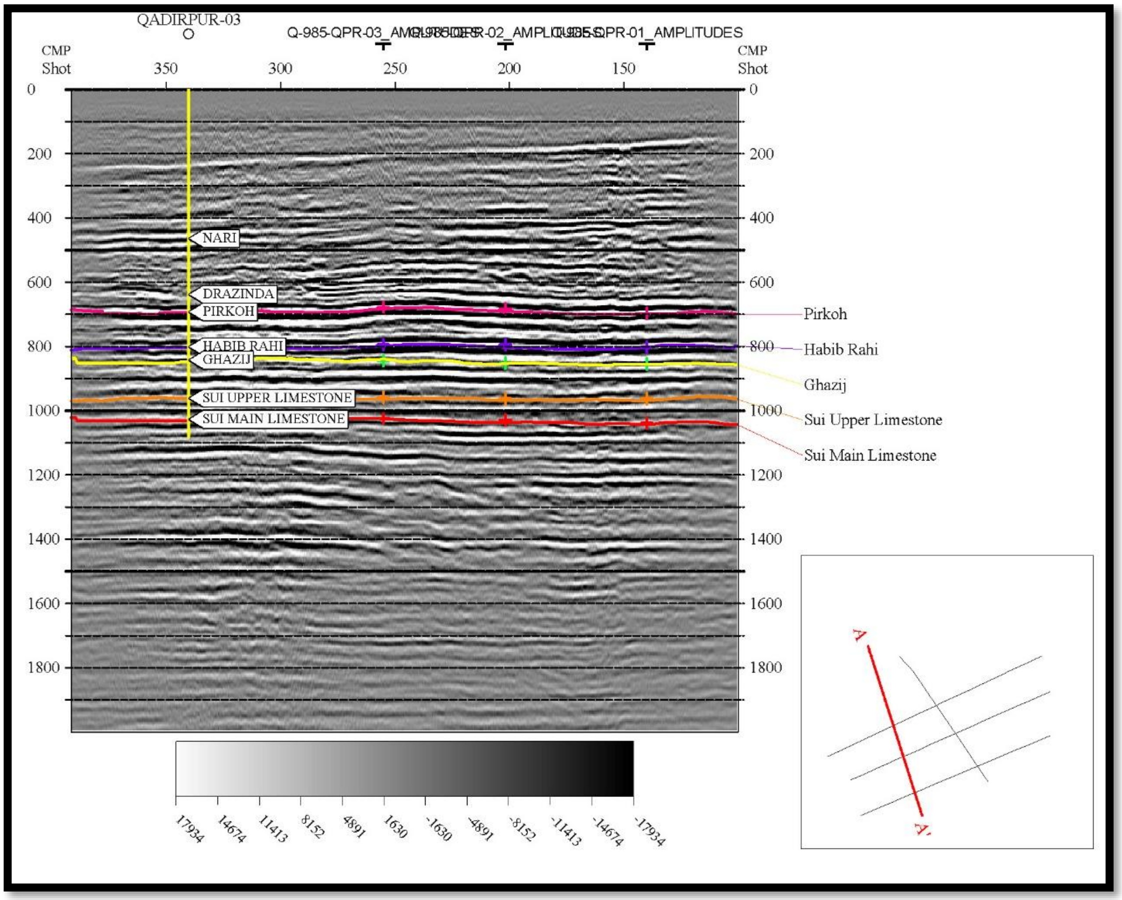

Figure 3.4: Interpreted Seismic Control Line (90-QPR-05)

This line is North-West trending. In this line the general trend of a structure is marked with the help of reflectors of Pirkoh Formation, Habib Rahi Formation, Ghazij Formation, Sui Upper Limestone and Sui Main Limestone.

985-QPR-03 is a dip line and has a trend towards North-East. On this line, with the help of the previous line, we have marked horizons that are Pirkoh Formation by pink, Habib Rahi Formation by purple, Ghazij by yellow, Sui Upper Limestone by orange and Sui Main Limestone by red color.

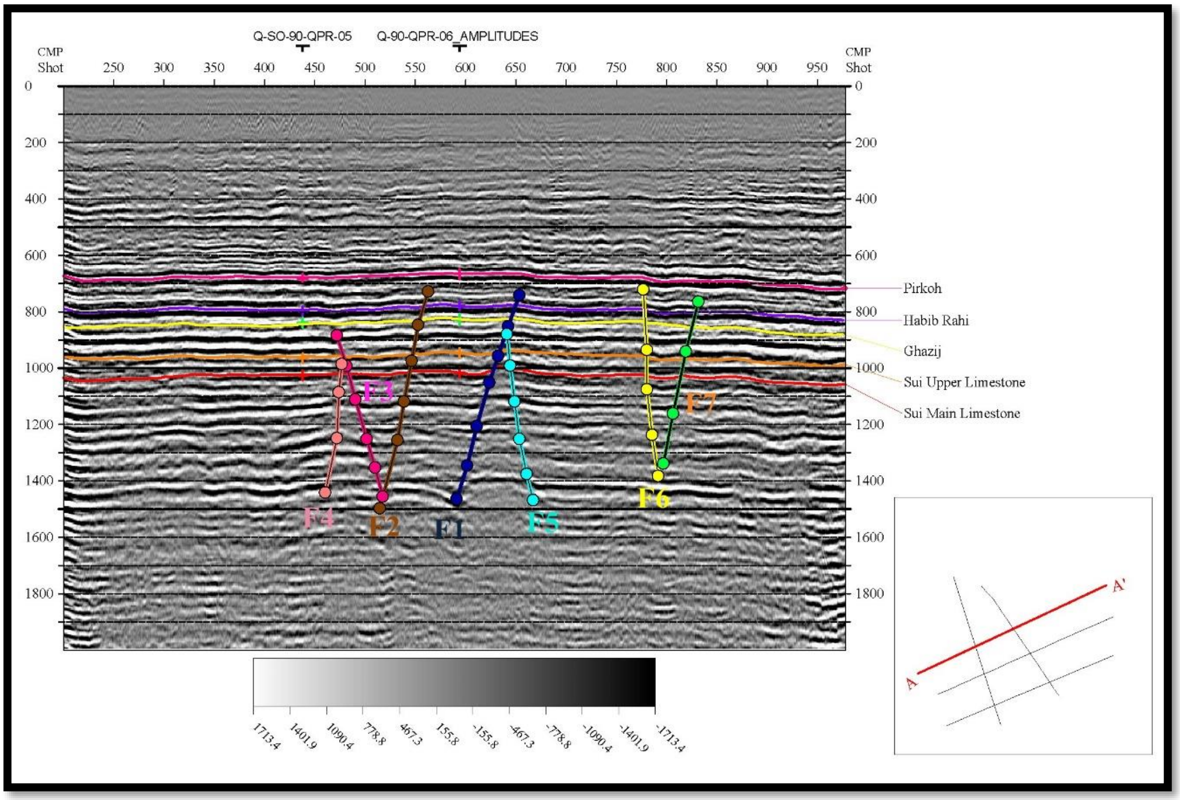

Figure 3.5: Interpreted Seismic Control Line (985-QPR-03)

Additionally, faults are also marked on this line that are F1, F2, F3, F4, F5, F6 and F7. These faults are generally normal faults which are making four horst and graben structures repetitively.

985-QPR-02 is a dip line and has a trend towards North-East. This dip line has the same number of horizons, associated with same colors, marked on it as on all other seismic control lines.

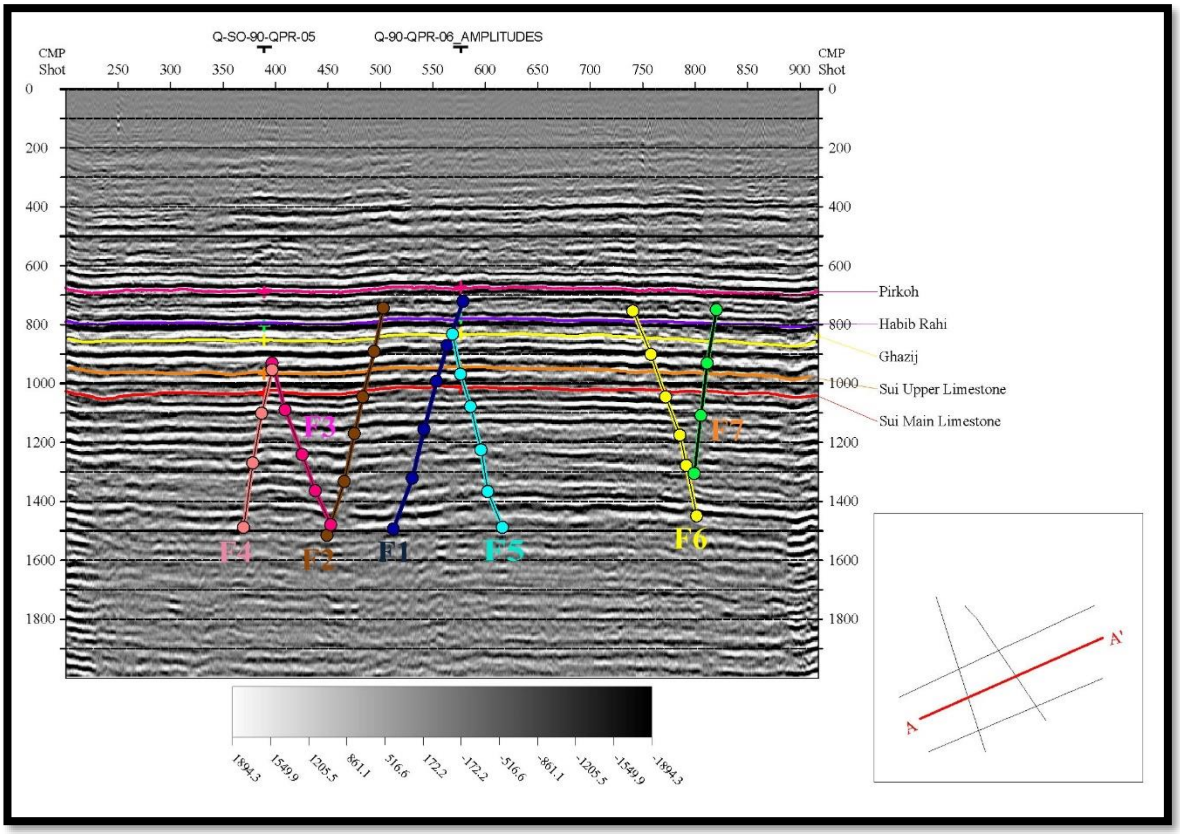

Figure 3.6: Interpreted Seismic Control Line (985-QPR-02)

The faults that are marked in this dip line are also seven and they are making four horst and graben structures too.

Seismic line **985-QPR-01**, characterized as a dip line, exhibits a trend towards the North-East. Consistency in the seismic interpretation process is maintained on this line, with the same number of horizons identified and marked with corresponding colors as on the other seismic control lines.

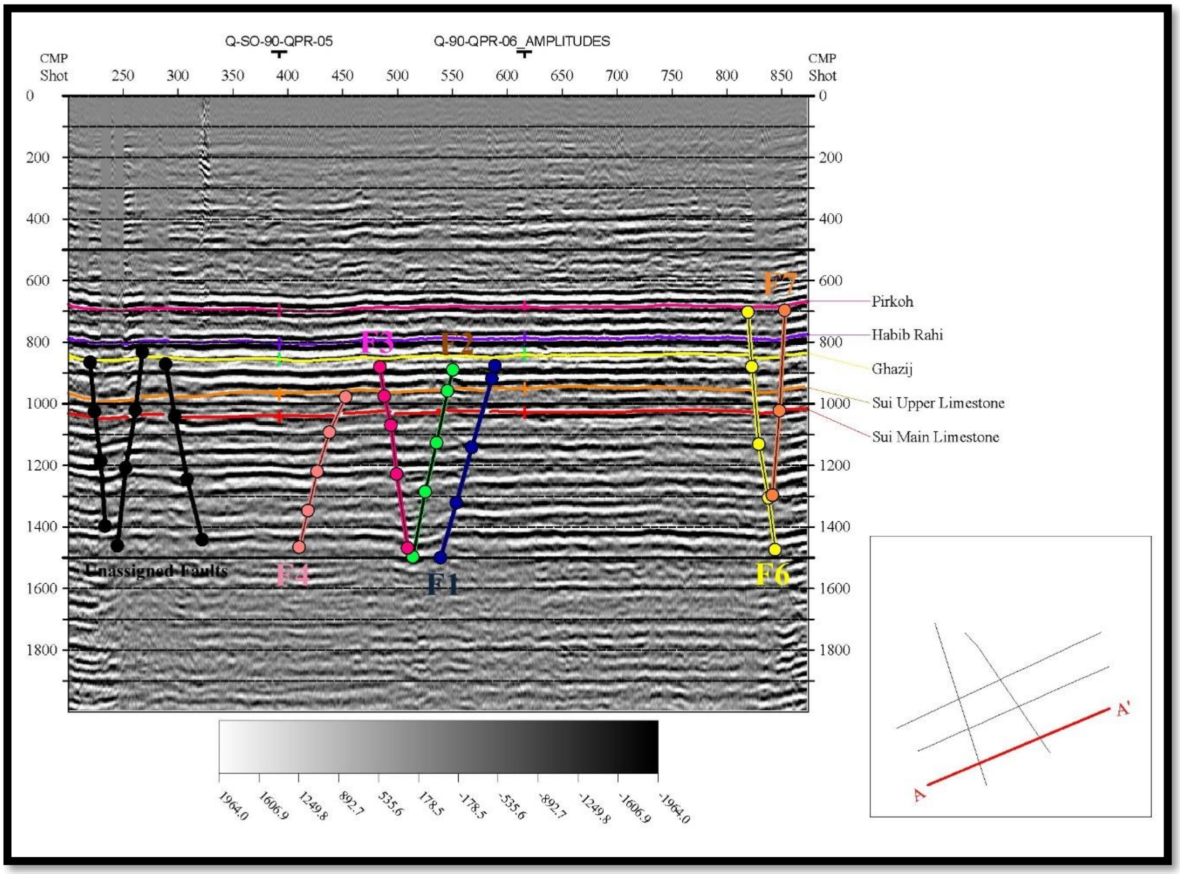

Figure 3.7: Interpreted Seismic Control Line (985-QPR-01)

On this dip line, a total of six faults have been marked. These faults collectively contribute to the formation of three distinct horst and graben structures.

90-QPR-06 is a strike line trending in the direction of North-West. This line also has five horizons marked on it and identified with their associated colors as in above figures.

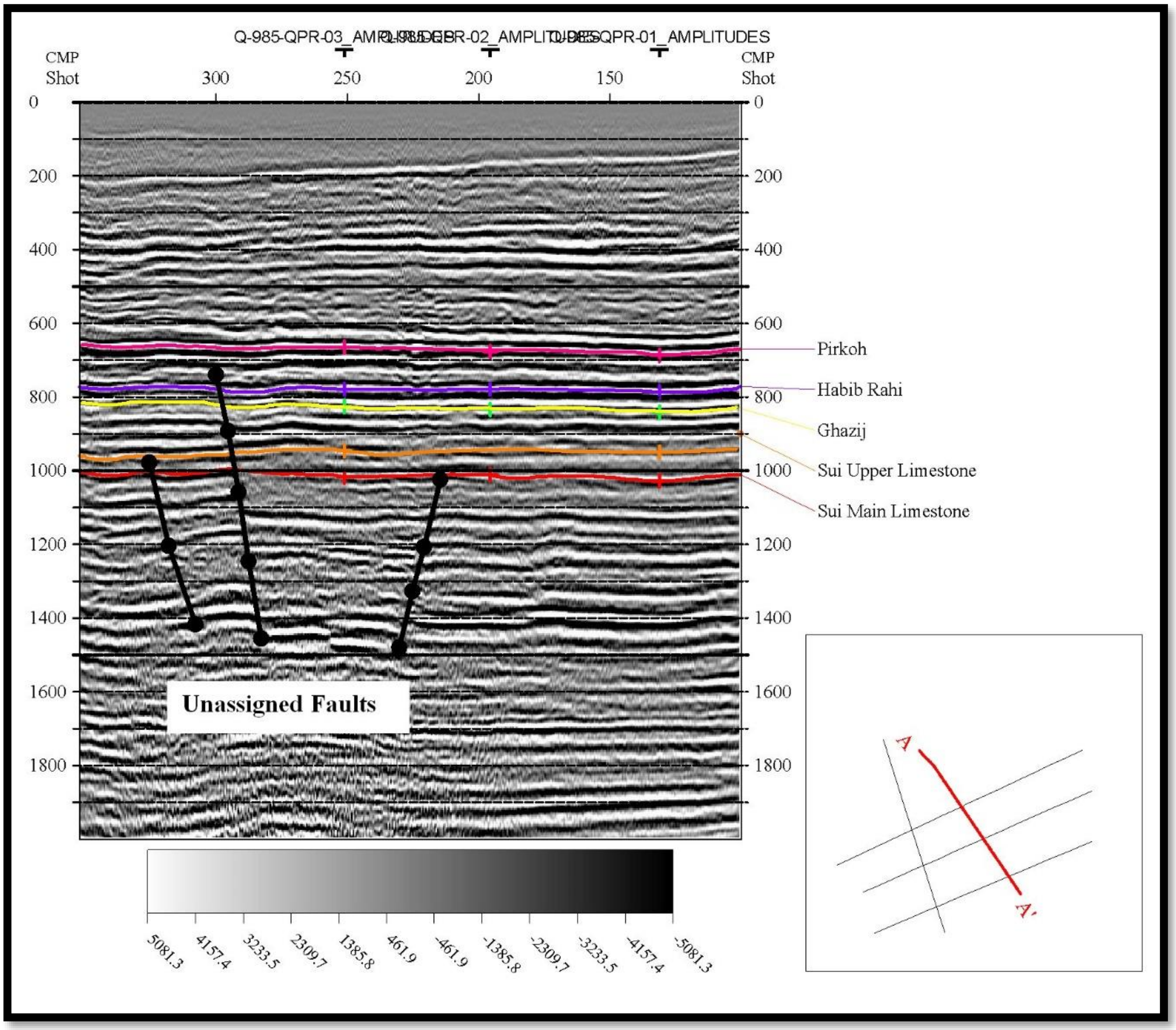

Figure 3.8: Interpreted Seismic Control Line (90-QPR-06)

The black lines which appear to be faults over here are basically projections of the faults marked on the dip lines.

3.3.8 Time Picking

Upon identifying the horizons and faults, the next step in seismic interpretation for the Qadirpur-03 area involves time picking across reflectors. This process is conducted using four dip lines and two strike lines. Time picking is achieved by tracking the time at the second shot point of each reflector, focusing specifically on the Habib Rahi Formation and the Ghazij Formation. Due to significant vertical displacements caused by faults, these reflectors exhibit discontinuity and an erratic trend on the dip lines.

3.4 Two-Way Time Travel (TWT) Contour Maps

Contour maps are instrumental in representing physical quantities in two dimensions, constructed from contour lines that connect points of equal elevation. In seismic studies, time contour maps display seismic lines with identical time values, illustrating the two-way travel time (TWT) of seismic waves. These waves travel from a source to a receiver, reflecting off subsurface layers due to acoustic impedance contrasts.

For each formation, including the Habib Rahi and Ghazij formations, a temporal contour map is created using travel time data and X and Y coordinates. TWT refers to the time duration for seismic waves to penetrate the subsurface, reflect off a boundary, and return. The contour maps of these formations, as presented below, provide insights into the subsurface structures at various locations. TWT contour maps specifically for the Habib Rahi Formation and Ghazij Formation are crucial for understanding the geological features and potential hydrocarbon reservoirs in the area.

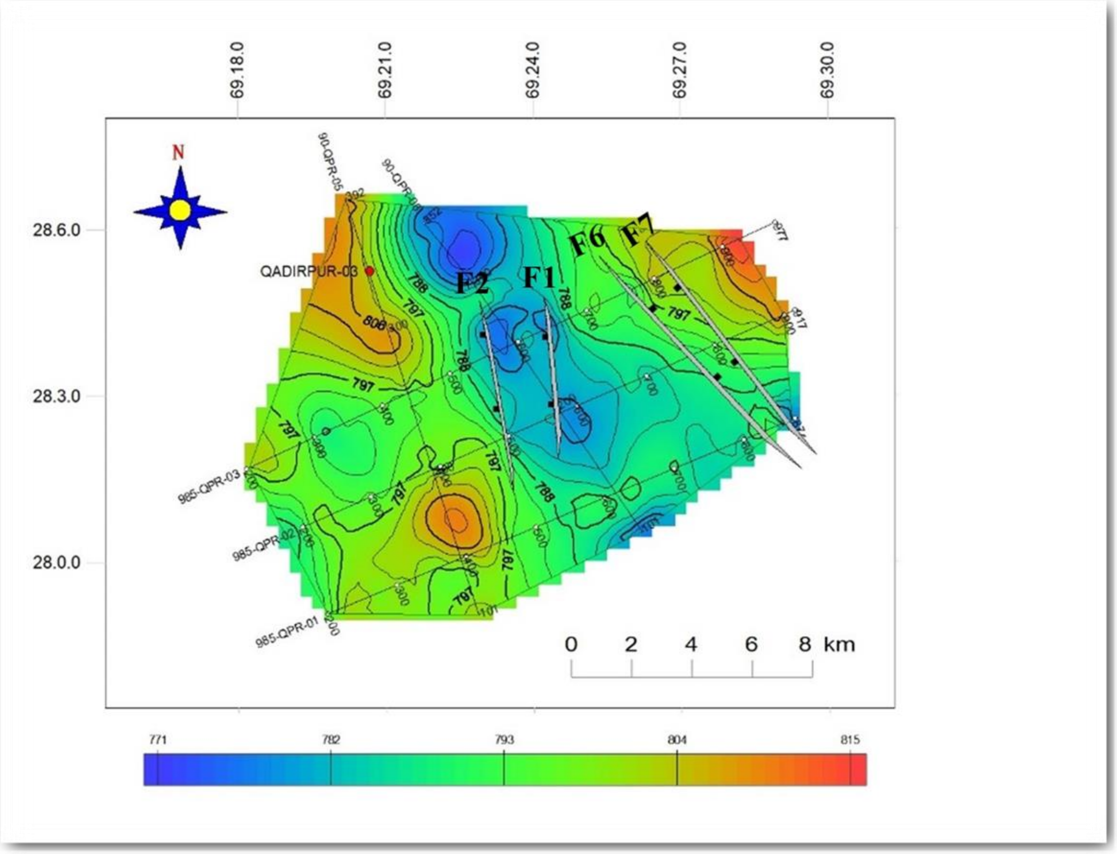

Figure 3.9: Habib Rahi Time Contour Map with Fault Dipping

It is prepared by making grid boundaries. Time surface generated using seismic control lines and then contour generated on it. This figure represents the time contour of Habib Rahi Formation. There is a color variation in this figure which tells about shallower and deeper parts. The blue color represents shallow area and Red represents deeper as mentioned in the scale below. There are also 4 faults marked on the figure that are F1, F2, F3 & F4. The central part of the figure is the shallowest part and East and West parts are deeper parts. Blue color highlighting the center portion of the figure is mainly the prospect location for closure. The faults F1, F3 & F4 are dipping in the South-West direction whereas fault F2 is dipping in the North-East direction.

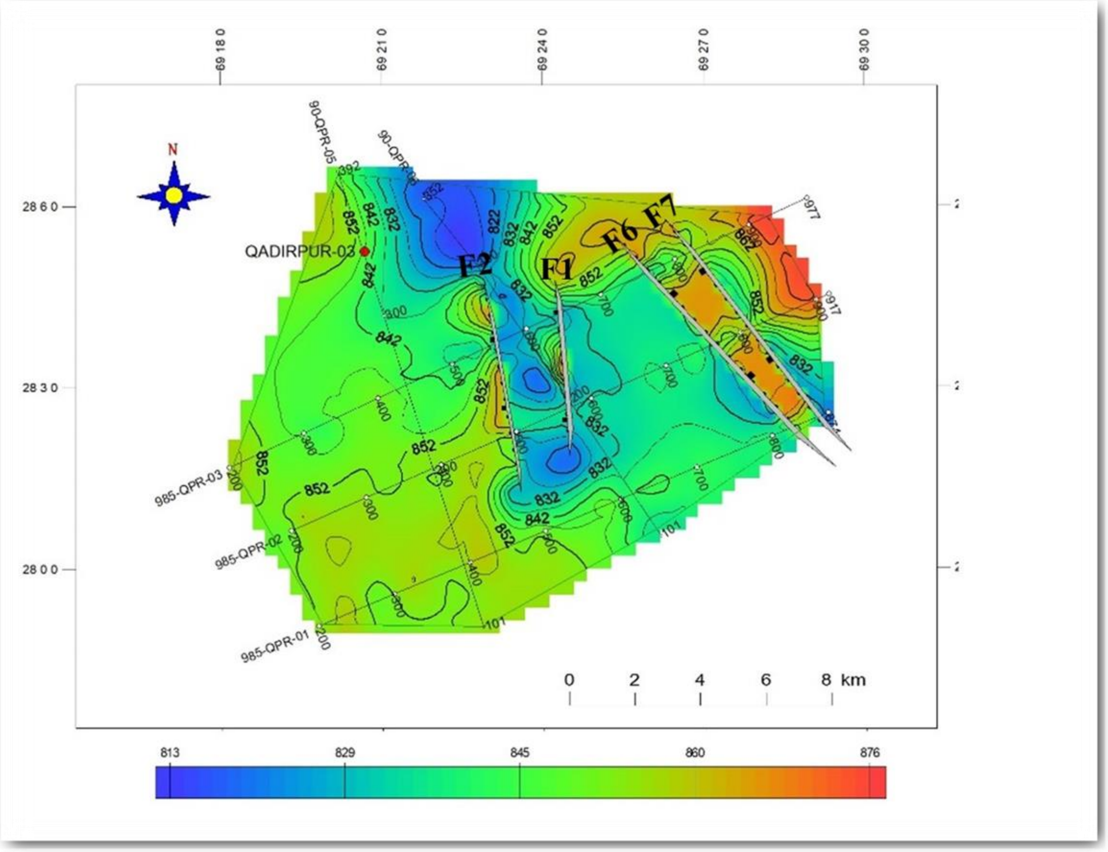

Figure 3.10: Ghazij Time Contour Map with Fault Dipping

It is prepared by making grid boundaries. Time surface generated using seismic control lines and then contour generated on it. This figure represents the time contour of Ghazij Formation. There is a color variation in this figure which tells about shallower and deeper parts. The blue color represents shallow area and Red represents deeper as mentioned in the scale below. There are also 4 faults marked on the figure that are F1, F2, F3 & F4. The central part of the figure is the shallowest part and East and West parts are deeper parts. Blue color highlighting the center portion of the figure is mainly the prospect location for closure. The faults F1, F3 & F4 are dipping in the South-West direction whereas the fault F2 is dipping in the North-East direction.

3.5 Depth Contour Mapping

In the process of depth analysis for the Qadirpur-03 well, velocities for specific formations, namely the Habib Rahi Formation and Ghazij Formation, are calculated. This velocity estimation for each reflector is derived from observing velocity windows at the top of seismic sections of the control line. Subsequently, depth is calculated using the identified time horizon and the velocity of each horizon, applying a specific formula. The results of this analysis are then represented through depth contour maps.

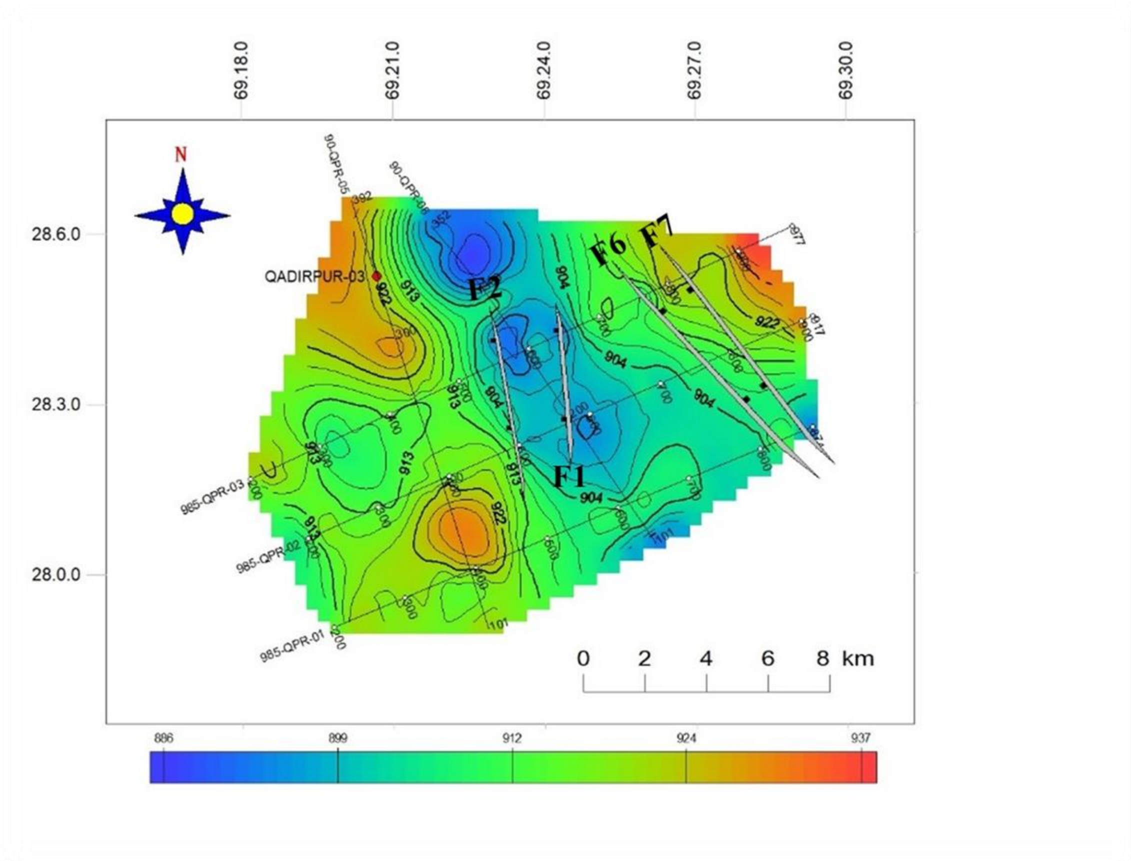

Figure 3.11: Habib Rahi Depth Contour with Fault Dipping

It is prepared by making grid boundaries. Depth surface generated using seismic control lines and then contour generated on it. This figure represents the depth contour of Habib Rahi Formation. There is a color variation in this figure which tells about shallower and deeper parts. The blue color represents shallow area and Red represents deeper as mentioned in the scale below. There are also 4 faults marked on the figure that are F1, F2, F3 & F4. The central part of the figure is the shallowest part and East and West parts are deeper parts. Blue color highlighting the center portion of the figure is mainly the prospect location for closure. The faults F1, F3 & F4 are dipping in the South-West direction whereas fault F2 is dipping in the North-East direction.

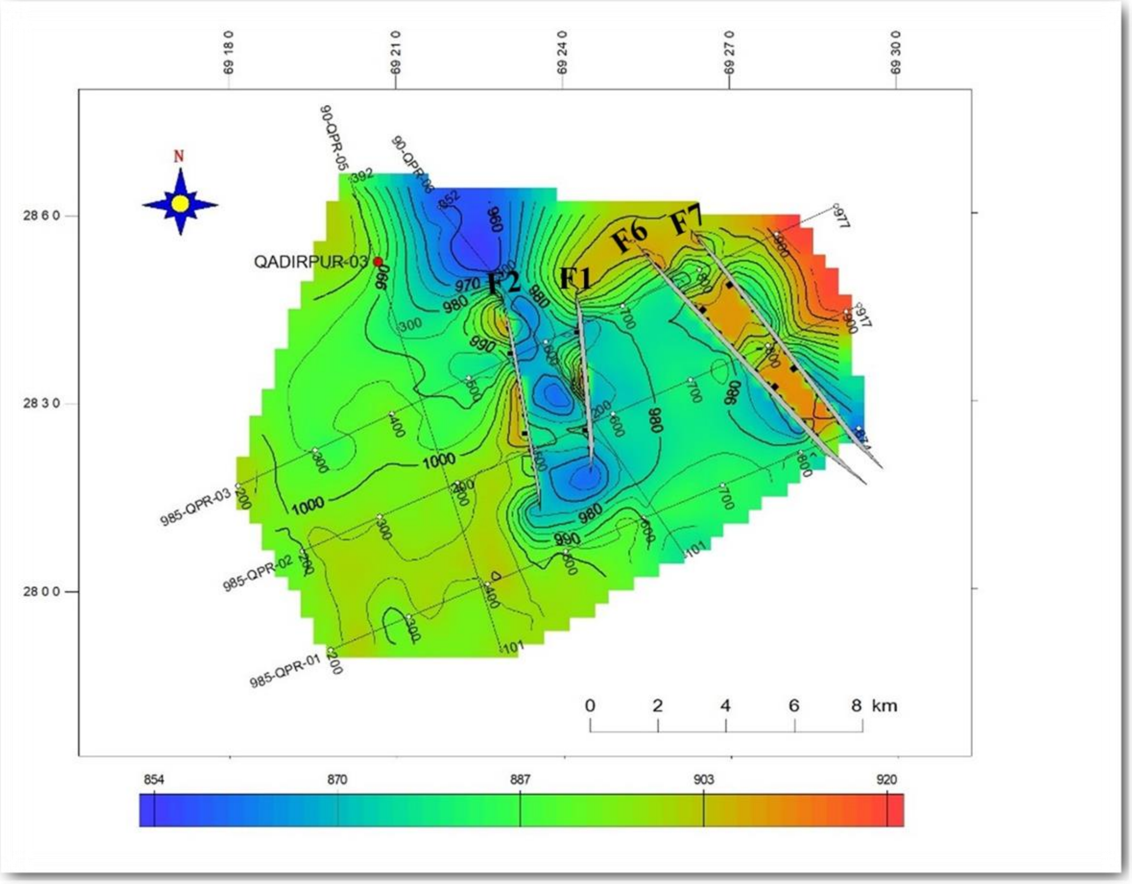

Figure 3.12: Ghazij Depth Contour Map with Fault Dipping

It is prepared by making grid boundaries. Depth surface generated using seismic control lines and then contour generated on it. This figure represents the depth contour of Ghazij Formation. There is a color variation in this figure which tells about shallower and deeper parts. The blue color represents shallow area and Red represents deeper as mentioned in the scale below. There are also 4 faults marked on the figure that are F1, F2, F3 & F4. The central part of the figure is the shallowest part and East and West parts are deeper parts. Blue color highlighting the center portion of the figure is mainly the prospect location for closure. The faults F1, F3 & F4 are dipping in the South-West direction whereas the fault F2 is dipping in the North-East direction.

CHAPTER 4

PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysical analysis is a key aspect of evaluating the subsurface geological formations at the Qadirpur-03 well in the Central Indus Basin. This analysis involves the study of the physical and chemical properties of rocks, including their mineral content and the distribution of fluids such as water, oil, and gas. (Pandey et al., 2019)

For the Qadirpur-03 well, petrophysical analysis is primarily conducted through the interpretation of well log data and the examination of core samples. This process helps in identifying formations that are potential carriers of hydrocarbons. Essential parameters such as porosity, which indicates the ability of the rock to hold hydrocarbons, are assessed. (Abd El Aziz & Gomaa, 2022)

The analysis includes the use of additional data sources like engineering, production, and mud logs when available. An initial focus of this study is the differentiation between formations bearing gas, water, and oil, alongside an estimation of their porosity and hydrocarbon saturation. Further, laboratory analyses are utilized to gauge the recoverability of hydrocarbons and to inform strategies for effective reservoir management, (Aigbogun & Utah, 2020) aimed at enhancing the extraction of oil and gas.

In essence, petrophysical analysis provides critical insights into the subsurface properties at the Qadirpur-03 well, guiding exploration and extraction processes in the Central Indus Basin.

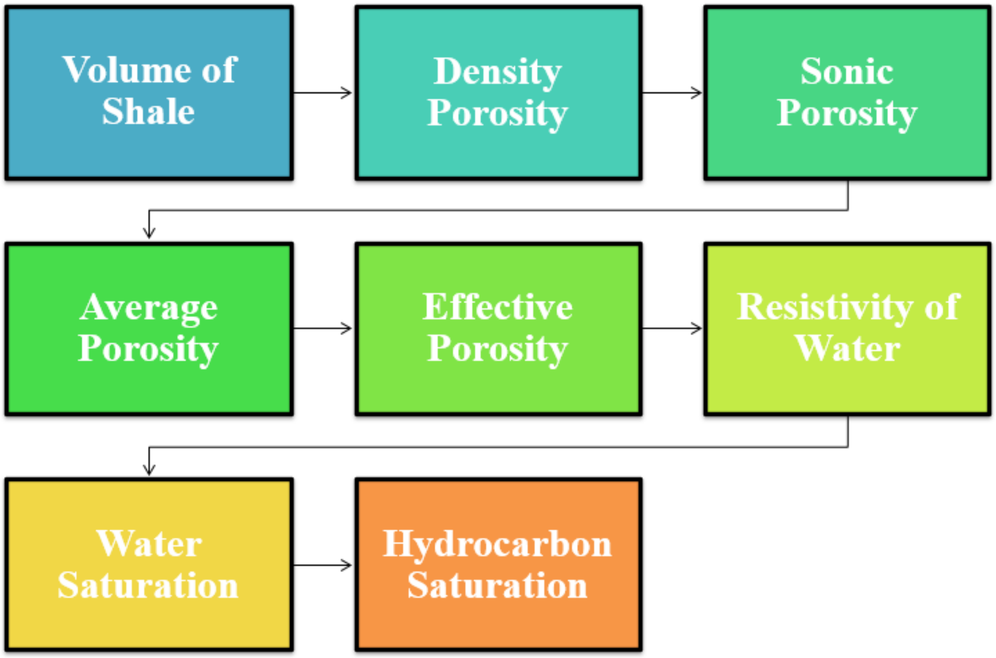

Figure 4.1 Petrophysical Analysis Workflow

4.2 Logging Objectives and Methodology

The primary goal of the petrophysical investigation for the Qadirpur-03 well in the Central Indus Basin is to conduct a thorough examination using basic Wireline Logging methods for hydrocarbon exploration. Well logs are instrumental in providing insights into lithology, presence of hydrocarbons, porosity, and other crucial rock properties. (Khan et al., 2016)

The main objectives of well logging in this context are:

(1) Reservoir Evaluation
(2) Unconventional Source Evaluation

4.3 Types of Logs Used

The Petrophysical Analysis was conducted using the logs obtained from the Qadirpur-03 Well as follows:

(1) Gamma Ray Log
(2) Density Log
(3) Neutron Log

(4) Resistivity Log (MSFL, LLS, LLD)

(5) Sonic Log

(6) Porosity Log (PHIN)

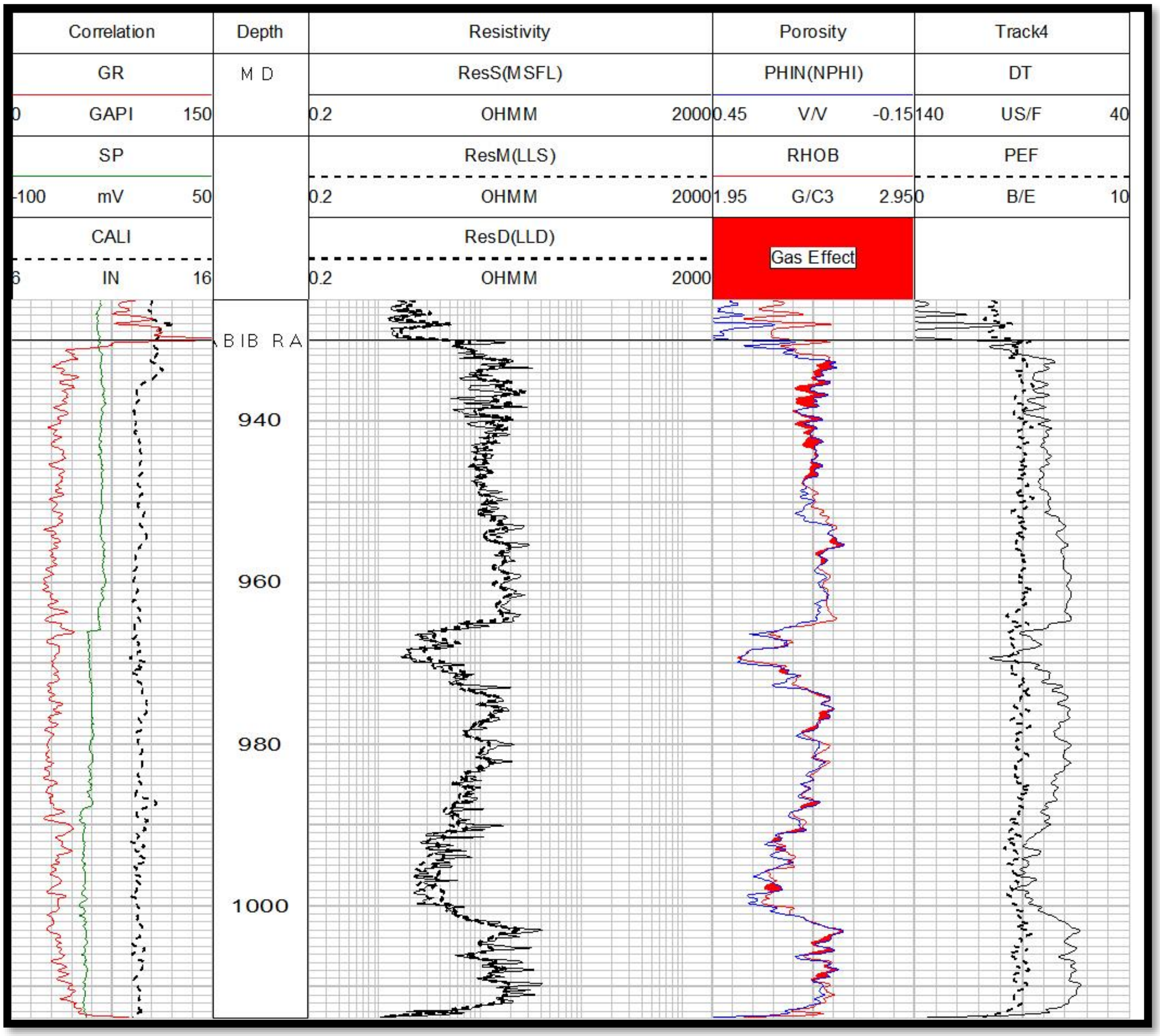

Figure 4.2: QADIRPUR-03-raw curves of GR, SP, CALI, MSFL, LLS, LLD, NPHI, RHOB, DT & PEF

4.4 Reservoir Evaluation

This includes identifying different lithologies, estimating porosity, and determining fluid saturation. Specific objectives are:

- Accurate depth determination of specific lithologies, alongside knowledge about their thickness and interval velocity.

- Analysis of cuttings brought up with mud filtrate during well logging, providing information on the material, fossils, and depositional environment.
- Mapping reservoir quality through the identification of rock types, fractures, and geological environments.
- Determining reservoir pressure, reservoir fluid contact locations, and estimating recoverable hydrocarbons in place.
- Assessment of porosity and pore size distribution.

COMPUTED PARAMETERS

4.4.1 Calculation of Volume of Shale (V_{SH})

Gamma ray logs are utilized to estimate the volume of shale (V_{SH}) in a formation. Shale rocks, due to their high organic content, exhibit greater radioactivity compared to cleaner rocks like sand or carbonates. The volume of shale is calculated as a fraction or percentage and is crucial for assessing the hydrocarbon potential of a zone. The formula for calculating V_{SH} using gamma ray logs is:

$$V_{SH} = (GR_{log} - GR_{min}) / (GR_{max} - GR_{min})$$

Where:

- GR_{log} is the gamma ray log value at a specific depth.
- GR_{min} and GR_{max} are the minimum and maximum values of the gamma ray log curve, respectively.

4.4.2 Density Porosity (PHID)

Density porosity is derived from density log readings and is a critical measure of a rock's porosity. It is calculated using the formula:

$$\varphi_d = (\rho m - \rho log) / (\rho m - \rho f)$$

Where:

- ρf is the fluid density.
- ρm is the matrix density.
- ρlog is the log density.
- φd is the density porosity.

4.4.3 Neutron Porosity

Neutron porosity is directly measured using neutron logs and is a key indicator of a formation's porosity. It is particularly useful for identifying the presence of fluids within the rock matrix.

4.4.4 Average Porosity (PHIA)

The average porosity is given by:

$$PHIA = \left(\frac{PHID + PHIN}{2}\right)$$

Where:

PHID and RHIN are density porosity and neutron porosity, respectively.

4.4.5 Effective Porosity (PHIA)

Effective porosity (ϕ_e) is computed as the product of average porosity (ϕ_A) and the volume of sand, derived from the volume of shale. It can be expressed as:

$$\text{Effective Porosity} = \phi_A \times V_{sand}$$

This measure is generally lower than the average porosity and is critical for evaluating the reservoir's storage capacity.

4.4.6 Resistivity Of Water by PICKETT Plot Method

The Pickett plot is a graphical method used to correlate water saturations across various wells in a reservoir. It visually represents the Archie equation, allowing for the estimation of water saturation ranges. The process involves plotting porosity and true resistivity (R_t) data, followed by the resistivity of water on the Rt scale. From this analysis, the resistivity of water is determined, aiding in the interpretation of water saturations within the reservoir.

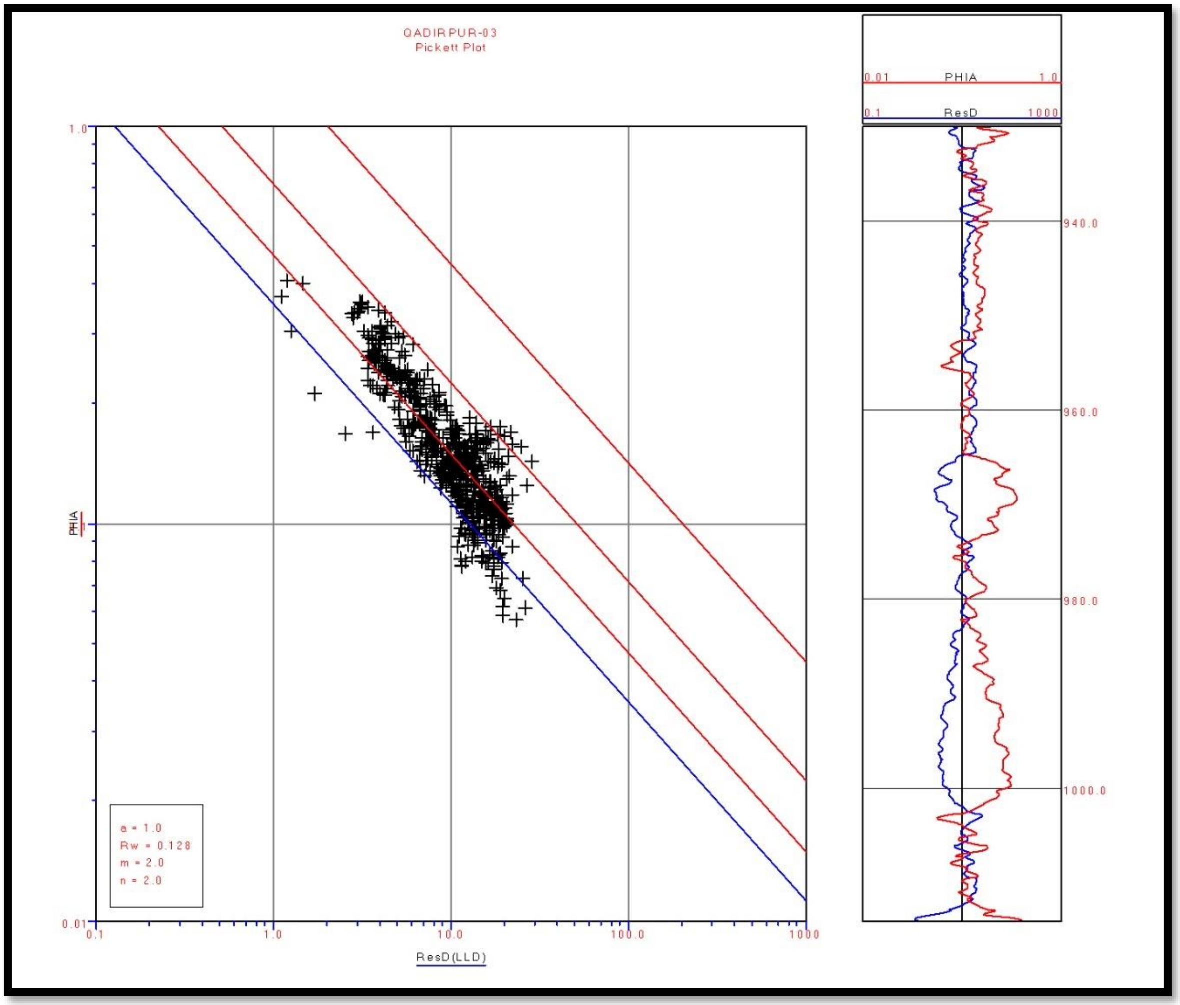

Figure 4.3: Pickett Plot of Habib Rahi (Reservoir)

4.4.7 Water Saturation (S_W):

The Indonesian Equation is the method which I used for calculating water saturation, especially in shaly formations. It is formulated as:

$$S_{WI} = \frac{\sqrt{\frac{1}{R_t}}}{\left(\frac{{V_{sh}}^{(1-0.5*V_{sh})}}{\sqrt{R_{sh}}}\right) + \sqrt{\frac{{\varphi_E}^{m}}{a*R_w}}}$$

This equation accounts for the effect of shale (represented by V_{sh} and R_{sh}) on water saturation readings.

Both Archie's Equation and the Indonesian Equation are essential for interpreting well log data and assessing the hydrocarbon potential of a reservoir.

4.4.8 Hydrocarbon Saturation (S_w):

Understanding hydrocarbon saturation in a reservoir is essential and it starts with determining the water saturation. There's an inverse relationship between water saturation and hydrocarbon saturation in a reservoir. In essence, zones with higher water saturation typically exhibit lower hydrocarbon saturation.

The calculation of hydrocarbon saturation can be approached by understanding this inverse relationship. The formula for hydrocarbon saturation (S_h) is based on the water saturation (Sw) of the uninvaded zone and is expressed as:

$$\text{Hydrocarbon Saturation} = (1\text{-}Sw)$$

Where:

- S_h is the saturation of hydrocarbons.
- S_w is the saturation of water in the uninvaded zone.

This relationship implies that as the water saturation decreases, the hydrocarbon saturation increases, indicating a more promising zone for hydrocarbon extraction.

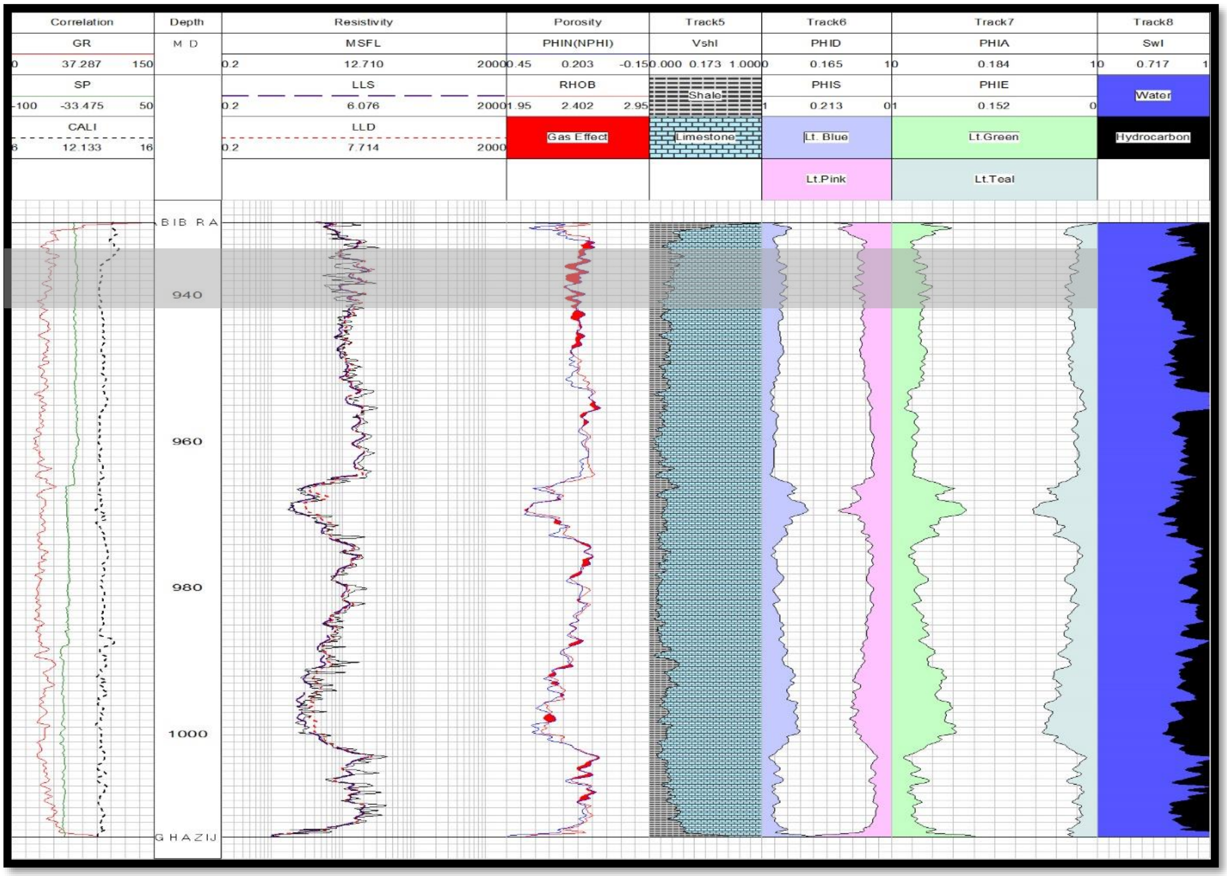

Figure 4.4: Qadirpur-03 Well Reservoir showing hydrocarbon and water intervals.

Reservoir Zone (935.25m-944.38m depth) is present where gas effect is shown by using the Resistivity logs. The lowest record volume of shale is 0.104 at the depth of 943m.Volume of shale must be determined to calculate porosities as shale destroys porosity. The figures clearly represent curves of porosities and also show saturation of water and saturation of hydrocarbons at this zone. The Zone values and parameters have been shown in the Table below and the zone can be also seen on the Qadirpur-03 well Reservoir Curves Figure added.

Table 4.1: Reservoir Interval Zone and Parameters

Depth	V_{sh}	PHIA	PHIE	S_w	S_h
935.25	0.161	0.106	0.089	0.693	0.307
936	0.239	0.174	0.133	0.507	0.493
937	0.209	0.135	0.107	0.656	0.344
938	0.185	0.159	0.129	0.479	0.521

939	0.225	0.191	0.148	0.626	0.374
940	0.172	0.143	0.119	0.605	0.395
941	0.108	0.139	0.124	0.594	0.406
942	0.183	0.147	0.12	0.651	0.349
943	0.104	0.153	0.137	0.677	0.323
944.38	0.191	0.132	0.107	0.783	0.217
Average	0.17770	0.1479	0.1213	0.6271	0.3729
Average in %age	**17.77**	**14.79**	**12.13**	**62.71**	**37.29**

4.5 Unconventional Source Evaluation

This involves the identification of prospects and estimation of Total Organic Carbon (TOC):

- Evaluating the potential of unconventional sources through detailed petrophysical measurements.
- Correlating these measurements to the volume, fraction, and type of fluids found in the porosity present in the formation.
- Differentiating between the properties of the rock and the fluids within the pore spaces.
- Estimating water salinity, an important factor in unconventional resource evaluation.

QUANTITATIVE ANALYSIS METHODS USED

Geophysical logging methods allow for the quantitative analysis of source rock. These methods include:

4.5.1 Visual Analysis from Logs

(1) Gamma Ray Log:

Gamma ray logs typically show higher values in source rocks. Spectral gamma ray logging provides information on uranium, potassium, and thorium. Uranium presence can indicate TOC, especially in rocks deposited under certain conditions like weathered granitic rocks or reducing environments.

(2) Resistivity Log:

This log varies depending on the maturity of organic matter. In immature source rocks, pores are water-filled, while in mature rocks, they contain both water and hydrocarbons. High resistivity indicates hydrocarbon presence.

(3) Density Log:

Useful for estimating organic content, as organic matter is less dense than the surrounding rock matrix. Density logs are less affected by borehole size variations but less effective in washout-prone shales.

(4) Sonic Log:

Organic content increases travel time, decreasing velocity in the source rock. Organic content also reduces density, affecting travel time.

4.5.2 Passey's "DlogR" Method

This method uses sonic, neutron, and density logs. Shales with lower resistivity are non-source, while potential source rocks show a crossover between sonic and resistivity curves. The "$D_{\log}R$" is calculated as follows:

$$\mathrm{DlogR} = \log\left(\frac{RESD}{\mathrm{RESDbase}}\right) + 0.02 \times (\mathrm{DTC} - \mathrm{DTCbase})$$

Where:

- RESD = Deep resistivity in any zone.
- RESDbase = Deep resistivity baseline in non-source rock.
- DTC = Compressional sonic log reading in any zone.
- DTCbase = Sonic baseline in non-source rock.
- DlogR = Passey's number from sonic.

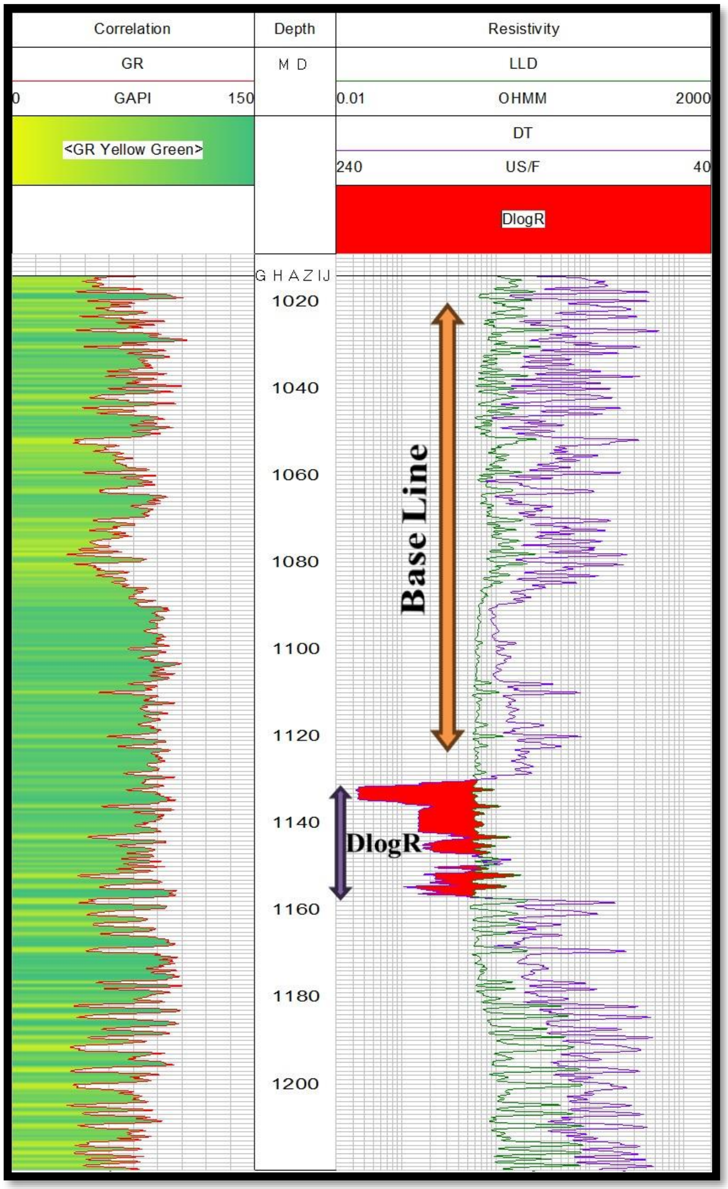

Figure 4.5: Qadirpur-03 DlogR showing baseline and DlogR Zone

These methods are critical in assessing the hydrocarbon potential of the source rock, including TOC and maturity levels.

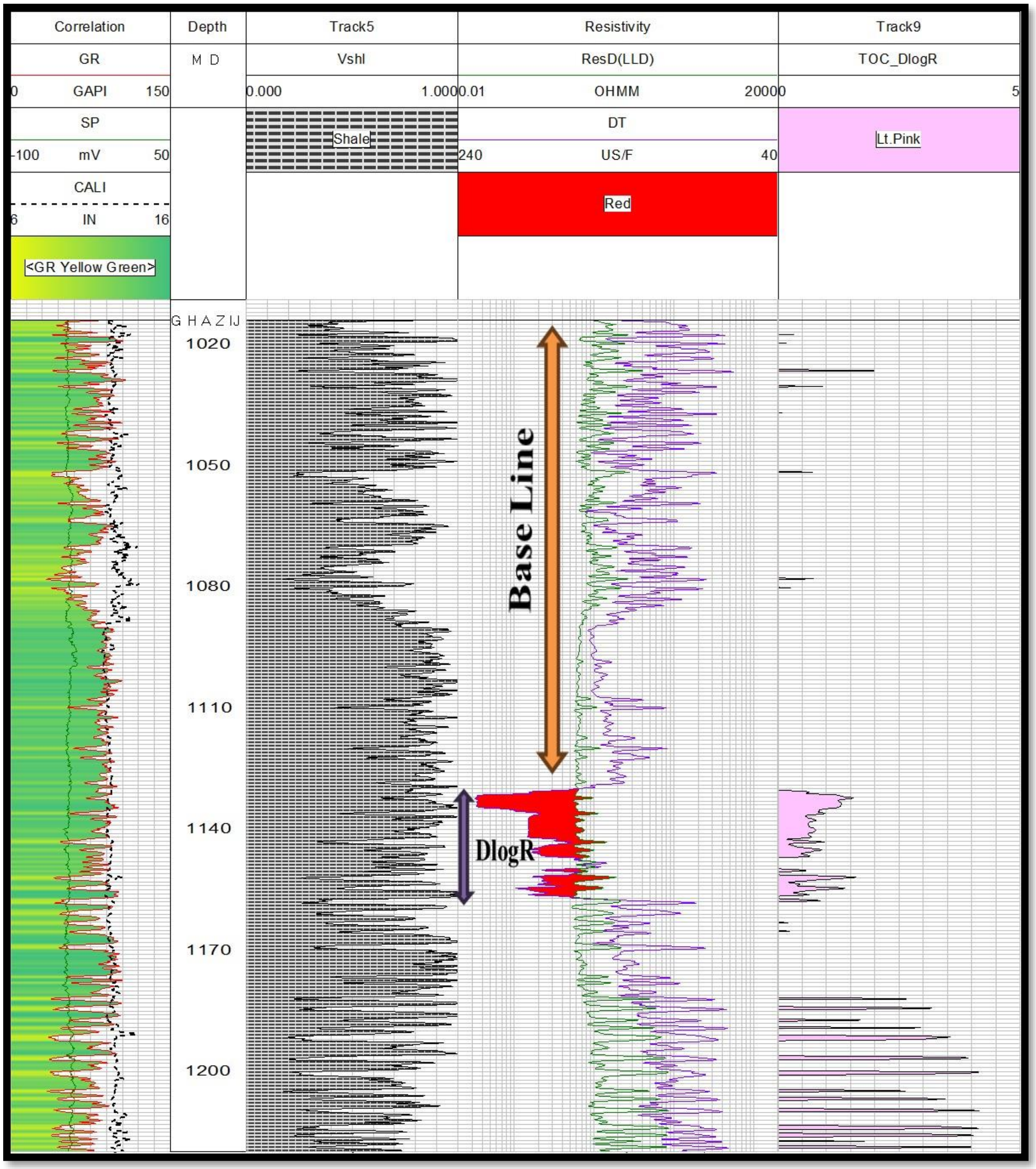

Figure 4.6: Qadirpur-03 TOC showing Baseline and Interval for Hydrocarbon

The figure above shows the zone where the TOC tells about assessing the potential of hydrocarbons present in the zone between Ghazij Formation and Sui Upper Limestone. The table below shows the parameters where it is maximum in the curve and where it is minimum, as it is making a zone of TOC which is from depth (1014m- 1220m depth) are in the Table.

Table 4.2 TOC Evaluation Parameters

TOC Zone Depth (Meters)	Maximum Value	Minimum Value	Average Value
[1130-1158]	1.6161	0.1	0.6173

CONCLUSION

(1) The subsurface structural interpretation of the study area reveals normal faults forming horst and graben structures.

(2) Reservoir potential of Eocene Habib Rahi Formation is evaluated using the conventional well log data. A potential zone of 11 m thickness is marked at the top of Habib Rahi Formation which showed 17% volume of shale, with 12% effective porosity and having 37% hydrocarbon saturation.

(3) Shales of the Ghazij Formation evaluated for its unconventional reservoir potential showed a 28 m source interval having average 0.6% TOC values with maximum value exceeding 1.6%.

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