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

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ABSTRACT

The research was carried out on Fort Abbas area which is in the Thar desert Punjab Pakistan. Fort Abbas area is in the Central Indus Basin which is a tectonically stable area. 2D seismic interpretation and petrophysical analysis was conducted to determine the subsurface geology of the area under study i.e Fort Abbas. These operations were done to identify the potential reserves of source and reservoir. The petrophysical analysis was specifically done on Bijnot-01 well to identify the potential reservoir and source in Fort Abbas. Four migrated seismic lines data were obtained which included one strike line (FABS-11) and three dip lines (FABS-13, FABS-41, FABS-43) trending Northeast and Southeast respectively. The Horst and Graben structures are observed because Fort Abbas area lies under tectonic regime. Petrophysical analysis of Bijnot -01 well was performed to determine the reservoir characteristics of Khewra sandstone and source characteristics of Mughal Kot. The properties computed through petrophysical analysis are volume of shale, Porosity and resistivity of water for reservoir evaluation. The three horizons marked for reservoir are Sui Main Limestone, Chiltan limestone, and Khewra Sandstone. The horizon marking is followed by fault marking and time to depth contour maps are also generated. The logs utilized for source rock evaluation are gamma ray, resistivity and density logs.

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CHAPTER 1
INTRODUCTION

Seismic interpretation is the process of extracting subsurface geologic data from seismic data. One of the characteristics of reflection seismic data is the continuity of reflections, which suggests geologic structure. Variations in reflections can be used to determine the stratigraphy, fluids, and reservoir fabric of a reservoir. A subset of the seismic wave is the seismic wavelet. Errors in data and noise of all kinds. Petrophysics analysis involves the examination of both the physical and chemical characteristics of rocks and the fluids that interact with them. Since a long time ago, geophysicists have attempted to explore hydrocarbons and developed numerous methods for doing so. Earth's interior is studied using geophysical techniques. These methods can detect variations in the earth's subsurface properties both horizontally and vertically when measurements are taken at or close to the surface. These variations have been investigated using logs like resistivity, acoustic, and gamma ray (Shami and Baig, 2002).

1.1 Location

Fort Abbas is in the Bahawalnagar District which is in the Thar Desert of Punjab. The area lies at 29°11′35″N to 32°N latitudes and 68°E to 72°51′13″E longitudes. The area under investigation is in the Tehsil Fort Abbas, District Bahawalnagar, Punjab Province. It is part of Pakistan's Central Indus Basin. OGDCL received a license to explore the Fort Abbas field in June 1992. Oil and Gas Development Company Limited (OGDCL) obtained and analyzed this 2-D seismic data. on the Fort Abbas field in 1994. On the Punjab platform, exploratory wells Fort-Abbas-01 and Bijnot-01 were drilled in 1994 and 1996, respectively, to discover the petroleum potential of Infra Cambrian reservoir rocks.

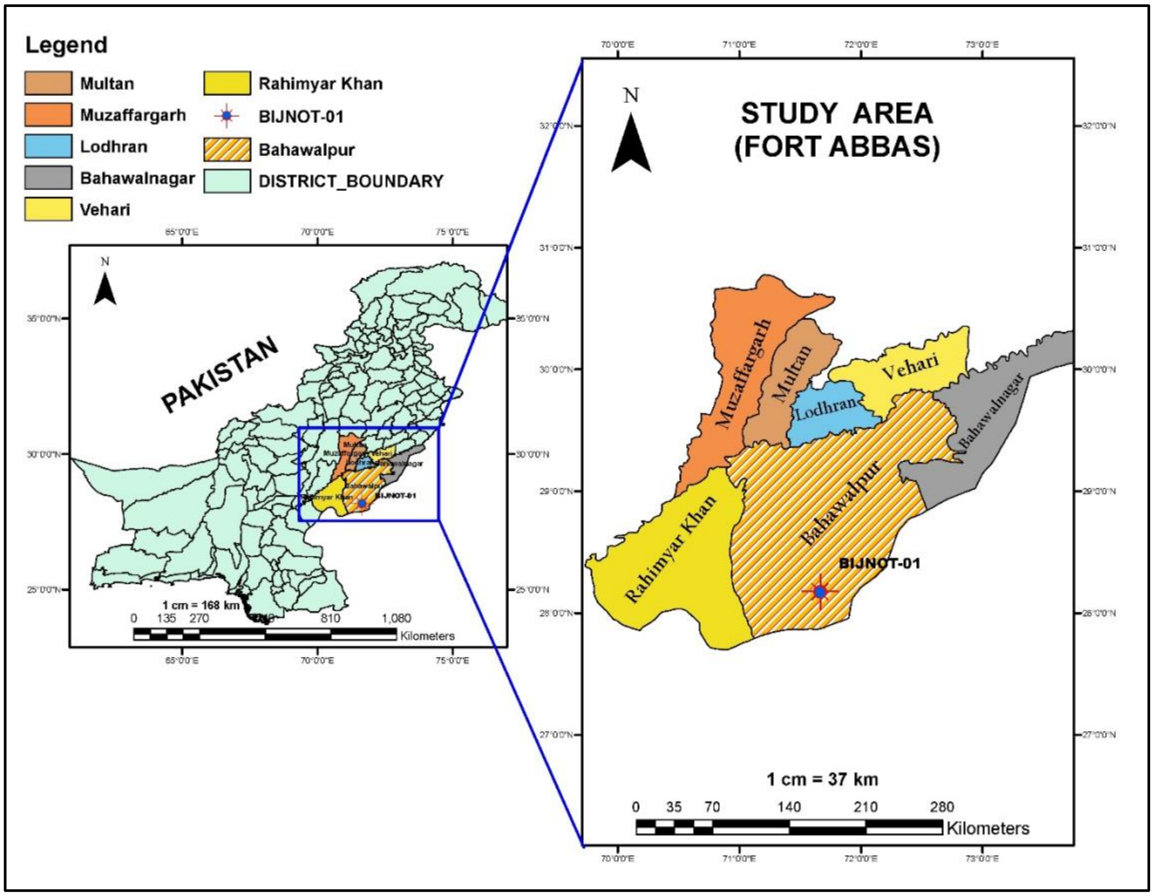

Figure 1.1. Location Map of Study Area (Created on ArcMap 10.7.1).

1.2 Study area

The Sargodha and Khairpur highs, respectively, serve as the boundaries between the Upper, Middle, and Lower Indus Basins (Qadri, 1995). The Middle Indus Basin in Pakistan has been divided into three main regions from east to west into Punjab Platform, Sulaiman Fold Belt and Sulaiman Fore-deep. Punjab Platform is situated between the Sukkur Rift Zone to the south, Precambrian Sargodha High to the north and the Bikaner Basin of India to the east. It slopes westward and marks the leading edge of the passive continental margin. Wells and outcrops along the northwest edge of the platform show moderate thicknesses of Paleozoic, Mesozoic and Cenozoic layers over the basement. This platform extends into India where it forms petroliferous basins. The Punjab Platform is a significant area within the Middle Indus Basin that is characterized by its geological features and petroleum potential. (Aadil et al., 2011). The Central Indus Basin's Fort Abbas concession is a portion of the Punjab platform with a gradual geological rise to the east.

The Fort Abbas region lies in the extensional regime where due to normal faulting, horst and graben structures form which serve as structural traps. However, hydrocarbons are usually found in horsts (Khan et al, 2019).

1.3 Research objectives

The research's main objectives are:

1. Structural interpretation of the study area to delineate the subsurface structure.
2. Reservoir Rock Evaluation of Khewra Sandstone to evaluate its reservoir potential.
3. Evaluation of the Source Rock potential of Mughal Kot Formation.

1.4 Software used

1. Gverse Geographix 2019
2. ArcMap 10.7.1

1.5 Methodology

1.5.1 For Reservoir rock

1. Calculation of volume of shale
2. Porosity Estimation
3. Fluid Saturation

1.5.2 For Source rock

1. Identification of prospect zone
2. TOC Estimation
3. Mineral Identification

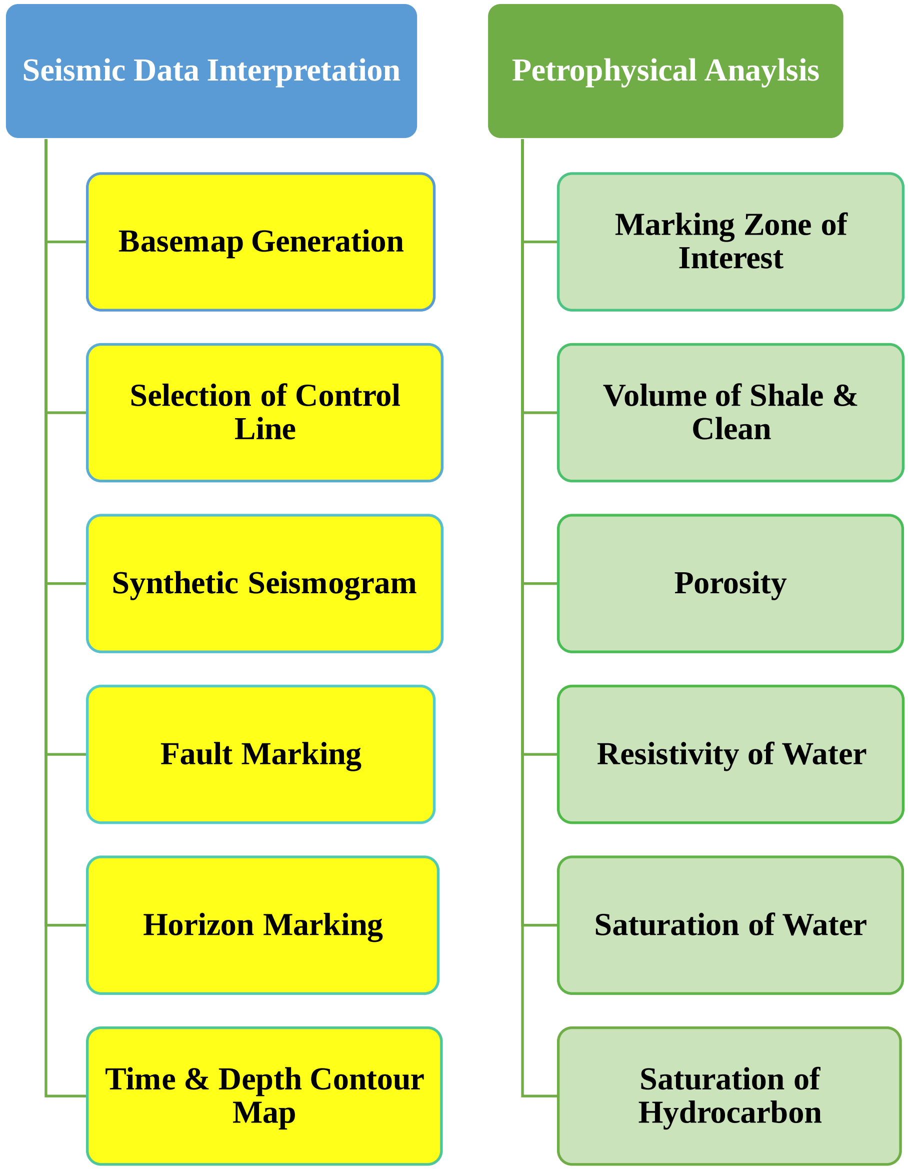

Figure 1.2. Workflow chart of petrophysical analysis and seismic data interpretation.

1.6 Data required

Data was acquired from Landmark Resources (LMKR) Pakistan, For the subsurface examination, the well log information was obtained along seismic lines. The exploration operation included seismic interpretation and petrophysical investigation. The data is given below:

1. Navigation File
2. Seismic Lines
3. Well data (Las & Well tops)

Table 1.1 Seismic lines and log data acquired.

Seismic			Well	
Line Name	**Line Type**	**Line Orientation**	**Well Name**	**Log Type**
931-FABS-11	Strike Line	SW-NE Tending	Bijnot-01	Gamma-ray Log
				Spontaneous Potential
				Caliper Log
931-FABS-13	Dip Line	NW-SE Trending		Density Log
				Neutron Log
944-FABS-41	Dip Line	NW-SE Trending		Sonic Log
				PEF
944-FABS-43	Dip Line	NW-SE Trending		Resistivity Log

CHAPTER 2
GENERAL GEOLOGY AND TECTONICS

A region's geology and tectonics play a fundamental and crucial role in its accurate translation and interpretation. It is important to note that formations with different lithologies can produce results for velocity that are not clear, whereas formations with similar lithologies can produce results for velocity that are different. Its borders are shared by the Eurasian, Indo-Pakistan, and Arabian plates. (Moghal et al., 2007).

2.1 Geology of Pakistan

Pakistan has a complex geological history which is related to the movements of the tectonic plates. In the eastern and southern regions such as Sindh and Punjab which belong to the Indian Plate, which formed part of Gondwana. Conversely, the western areas like Balochistan and the Frontier Provinces are positioned on the edge of the Iranian Plateau which is a segment of the Eurasian Plate. The formation of the mountainous regions in Pakistan is largely due to the uplifting phenomena caused by tectonic activity. For instance, the northern mountain ranges have been uplifted due to the Indian Plate's movement towards the Eurasian Plate. This tectonic activity has created several thrust zones, as well as normal faults in the various parts of the country along with the subductions and intrusions of basic material, believed to originate from the mantle.

The Nanga Parbat Massif which is located at the south of the Main Mantle Thrust Zone, claims the discovery of some of the oldest rocks which date back to 2.5–1.85 million years ago. These rocks have undergone significant metamorphism and show frequent occurrences of granitization. In regions like Azad Kashmir and Hazara, Proterozoic rocks linked to the Main Central Thrust have been identified. Towards the west of the Indus River there have been findings of granitic intrusions dated around 500 million years ago. The geological evolution in this area includes an initial orogenic event during the Early Proterozoic era followed by the intrusion of granite. The Himalayas have experienced one major orogenic event dating back to the Late Proterozoic–Early Cambrian period which is associated with the formation of magmatic rocks.

A significant orogeny which is like the Pan-African event that has occurred around 460 million years ago, resulting in the formation of granitic rocks and extensive metamorphism. Subsequently, three major mountain-building episodes took place during the Cretaceous and Tertiary periods, notably in the Himalayas and Karakoram regions. The third episode, during the Lower to Middle Miocene, was particularly intense. In the area south of the Karakoram, the Kohistan Island Arc Complex was formed. Additionally in the Peshawar region there was extensive alkaline igneous activity around 40 million years ago followed by the locating of several carbonatite intrusions 30 million years ago.

In the Main Mantle Thrust Zone there are records of post-Hercynian events. Subduction processes during the Late Cretaceous led to ophiolitic magmatism while sedimentary rocks were deposited over various periods. However, sedimentary processes vary across the different sedimentary basins in the country. Continuous sedimentation from the Precambrian to the Upper Paleozoic is not consistently observed in all basins. During the Mesozoic, sedimentary basins formed in the Sulaiman Range, the Kohat-Potwar Salt Range, and the West Pakistan Fold Belt, featuring mixtures of marine and terrestrial sedimentation, often interbedded with volcanic rocks. Tectonic movements caused over thrusting and nappe formation. In the Cenozoic, the closure of the Tethys Sea led to a variety of sedimentation processes, with the Indus Basin showing a shift from Paleogene marine sequences to terrestrial formations in the Neogene.

2.2 Central Indus Basin Subdivision

The Jacobabad and Mari Kandhkot highs, which are collectively referred to as the Sukkar Rift, divide the Middle and Lower Indus Basins. It is made up of duplex structures with big anticlines and domes. It includes sedimentary sequence from the Pre-Cambrian to the Recent. Nine gas fields make up this zone that is rich in natural gas. This region contains the primary gas fields of Mari, Kandhkot, Sui, Uch, Loti, Zin, Pir koh, and Jandran (Kamzi and Jan, 1997). From east to west Central Indus Basin has three subdivisions.

1. Punjab platform
2. Sulaiman depression
3. Sulaiman fold belt

2.2.1 Punjab Platform

According to (Raza et al.,2008) the Punjab platform is a monocline that dips westward and is covered in unconsolidated Quaternary deposits with a maximum thickness of about 500 meters. There are no surface outcrops in this mostly desert region (Kadri, 1995). The Central Indus Basin's basin structure is as follows: Sargodha High can be found in the north, Indian Shield can be found in the east, and West According to Kadri (1995), there is the Axial Belt and the Sukker Rift in the south. The Punjab Platform has non-tectonic origin structures because it was least affected during the Himalayan orogeny. There is no bed rock exposure on the Punjab platform. Alluvium (clay, silt, and sand) thick deposits cover most bed rocks. The basin's oldest rock is from the Triassic period. The Central Indus Basin is extremely stable because there are no active tectonic elements (Hasany et al., 2007).

2.2.2 Sulaiman Depression

During the post-Eocene time the Indian plate collides with the Eurasian plate, where the Sulaiman depression underwent significant tectonic activity which is leading to the formation of several geological structures. One such structure is the Zindapir folded zone which runs in a NS direction along the western flank of the depression. Another folded zone the Mari-Bugti formed on the southern edge of the depression. The movement of Eocene shale has resulted in the creation of buried anticlines that are visible on seismic data (Ali et al., 2021).

2.2.3 Sulaiman Foldbelt

Most folds are large. The Sulaiman foldbelt, which includes the Sulaiman Mountain range, emerges to the west from the Sulaiman depression. There are a lot of anticlinal structures in the foldbelt. The known potential reservoirs are exposed to the surface because most of them have been disturbed. The most important lithostratigraphic variations of Paleocene or Eocene age are revealed in the Sulaiman Foldbelt and Sulaiman Depression. The facies shifted from the north to the south and from the east to the west during these geologic periods. Plate collisions and other irregularities, which were the primary causes of the change in facies, resulted in the formation of many basins at the time (Martin Roddaz et al.,2011).

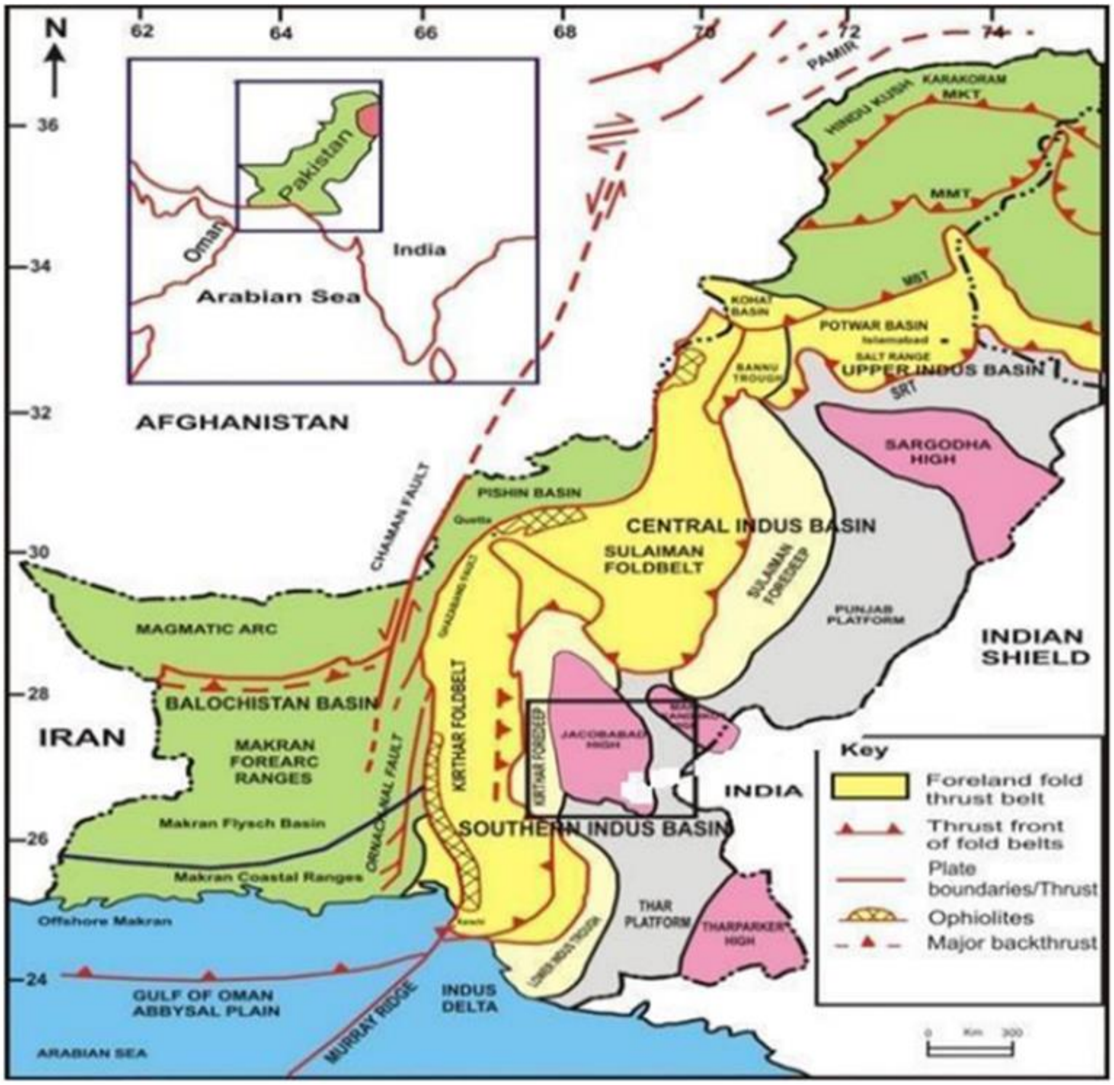

Figure 2.1 Regional geologic setting of Pakistan (Aziz and Khan,2003)

2.4 Structural Setting

The horst and graben structures, the former of great exploratory significance, characterize the generation of normal faults caused by the entire southern basin's extensional tectonics. In the eastern Lower Indus Basin, tilted fault blocks were formed by extensional tectonics in the Cretaceous (Kemal et al.,1991). The Lower Indus Basin exhibits a complex geological structure that is characterized by a back thrust running along the Kirthar Fold Belt. This thrust creates a frontal termination wall along the margin of the fold belt, extending through the Kirthar depression. This wall is not in alignment with the Kirthar depression sequence. Within the Kirthar and Karachi depressions there are various large anticlines and dome sands which contains small gas fields such as Sari, Hundi, Mazarani, and Kothar. In contrast, the eastern part of the basin features several faults and tilted blocks of Mesozoic rocks, forming structural traps that may contain small oil and gas fields. The northern side of the basin which is particularly the Sukkur Rift zone includes the Kandhkot and Mari gas fields and large anticlinal structures (Zaigham, 2000).

2.5 Generalized Stratigraphy of the Area

The primary focus of stratigraphy is the investigation of layering and rock layers (strata). stratification). There are two related subfields of stratigraphy: biostratigraphy as well as lithostratigraphy. The study area's generalized stratigraphy is discussed below:

2.5.1 Habib Rahi Formation

The Habib Rahi limestone served as the basis for the Stratigraphic Committee's formalization of the Habib Rahi formation. It is a hard, buff limestone with a grayish-brown weathering that can be described as white. It is predominantly argillaceous, has thin bedded fine grains, and occasionally grades into marl (Khitab et al., 2020).

2.5.2 Ghazij Sui Member

In the Lower Indus Basin and adjacent areas of the axial belt, the early Eocene episode's overall lithology consists of shale and marl. Kirthar formation is the component of the Ghazij Sui member. The Habib Rahi limestone, Sirki, Pir koh, and Drazinda components of the Kirthar formation can be separated in parts of the eastern Sulaiman province (Vredenburg,1908).

2.5.3 Ranikot Formation

Ranikot formation in the Laki range near Sindh was designated as the Ranikot fortress. In addition, the Ranikot group is acknowledged to be irritant. Khadro, Bara (lower Ranikot sandstone), and Lakhra (upper Ranikot limestone) are the three distinct formations that make up the Ranikot formation. In the lower part, limestone is surrounded by shale and brownish-yellow sandstone. The Lakhra formation also contains shale, and the lower Ranikot has diversified sandstone and shale in addition to gray to brown limestone.

2.5.4 Goru Formation

Williams was the one who introduced the term "Goru formation." Goru Formation is a geological formation in Pakistan that consists of interbedded sandstone, shale and siltstone1. It is divided into Upper, Middle and Lower Goru Formation. The Lower Goru Formation contains potential reservoirs (Kazmi and Jan 1997).

2.5.5 Mughal Kot Formation

Williams used the "Mughal Kot formation" as his method. According to Fatmi, the formation is lithological composed of calcareous shale and dark gray calcareous mudstone, interspersed with quartos sandstone and light gray argillaceous limestone (Khan, 2017).

2.5.6 Samana Suk Formation

It is revealed that a mountain peak in the Samana range gave rise to the name. It is made of sand, fine-grained limestone, clay, and limestone. The Chichali formation is at the top of the lower association, and the Shinawri is at the bottom. The precipitation environment is somewhat nautical (Davies, 1930).

2.5.7 Shinawari Formation

It can be found in the western part of the Samana range in Shinawri village. It has calcareous sandstone, non-calcareous shale, and sparse to well-stratified limestone nodular marl. The Samana Suk formation and the Datta formation are compatible with its lower association. Its precipitation environment is nautical (Fatmi and Cheema, 1972).

2.5.8 Datta Formation

It is situated in the Surghar range's Datta Nala. Shale, siltstone, and arenaceous make up the lithology. There is no strange, terrifying report in it; Nevertheless, there are some carbonaceous relics present. Its age is Early Jurassic, according to the law of superposition. Sandstone was the superior reservoir rock, while Datta shale served as the superior originator rock. Its precipitation environment is deltaic (Iqbal et al., 2015).

2.5.9 Warcha Formation

Sandstone with intermediate to coarse-grained zigzag stratification, conglomerate in some places, and shale interbeds make up its lithology. Along with quartzite, the unit's pebbles are primarily made of pink granite. It is Early Permian in age, according to the law of superposition. The Salt Range formation, the Khewra sandstone, and the Kussak formation, which is made up of sandstone and glauconitic shale, are all layered over each other (Ullah et al., 2005).

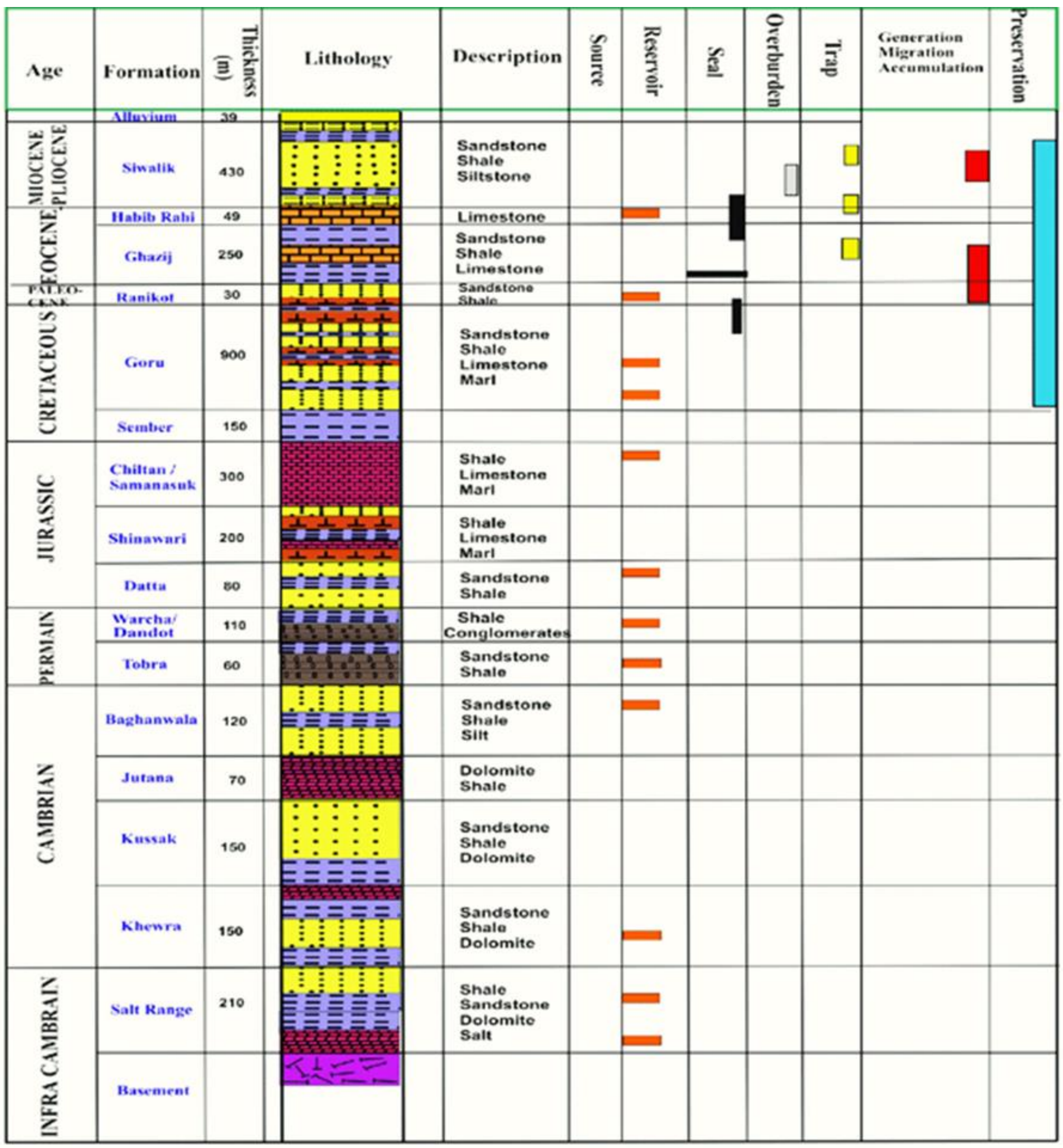

Figure 2.2 Stratigraphy of Central Indus Basin (Khalid et al; 2014)

Table 2.1. Borehole Stratigraphy of Bijnot-01 well.

FORMATION NAMES	AGES	FORMATION TOPS (M)	THICKNESS (M)	PETROLEUM PLAY
SIWALIK	RECENT	0	402	
SUI MAIN LIMESTONE	EOCENE	402	93	
RANIKOT	PALEOCENE	495	182	
MUGHAL KOT	CRETACEOUS	677	48	
PARH	CRETACEOUS	725	53	
LOWER GORU	CRETACEOUS	778	17	
UPPER GORU	CRETACEOUS	795	29	
CHILTAN	JURASSIC	824	26	
DATTA	JURASSIC	850	79	
WARCHA	PERMIAN	929	140	
TOBRA	PERMIAN	1069	57	
BAGHANWALA	CAMBRIAN	1126	138	
JUTANA	CAMBRIAN	1264	71	
KUSSAK	CAMBRIAN	1335	174	SEAL
KHEWRA SANDSTONE	CAMBRIAN	1509	103	RESERVOIR
SALT RANGE	PRE-CAMBRIAN	1612	243	SOURCE
BASEMENT		1855		

2.6 Hydrocarbon potential

Siberian and Omani platforms have yielded several oil and gas fields. This demonstrates that the sub-Cambrian platform's hydrocarbons should be investigated in greater depth. Near Pakistan, there were three wells without commercial success. Production from the Fort Abbas-1 well suggests a new game of exploration in Punjab Platform's explored areas. Since 1959, Punjab Platform's infra-cambrian work has not been sufficiently explored, but two wells have been drilled under Cambrian. However, during its entry into the basement, FortAbbas-1 successfully penetrated beneath the Cambrian with high levels of oil (Khalid et al., 2014).

2.7 Petroleum play

According to Kadri (1995), a play is defined as a cluster of prospects in a geological setting that share common characteristics in terms of their source, reservoir, and trap conditions. The existence of these play elements within a basin is fundamental to the accumulation of hydrocarbons.

2.7.1 Source rock

Source rocks are those organic-rich sedimentary rocks that have the potential to generate hydrocarbons when subjected to appropriate geological conditions such as burial depth, temperature, and time. These rocks typically contain a sufficient amount of organic matter which when heated and subjected to pressure over geological time scales can transform into hydrocarbons like oil and gas. The organic matter in these rocks is often derived from the remains of marine or terrestrial plants and animals that were buried and preserved in sedimentary environments. (Magoon et al., 2003).

2.7.1.1 Maturation

Thermal maturation, also known as maturation, is a significant quality indicator of the reservoir's hydrocarbons. The Kohat-Potwar rocks have been found to have a thermal maturation range of Ro 0.3 to more than 1.6% (Jadoon et al., 1999).

2.7.1.2 Migration

Hydrocarbon migration and production began in the Late Cretaceous. The migration of Cambrian source rocks began in the Late Cretaceous, and from the Pliocene to the present, the migration of younger source rocks began (Jaswal et al.,1997).

2.7.2 Reservoir rock

A reservoir rock is a coarse-grained rock with good permeability and porosity that collects and keeps the hydrocarbons from moving further (secondary migration). Only 10% of the existing source rocks are igneous and metamorphic, while about 90% are sedimentary, Lower Goru, the Datta Formation, and Khewra Sandstone are reservoir rocks in the Fort Abbas region (Ishimwe, 2014).

2.7.3 Seal rock

A relatively impermeable rock, typically salt, shale, or anhydrite, that acts as a barrier or cap above and around the reservoir rock to prevent fluids from escaping the reservoir. A seal is an essential part of any petroleum system. A seal with the ability to hold fluids throughout geologic time has a permeability of 10^{-6} to 10^{-8} darcy. The Upper Goru Formation, which acts as a seal, has been discovered.

2.7.4 Trap

Hydrocarbon traps can be made by extensional tectonics, which in turn are made by normal faults. Pattern of onlap structure in the Jodhpur, Bilara, and Salt Range Formation geological formations.

CHAPTER 3
SEISMIC DATA INTERPRETATION

Seismic data interpretation is a technique through which we identify subsurface geology by use of seismic data. Discovering subsurface hydrocarbon accumulations is the goal of seismic interpretation. Interpretation is the process of converting seismic reflection signal into a structural image using removal of noise, corrections, migration, and time depth conversion. The identification of the reflectors and the calculation of their positions based on correlations with the well data and the geology of the survey area are necessary for seismic reflection interpretation (Dobrin and Savit, 1988).

3.1 Objectives

1. Seismic data interpretation to decipher the subsurface structural geometry of the area.
2. Delineating the subsurface target horizons for hydrocarbons accumulations.
3. Integration of seismic and well data to enhance the precision of the interpretation process.
4. Conversion of the interpreted time section into depth section to identify the depth of key horizons and to construct depth surface maps of the reservoir rocks.

3.2 Seismic data interpretation approaches

Following are the main approaches for interpreting seismic reflection data:

a) Stratigraphic Interpretation
b) Structural Interpretation

a) Stratigraphic interpretation

The primary goal of stratigraphic interpretation is to distinguish seismic sequences that depict distinct depositional units identified by seismic facies' characteristics. The interpreter's job is to look for traps marked by pinch outs and unconformities caused by variation in sediment deposition. The drainage pattern that marks these irregularities provides direct information about the depositional environment. Stratigraphical traps include lenses, reef, and unconformity (Sheriff, 1999).

b) Structural Interpretation

Structural seismic interpretation aims to generate subsurface structural maps by analyzing the observed three-dimensional arrival time configuration. The study of reflector geometry based on reflection times is known as this. Seismic data is subjected to structural analysis to discover any area's structural traps, which serve as ideal locations for the accumulation of hydrocarbons. The identification of potential hydrocarbon leads and the development of plays in structural interpretation heavily rely on understanding faults, folds, and fractures (Chopra et al, 2007).

3.3 Methodology

The adopted methodology for the seismic data interpretation is show in figure 3.1.

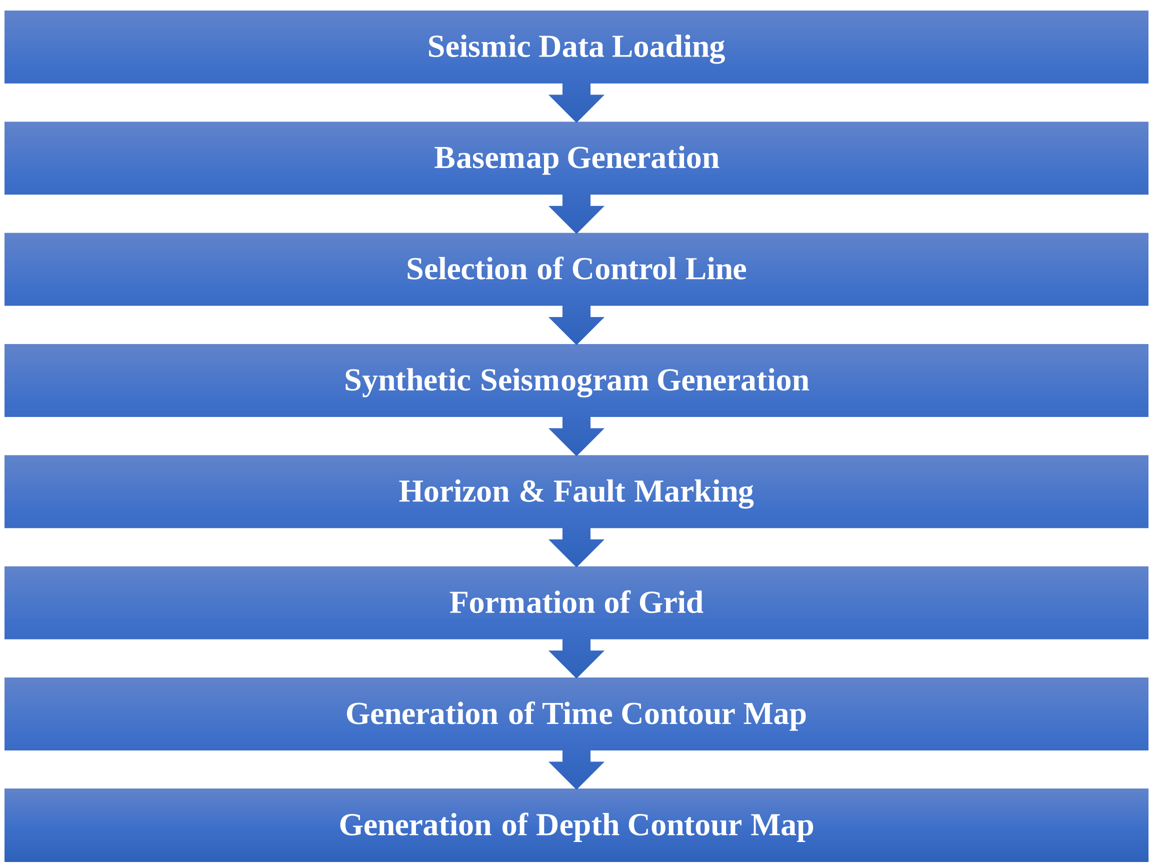

Figure 3.1 Methodology of seismic data interpretation.

3.4 Seismic Data Loading

Gverse Geographix 2019 software was used for seismic data interpretation in which seismic lines were loaded into the software with the help of navigation file and SEG-Y seismic data. Well, were loaded using their LAS files along with the well tops of the formations.

3.5 Basemap Generation

Well, seismic lines and seismic survey shot points with geographic coordinates longitude and latitude are shown on base map. The map has been constructed by utilizing navigation file provided by Director General Petroleum Concessions. Three dip lines (944-FABS-43, 944-FABS-41, 931-FABS-13) trending in Southeast-Northwest direction and one strike lines (931-FABS-11) trending in Northeast-Southwest Trending having a well on it named as Bijnot-01.

3.6 Selection of Control Line

The strike Line **931-FABS-11** is a control line where the Bijnot-01 well is present on shot point 1480. This control line is used to mark all the horizons on the other section. Horizons were marked and transferred to the other lines by using jump correlation technique. The strike line lies parallel to the faults. However, there were several prominent Normal faults in the dip lines.

3.7 Synthetic Seismogram Generation

Once the control-line is selected, the next step is to generate a Synthetic seismogram using well logs which are Sonic log and Density. After that the synthetic seismogram is adjusted and on the basis of it the reservoir formation is marked on the seismic time section.

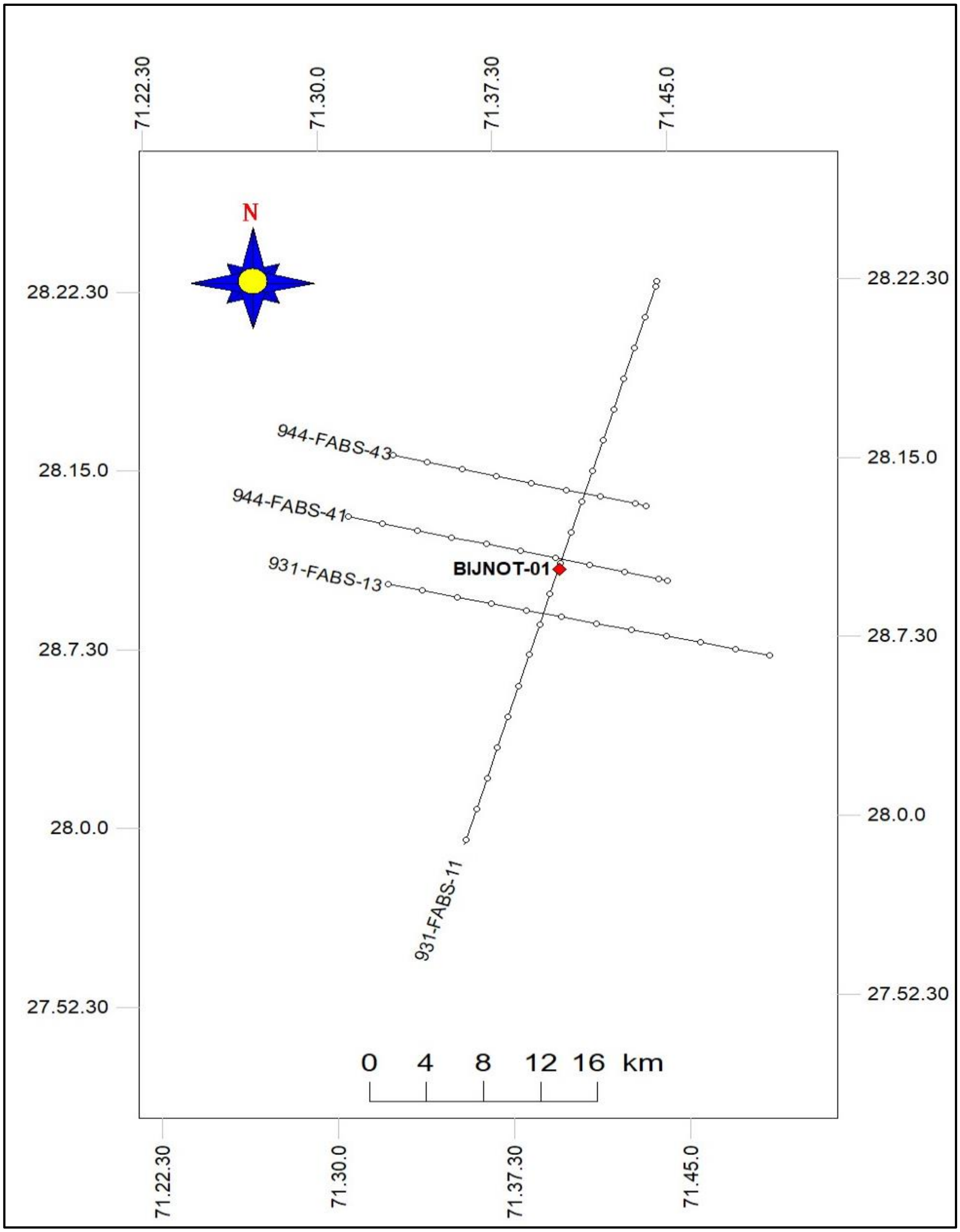

Figure 3.2 Base map showing fort abbas area seismic lines along with bijnot-01 well.

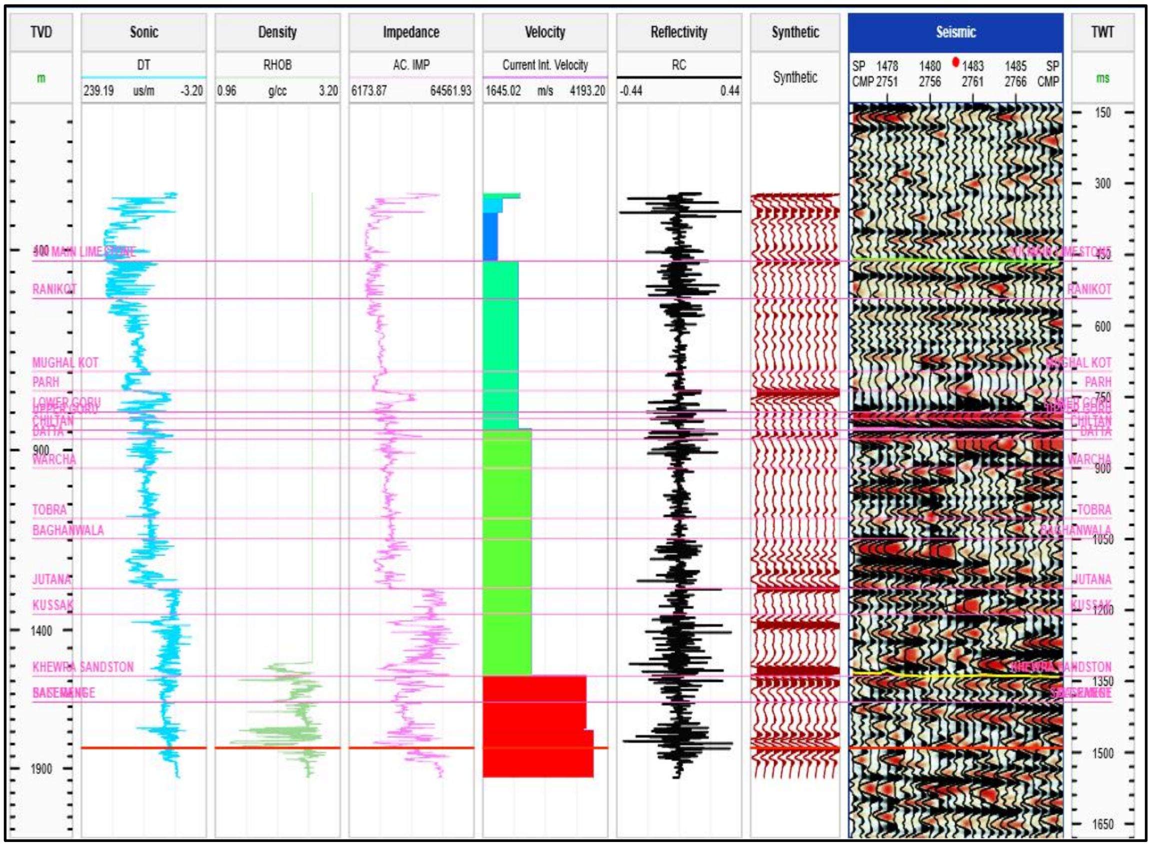

Figure 3.3 Synthetic seismogram generation using bijnot-01 well.

3.8 Horizon and Fault Marking

Once the Synthetic Seismogram is set the next step in seismic interpretation is the marking of the horizons, which determines which horizons must be interpreted and which formations serve as the area's reservoirs. The reservoir formations of the study area are Sui Main Limestone, Chiltan Limestone and Khewra Sandstone were chosen as the three horizons. These horizons are marked on the all the seismic lines (strike as well as dip lines). The control line is used for this process.

Once the horizons are marked on the seismic section, we identify and mark the fault based on a break in the reflector's continuity. Large vertical displacement faults are easy to spot, especially if reflections across their planes move quickly. The key problems are clearly obvious in the section record. Faults are essential in analysis of structures because they can provide a multitude of different entrapments for hydrocarbon buildup. The study area contains several normal faults which create horst and graben structure, these normal faults have been marked on all the seismic lines. This structure reflects the geological setting of the study area, which is characterized by extensional tectonic regime.

3.9 Interpretation of Seismic Lines

3.9.1 Interpreted 931-FABS-11

Seismic line 931-FABS-11 is a strike line having Northeast-Southwest direction which has a well on it, named Bijnot-01. This well is used to mark the horizon on this control line. The study area is in Extensional regime. This line contains several normal faults in which one fault is correlated with the other lines and the remaining two faults are not. These faults make a horst and graben structures. On this line three reservoir Formations have been marked by the help of synthetic seismogram which are Sui Main Limestone, Chiltan Limestone and Khewra Sandstone.

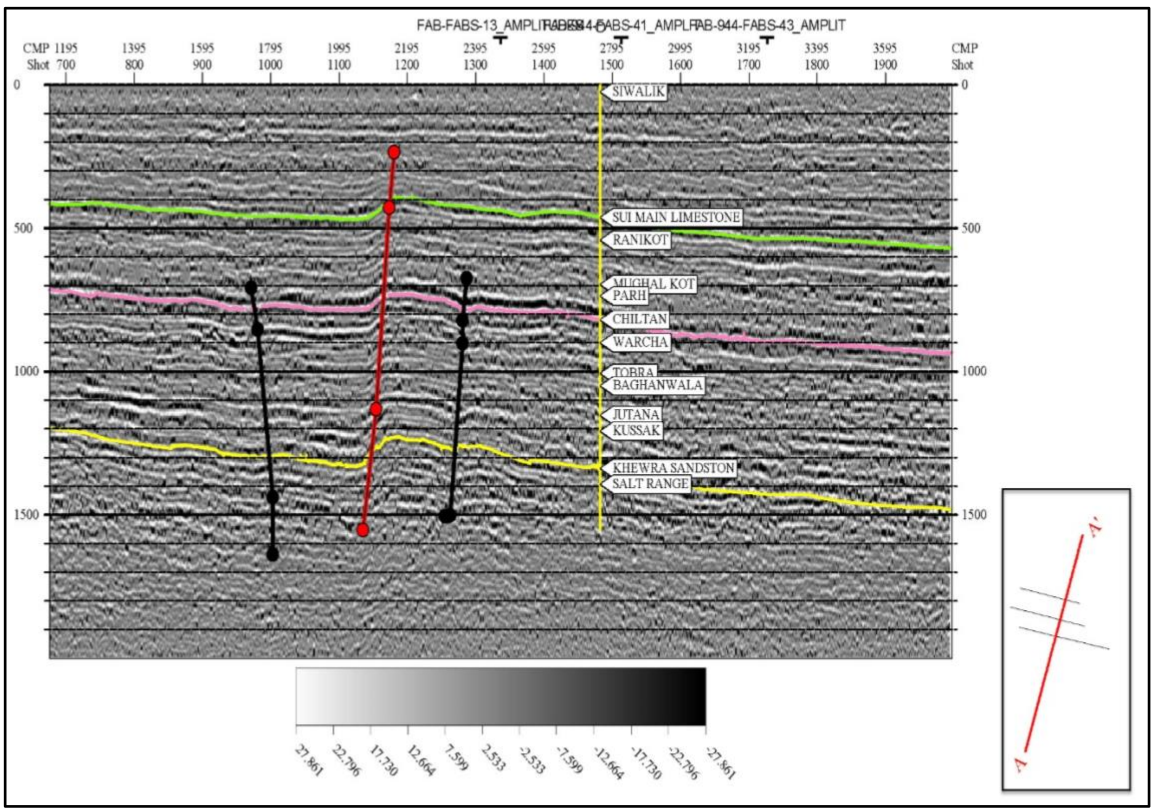

Figure 3.4 Marked horizons and faults on seismic line 931-FABS-11.

3.9.2 Interpreted 944-FABS-43

The first dip line is 944-FABS-43 having Southeast-Northwest direction which can be observed in the figure 3.5. This line also contains normal faults and is one of the reasons behind the creation of horst and Graben structures within the area. Several normal faults have been marked, in which all the three faults correlate on the other seismic lines. Same Reservoir Formation (Sui Main Limestone, Chiltan Limestone and Khewra Sandstone) that have been marked on 931-FABS-11 strike line has been marked on this dip line.

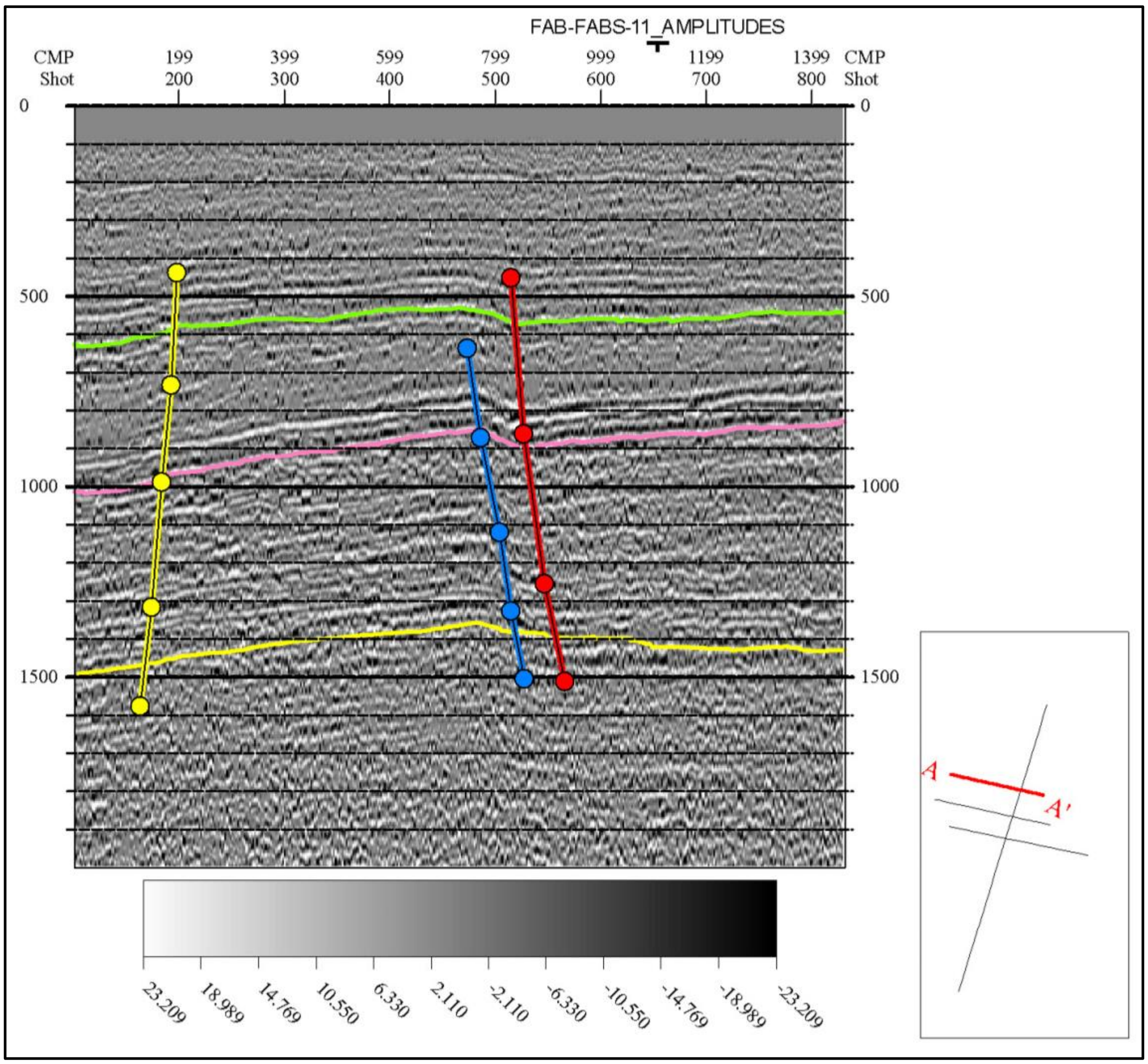

Figure 3.5 Marked horizons and faults on seismic line 944-FABS-43.

3.9.3 Interpreted 944-FABS-41

The second dip line is 944-FABS-41 having a Southeast-Northwest direction which can be observed in figure 3.6. This line also contains several normal faults that are also shown in the previous 944-FABS-43 dip line. Several normal faults have been marked in which all the three faults correlate on the other seismic lines and the remaining one is not. Same Reservoir Formation (Sui Main Limestone, Chiltan Limestone and Khewra Sandstone) that have been marked on 944-FABS-43 dip line has been marked on this dip line.

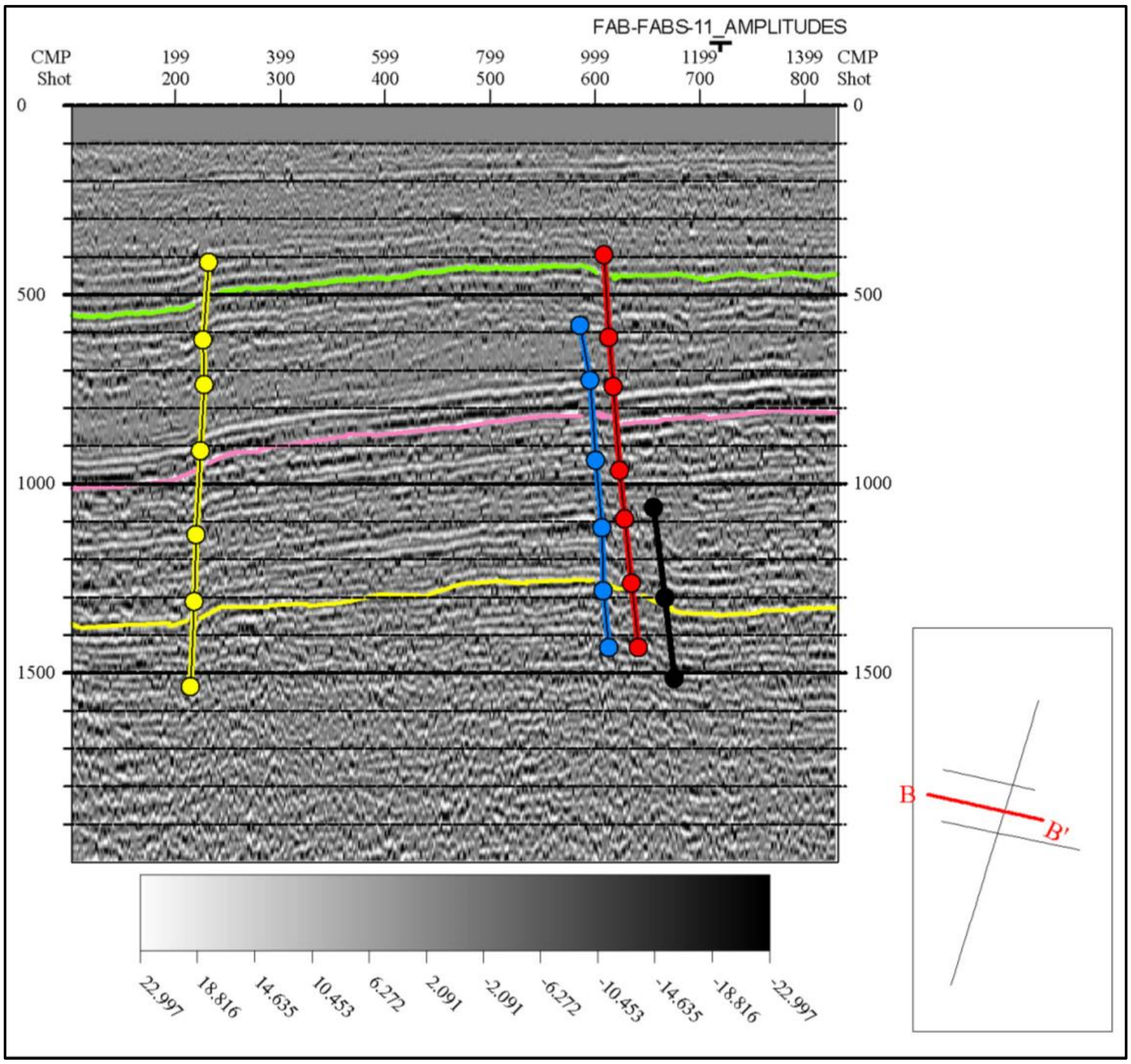

Figure 3.6 Marked horizons and faults on seismic line 944-FABS-41.

3.9.4 Interpreted 931-FABS-13

The third dip line is 931-FABS-13 having Southeast-Northwest direction which can be observed in figure 3.7. This line also contains several normal faults which make Horst and Graben structure, and they were repeatedly observed in all the dip lines. Several normal faults have been marked in which one fault correlates on the other seismic lines and the remaining four are not. Same Reservoir Formation (Sui Main Limestone, Chiltan Limestone and Khewra Sandstone) that have been marked on 944-FABS-43 dip line has been marked on this dip line.

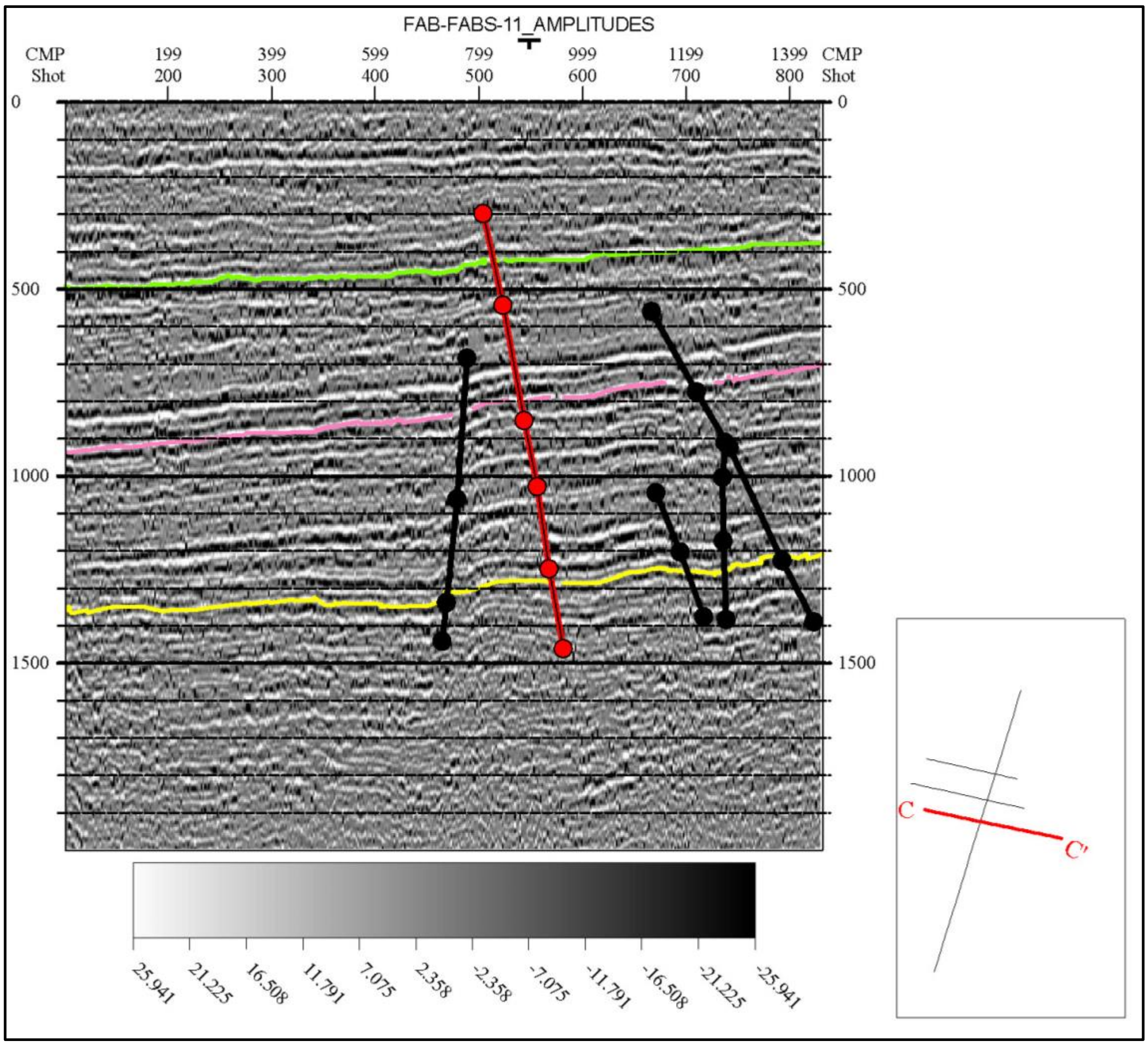

Figure 3.7 Marked horizons and faults on seismic line 931-FABS-13.

3.10 Time contour map

A time contour map in seismic data interpretation is a graphical representation that displays contours of constant two-way travel time of seismic waves reflected from subsurface geological layers. It helps geoscientists visualize and analyze the subsurface structure and identify potential hydrocarbon reservoirs in the Earth's subsurface. The contours connect points of equal travel time, allowing interpreters to infer the depth and shape of subsurface geological features.

3.10.1 Time contour map of Sui Main Limestone

The figure represents the time contour map of Sui Main Limestone. In this contour map, the same correlated faults **F1 and F3** that cuts the Sui Main Limestone horizon, which have been marked on seismic section are displayed. The color variation from darker to light color represents shallower and deeper time on the contour map. The contour map is formed using the contour interval of 20ms. In which the minimum contour value is 310ms and maximum contour value is 610ms.

3.10.2 Time contour map of Chiltan Limestone

The figure represents the time contour map of Chiltan Limestone. In this contour map, the same correlated faults **F1, F2 and F3** that cut the Chiltan Limestone horizon, which have been marked on seismic section are displayed. The color variation from darker to light color represents shallower and deeper time on the contour map. The contour map is formed using the contour interval of 20ms in which the minimum contour value is 620ms and maximum contour value is 1000ms.

3.10.3 Time contour map of Khewra Formation

The below figure represents the time contour map of Khewra Formation. In this contour map, the same correlated faults **F1, F2 and F3** that cuts the Khewra horizon, which have been marked on seismic section are displayed. The color variation from darker to light color represents shallower and deeper time on the contour map. The contour map is formed using the contour interval of 20ms in which the minimum contour value is 1140ms and maximum contour value is 1480ms.

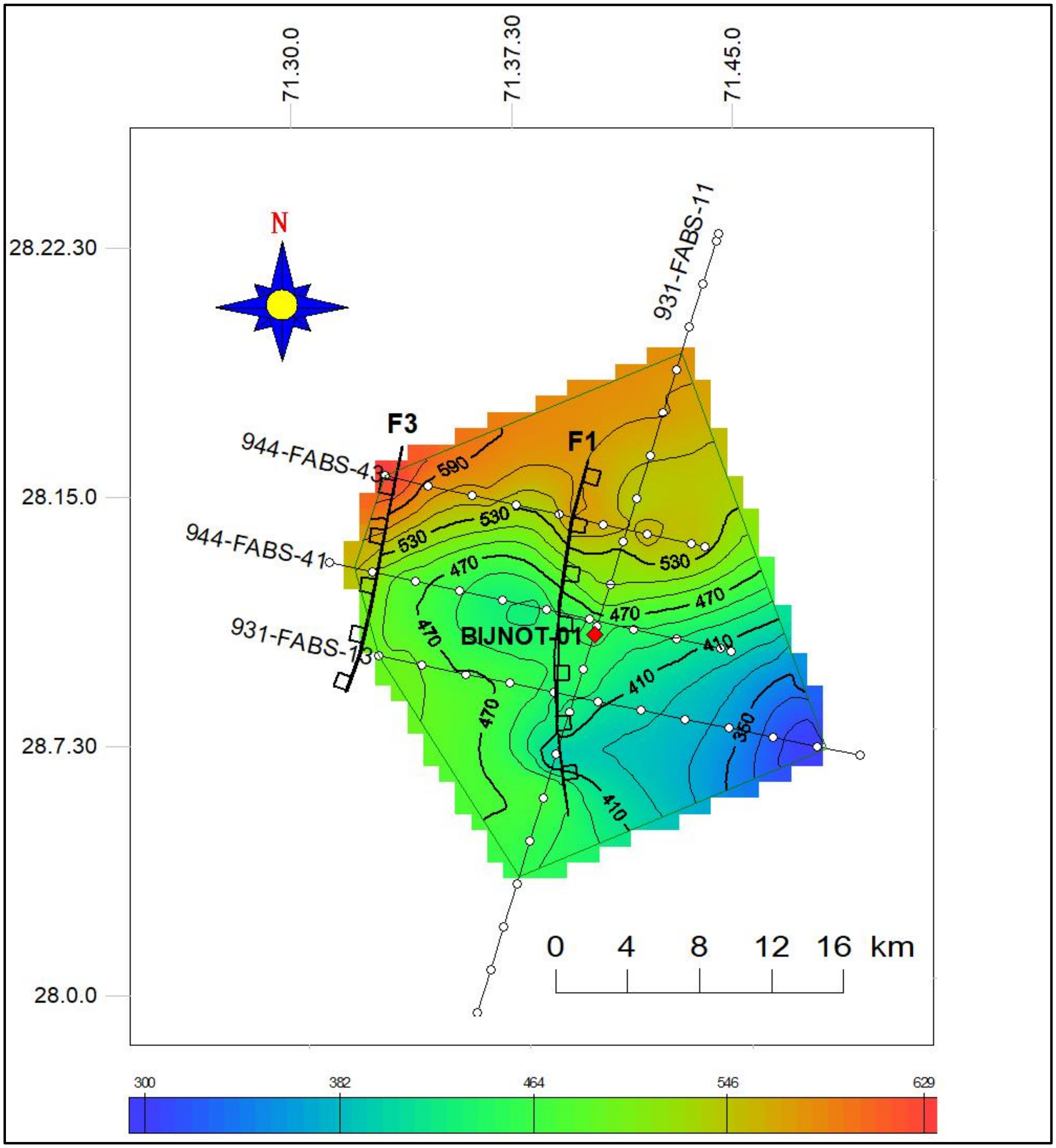

Figure 3.8 Time contour map of Sui Main Limestone.

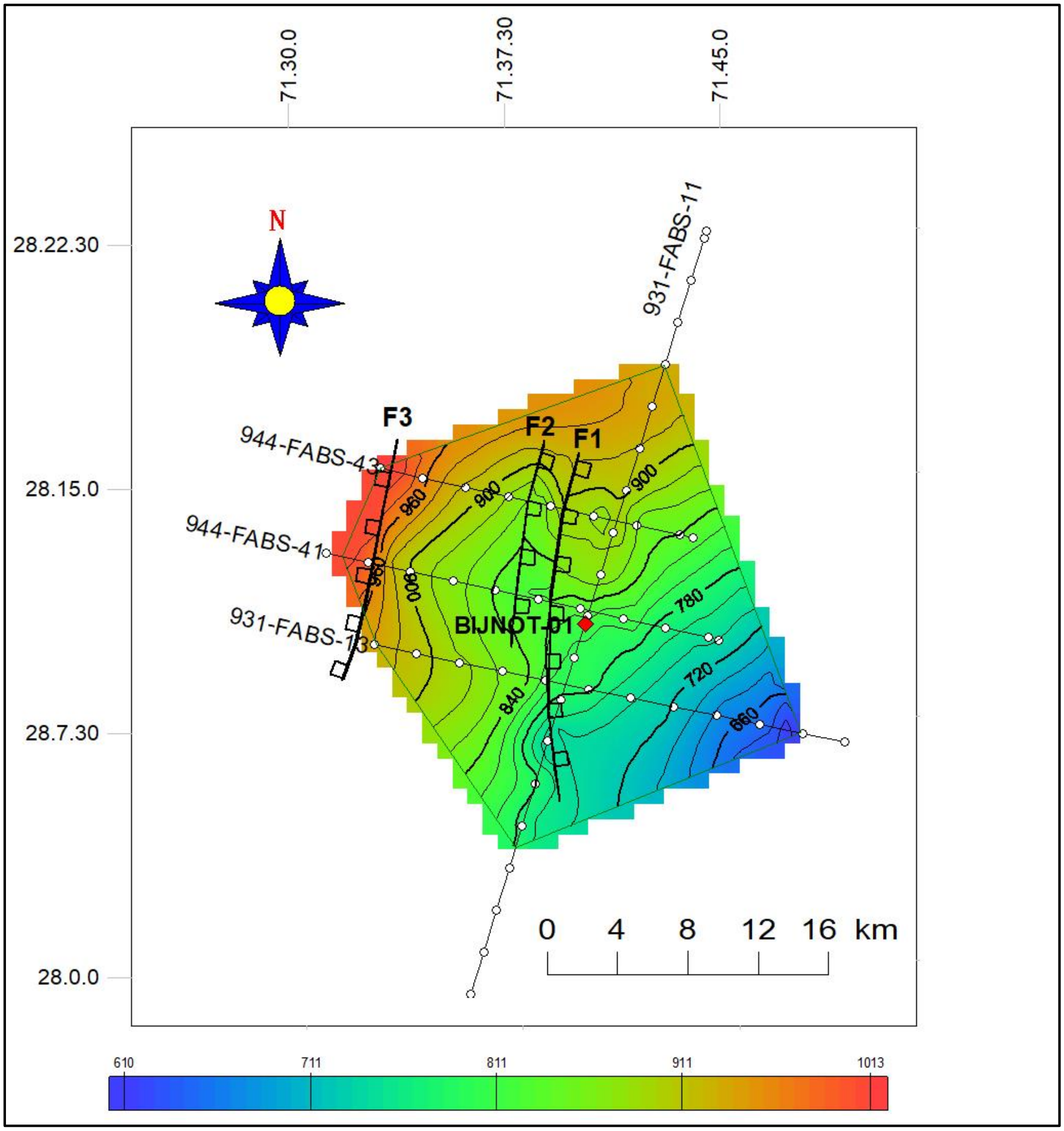

Figure 3.9 Time contour map of Chiltan Limestone.

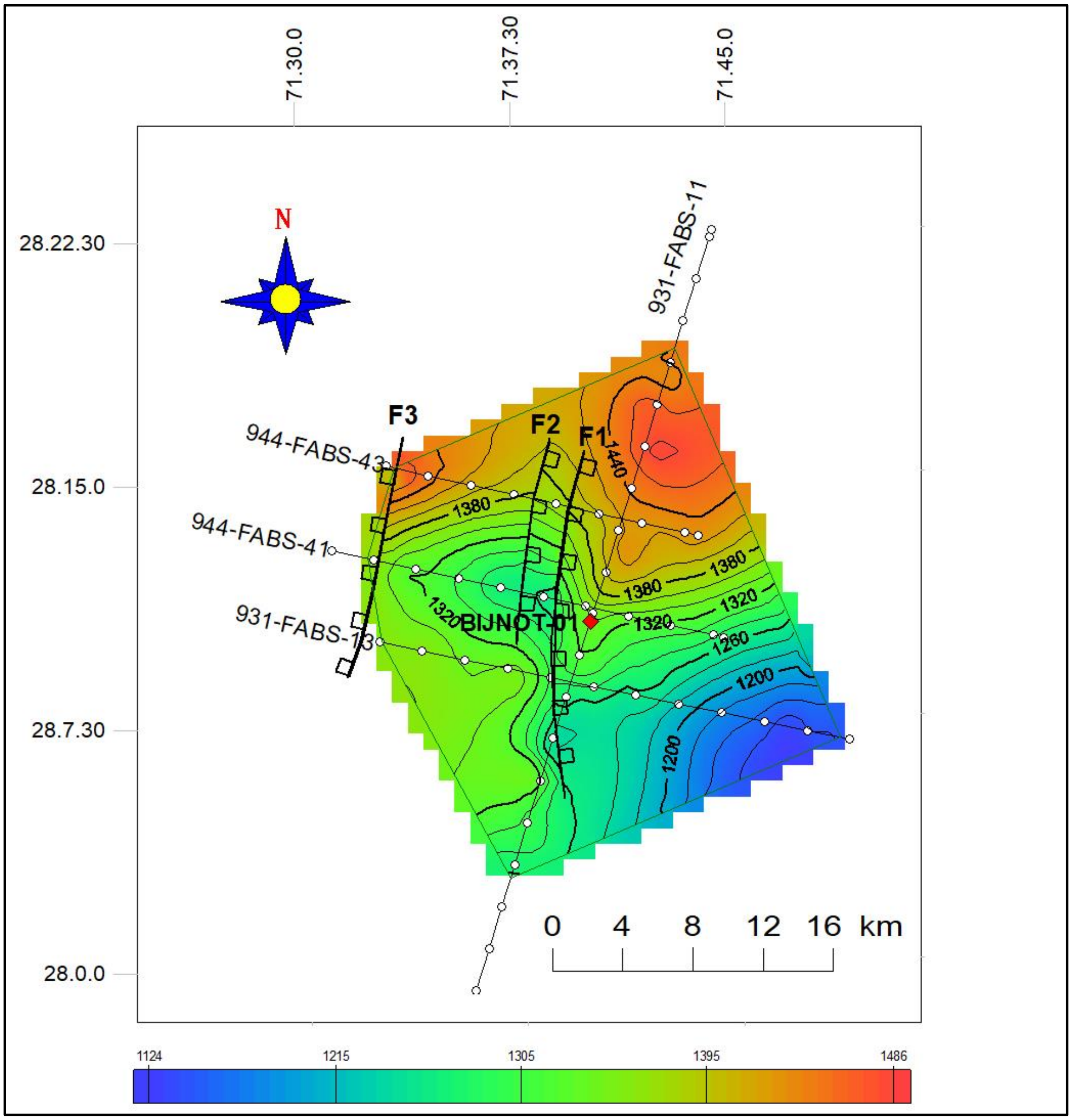

Figure 3.10 Time contour map of Khewra Formation.

3.11 Depth contour map

A depth contour map in seismic data interpretation represents the subsurface structure of the Earth in terms of depth below the surface rather than time. It is created by converting seismic data from time domain to depth domain using velocity information, allowing geoscientists to visualize and analyze the distribution of subsurface features at different depths. Depth contour maps are crucial for understanding the geological structure and identifying potential hydrocarbon reservoirs in the subsurface.

3.11.1 Depth contour map of Sui Main Limestone

For the conversion of time to depth, the well velocity 1710ms-1 that is calculated by the formula V=2S/T where S is the depth of the Sui Main Limestone and T is the time of reflector which has been picked through the synthetic seismogram. Then depth contour was then formed by using formula S=$\boldsymbol{V*T/2}$ where here T is the time contour map of Sui Main Limestone and V is the computed well velocity. The contour map is formed using the contour interval of 20m. In which the minimum contour value is 290m and maximum contour value is 530m. Same correlated faults **F1 and F3** that are on the time contour of Sui Main Limestone are shown here which represents horst and graben structure. The color variation from darker to light color represents shallower and deeper depth on contour map.

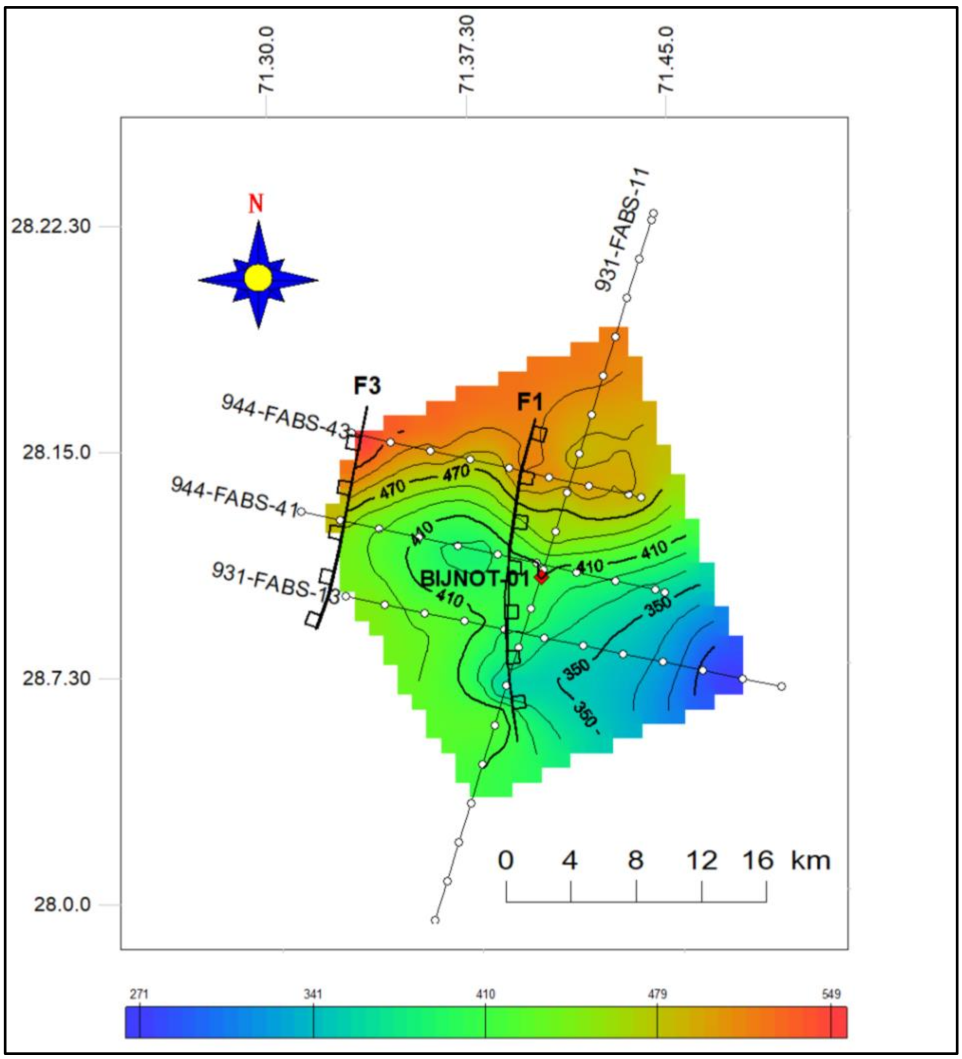

Figure 3.11 Depth contour map of Sui Main Limestone.

3.11.2 Depth contour map of Chiltan Limestone

For the conversion of time to depth, the well velocity 2034ms-1 that is calculated by the formula V=2S/T where S is the depth of the Chiltan Limestone and T is the time of reflector which has been picked through the synthetic seismogram. Then depth contour was then formed by using formula S=$\boldsymbol{V*T/2}$ where here T is the time contour map of Chiltan Limestone and V is the computed well velocity. The contour map is formed using the contour interval of 20m. In which the minimum contour value is 693m and maximum contour value is 1033m. Same correlated faults **F1, F2 and F3** that are on the time contour of Chiltan Limestone are shown here which represents horst and graben structure. The color variation from darker to light color represents shallower and deeper depth on contour map.

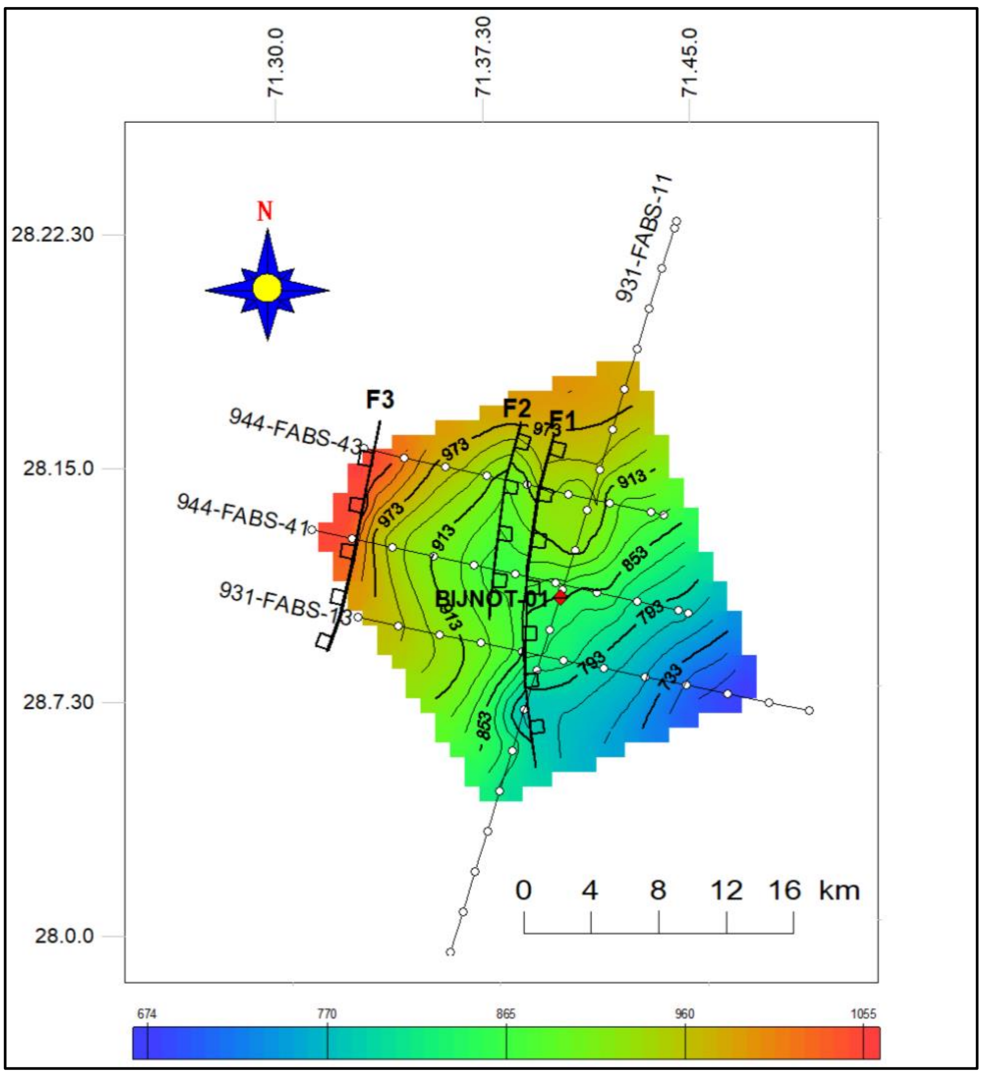

Figure 3.12 Depth contour map of Chiltan Limestone.

3.11.3 Depth contour map of Khewra Formation

For the conversion of time to depth, the well velocity 2269ms-1 that is calculated by the formula V=2S/T where S is the depth of the Khewra Formation and T is the time of reflector which has been picked through the synthetic seismogram. Then depth contour was then formed by using formula S=$\boldsymbol{V*T/2}$ where here T is the time contour map of Khewra Formation and V is the computed well velocity. The contour map is formed using the contour interval of 20m. In which the minimum contour value is 1313m and maximum contour value is 1653m. Same correlated faults **F1, F2 and F3** that are on time contour of Khewra Formation are shown here which represents horst and graben structure. The color variation from darker to light color represent shallower and deeper depth on contour map.

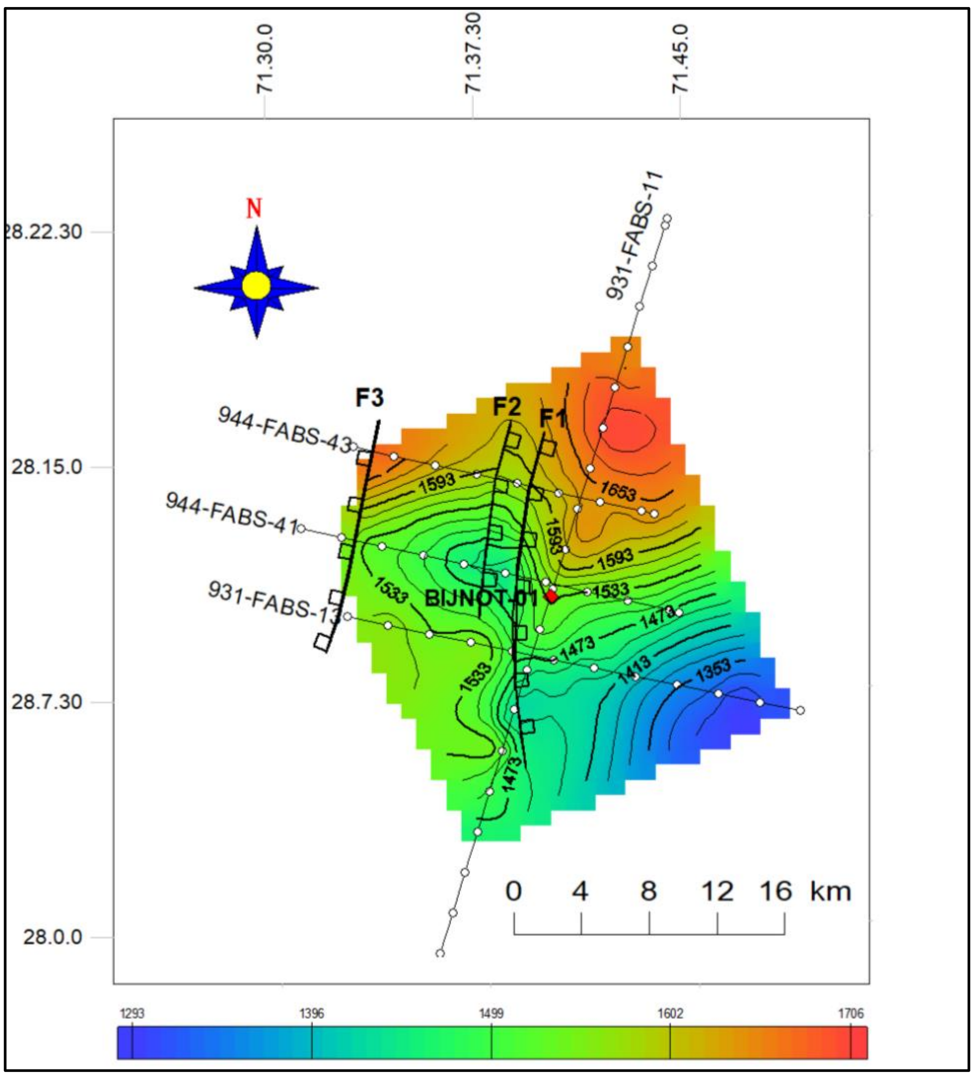

Figure 3.13 Depth contour map of Khewra Formation.

CHAPTER 4
PETROPHYSICAL ANALYSIS

4.1 Introduction

Petrophysics involves examining the physical characteristics related to the presence of rocks, their behavior, and the fluids contained within them. Its purpose is to assess and describe the quality of a reservoir by analyzing the amount and nature of fluids within the rock. To accurately identify potential hydrocarbon zones, a comprehensive grasp of reservoir physical parameters, including shale volume, porosity, and water and hydrocarbon saturation, is essential. In the Fort Abbas field area, the primary goal of this study is to measure the distinct properties of reservoir formations (Archie et al.,1950).

4.2 Objectives

To gain insights into petrophysical properties for hydrocarbon exploration, fundamental Wireline logging techniques are employed. Well logs provide a continuous record of in-situ measurements related to rock properties such as porosity, lithology, and the presence of hydrocarbons. They offer valuable insights into subsurface geology, assisting in the evaluation of reservoir potential and decisions related to drilling.

(1) Identifying potential zones containing hydrocarbons.

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

To calculate reserves in a reservoir, the following are essential:

(1) Porosity of the formation.

(2) Thickness of formations containing oil.

(3) Saturation of oil.

4.3 Methodology for Reservoir Evaluation

The methodology workflow adopted for the petrophysical interpretation of Bijnot-01 well as shown in figure 4.1.

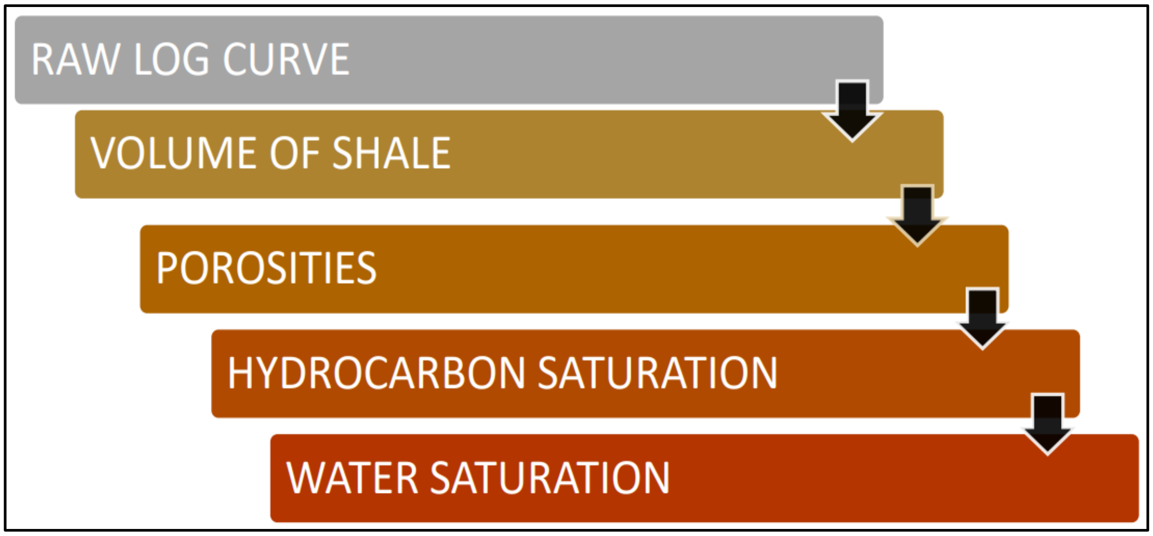

Figure 4.1 Flowchart showing sequence for reservoir evaluation.

4.4 Marking Zone of Interest

The portion of the geological formation identified as the potential reservoir is referred to as the zone of interest, and its extent can vary from a few meters to several tens of meters, depending on the specific formation. The determination of the zone of interest is based on various logging measurements, including gamma ray, caliper, neutron, density, and resistivity logs. The criteria for marking the zone of interest are outlined as follows:

1. The initial criterion involves ensuring the stability of the caliper, meaning it should not deviate significantly from the size of the drilling bit.
2. The second criterion is to have a low gamma ray reading, indicating a lithology with minimal shale content and overall cleanliness.
3. The third criterion involves the resistivity log curve following a specific order: MSFL < LLS < LLD.
4. The fourth criterion is to observe the N-D crossover, where both logs intersect and trend towards lower values.
5. The fifth criterion involves identifying a negative deflection in the SP log, indicating potential permeability.

4.5 Reservoir Evaluation

4.5.1 Volume of shale calculation

In order to calculate volume of shale we use Gamma ray log because shale is more radioactive due to presence of high organic content as compared to sand and other carbonates (Kamel et al, 2003).

$$\mathbf{V_{Shale}} = \frac{\mathbf{GR_{log} - GR_{min}}}{\mathbf{GR_{max} - GR_{min}}} \qquad (4.1)$$

GR log= value of gamma ray log at certain depth. GR min= gamma ray log minimum value. GR max= gamma ray log maximum value.

4.5.2 Porosity

Porosity Measurement There are different methods for porosity calculation that are used respective to their limitations.

1. Neutron Porosity

Neutron porosity log is influenced by the concentration of hydrogen ions within the formation. This measurement offers an indication of the porosity in a pure sedimentary deposit, where the pores are filled with either water or oil. The neutron log also helps determine the hydrogen index (HI) within the formation.

2. Density porosity

The density porosity is calculated from the density log. The principle of density log is to measure the bulk density by detecting the number of gamma rays emitted by a source on the detector. The following equation is used for the calculation of porosity (Schlumberger, 1989).

$$\boldsymbol{\varphi_D} = \frac{\boldsymbol{\rho_m - \rho_b}}{\boldsymbol{\rho_m - \rho_f}} \qquad (4.2)$$

Where, φ_D= Density porosity

ρm = Density of matrix

ρb= Bulk density of the formation

ρf = Density of fluid

3. **Sonic porosity**

The sonic porosity, a measure of porosity, determines the elastic wave velocity through a specific lithology. It is calculated by the following equation.

$$\boldsymbol{\varphi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}} \qquad (4.3)$$

φ_s = Sonic porosity,

Δt = Transit time in the formation of interest

Δt_{ma} = Transit time through 100% of the rock matrix

Δt_f = Transit time through 100% of the pore fluid

4. **Average Porosity**

Average porosity is critical in the production of oil and gas in a well. Porosity values at every meter are averaged in order to calculate total reservoir pore volume by taking the mean of the neutron and density porosities. by adding density and neutron porosity and then divided by two give average porosity 46 respectively (Serra, 1984)

$$\boldsymbol{\varphi_A = \frac{(\varphi_D + \varphi_N)}{2}} \qquad (4.4)$$

φ_A = Average Porosity

φ_N = Neutron Porosity

φ_D = Density Porosity

5. **Effective Porosity**

Effective porosity is defined as measurement of a porous material's total empty space that can transmit a fluid. Total porosity is defined as the ratio of total void volume to total bulk volume (Valentín et al., 2018).

$$\boldsymbol{\varphi_E = \varphi_A * (1 - V_{Shale})} \qquad (4.5)$$

4.5.3 Resistivity of Water

Water saturation, a critical parameter in fluid analysis, heavily relies on the computation of water resistivity (Rw). Understanding the saturation of the fluid present necessitates the determination of Rw. The Picket plot method is employed to calculate Rw.

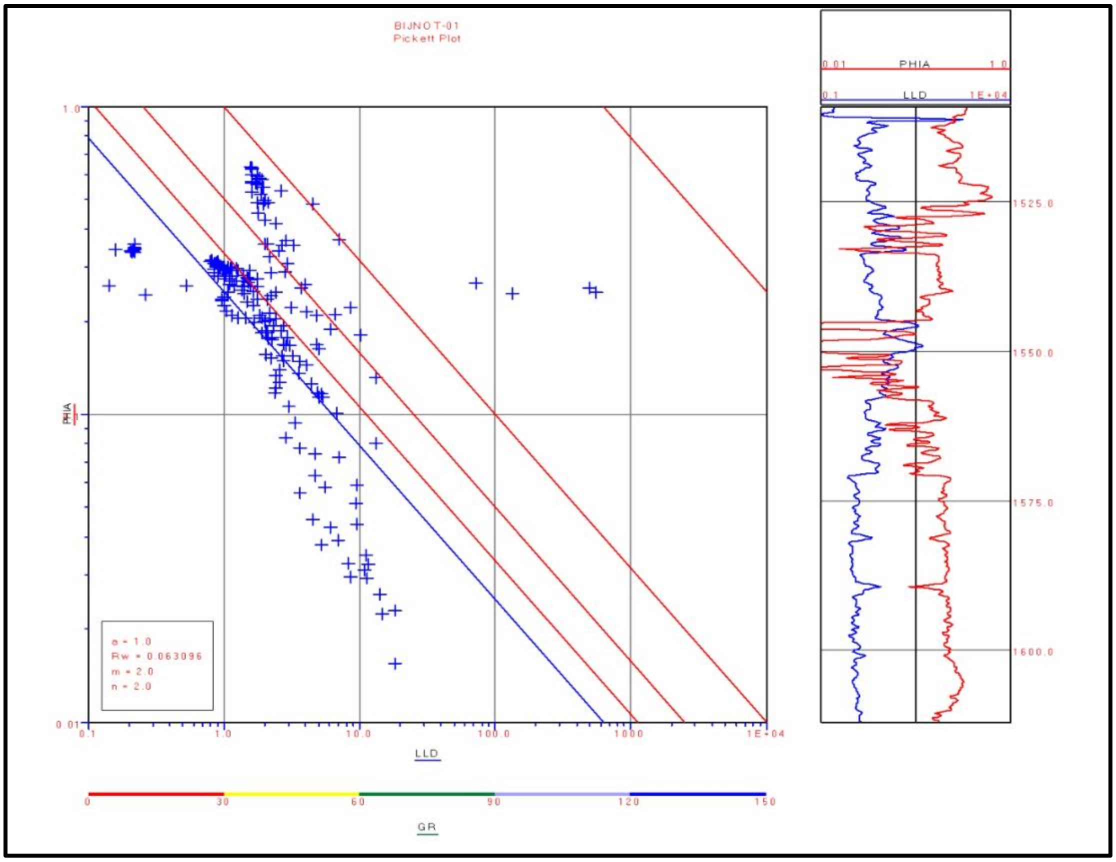

Figure 4.2 Picket plot construction of Khewra Sandstone of Bijnot-01 well.

4.5.4 Water Saturation

Water saturation indicates the proportion of empty spaces within a rock that contains water while hydrocarbon saturation denotes the quantity of hydrocarbons remaining in those same voids within the rock. In the estimation of water saturation, the Indonesian equation will be applied for shaly sand (Schlumberger, 1974).

$$S_{w_I} = \left[\frac{\sqrt{\frac{1}{R_t}}}{\left(\frac{V_{sh}^{(1-0.5*V_{sh})}}{\sqrt{R_{sh}}} \right) + \sqrt{\frac{\varphi_E{}^m}{a*R_w}}} \right] \qquad (4.6)$$

4.5.5 Hydrocarbon Saturation

Saturation of hydrocarbon is computed by subtracting the quantity of water saturation from the cumulative fluid volume. The formula used for calculating hydrocarbon saturation is given below (Rider, 2002).

$$\mathbf{S}_{hc} = \mathbf{1} - \mathbf{S}_{\mathrm{w_I}} \qquad (4.7)$$

S_{hc} = Saturation of hydrocarbon

S_{w_I} = Saturation of water

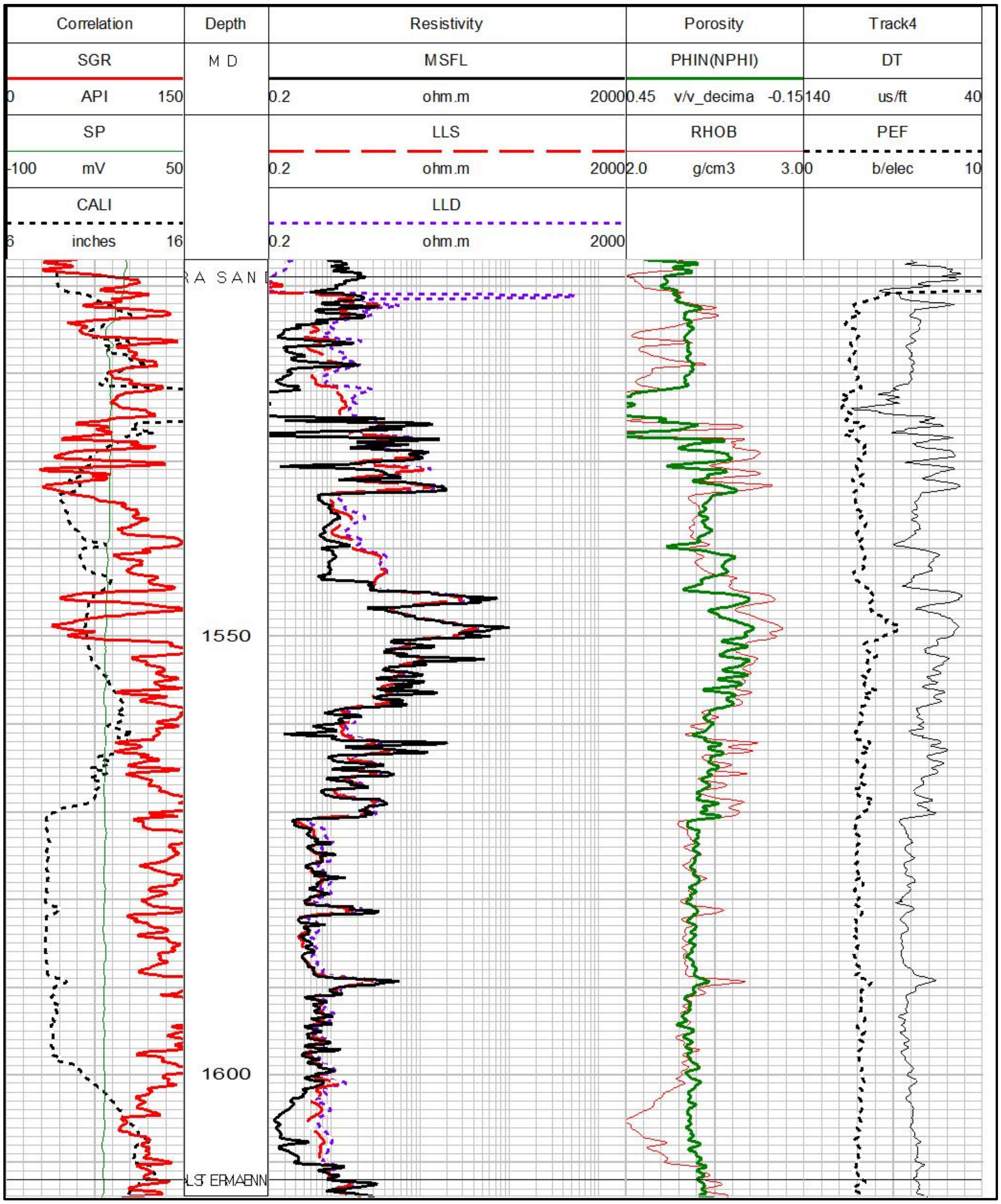

Figure 4.3 Raw log curves of Khewra formation of bijnot-01 well.

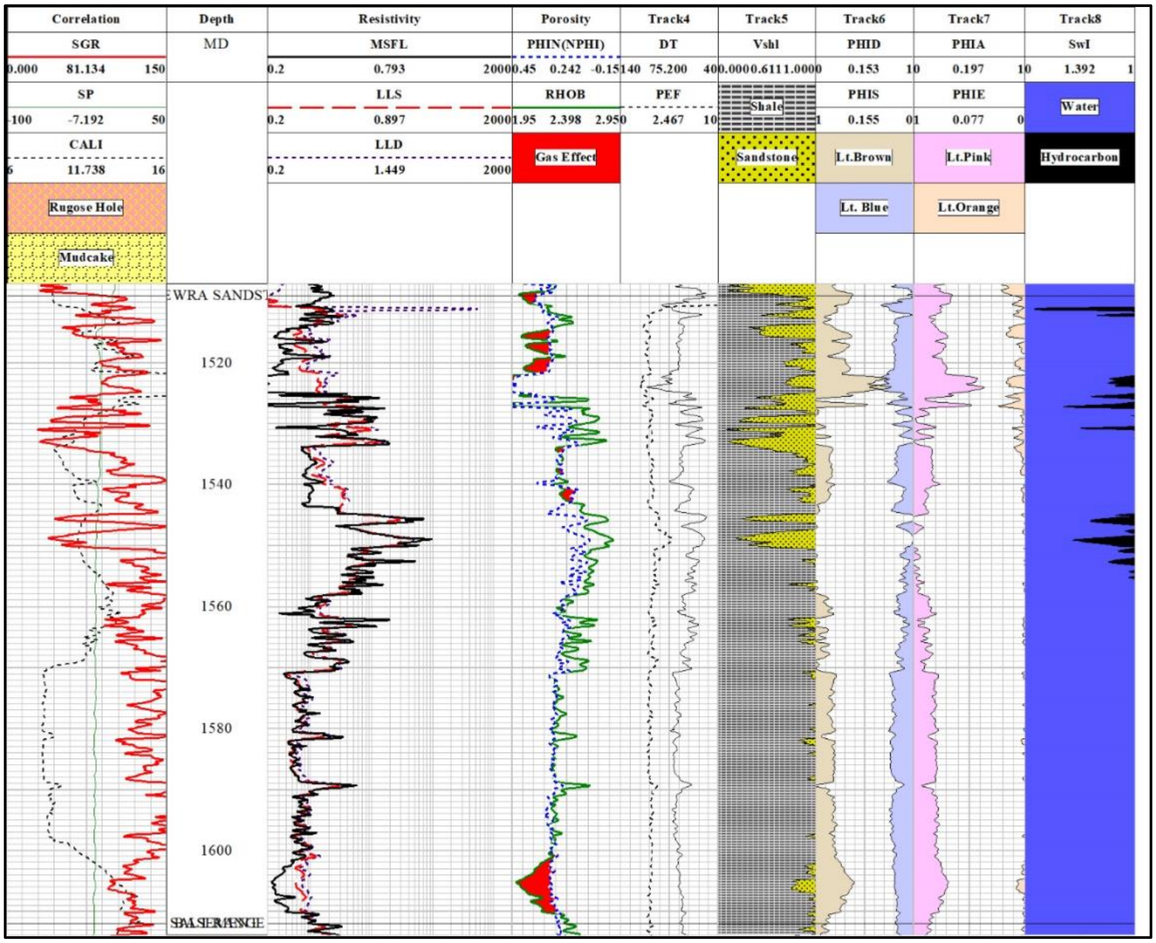

Figure 4.4 Interpreted curves of Khewra formation showing hydrocarbon and water intervals.

The whole reservoir formation is taken as zone in which the average presence of volume of shale is 87.63% with average porosity of 17.95% and effective porosity of 1.85%. The above interpreted figure shows all the computed properties of reservoir evaluation along with the saturation of water which is 1.83 and saturation of hydrocarbons at this formation is -0.833. The Zone values and parameters of bijnot-01 have been shown in the Table.

Table 4.1: Reservoir Computed Properties

Formation	Vsh	PHIA	PHIE	Sw	Sh
Average	0.8763	0.1795	0.145	0.98	0.02
Average%	87.63	17.95	14.5	98	2

4.6 Source Evaluation in Fort Abbas Area

Source rocks are sedimentary rocks abundant in organic carbon, sufficient to generate hydrocarbons. They typically consist of fine-grained sediments such as shales, micritic limestones, or mudstones. The assessment of source rock richness can be qualitative, involving the identification of organic-rich formations, or quantitative, employing conventional well logs to estimate the organic matter content. Organic matter is deemed the crucial element in source rocks. Rocks with a total organic carbon (TOC) exceeding 1% are regarded as suitable for economically viable hydrocarbon production (Tissot & Welte 1984).

4.7 Quantitative Analysis Methods

Quantitative analysis techniques in petrophysics are essential for assessing source rocks, offering valuable information about their composition and potential hydrocarbon reserves. Gamma ray logging, resistivity logging, and density logging are commonly employed to evaluate source rocks.

1. Gamma ray Log

Gamma ray logging involves the measurement of the natural gamma radiation emitted by geological formations. Source rocks generally display increased gamma ray readings as a result of containing radioactive minerals such as uranium, thorium, and potassium. This logging method offers a numerical assessment of radiation levels, enabling Petrophysicists to recognize and evaluate potential source rock layers. High gamma ray readings in a well log can suggest the existence of organic-rich shales, which are frequently favorable for the generation of hydrocarbons (Darling, T. 2005).

2. Resistivity Log

Resistivity logging involves the assessment of the electrical resistivity of formations beneath the Earth's surface. Source rocks such as organic-rich shales, typically exhibit high resistivity in contrast to the surrounding formations. This is attributed to the insulating properties of organic matter which diminishes the rock's conductivity. Petrophysicists utilize resistivity logs to detect and quantify the existence of potential source rocks. The resistivity log proves valuable in distinguishing between formations containing hydrocarbons and those lacking them, aiding in the understanding of source rock characteristics (Archie, G. E. 1942).

3. Density Log

The density log is employed to estimate organic content by exploiting the lower density of solid organic matter compared to the surrounding rock matrix. This method is more precise than the total gamma ray approach because the density log is minimally affected by bore gauging variations. However, its reliability diminishes in shale-prone areas susceptible to washouts. To quantify the impact of organic matter within a specific interval, the log values of the adjacent non-source interval are subtracted (Schmoker, 1979).

4.8 Passey's "DlogR" Method

The DlogR method is applied across the entire formation zone by aligning the sonic log with the top of the logarithmically scaled resistivity log. This ensures that the sonic log curve is positioned above the resistivity log. In our current investigation, sonic and resistivity data are scaled, with 50 µsec/feet equivalent to one logarithmic cycle on the resistivity log, as per Rider (2002). The separation between the sonic and resistivity logs, referred to as DlogR, indicates the source interval. Baseline intervals, where sonic and resistivity curves overlap, represent non-source intervals. The DlogR separation is observed at various depths in all three wells, signifying source intervals. The figure for Bijnot-01 Well illustrates DlogR and baseline intervals. To estimate total organic carbon (TOC) using the Passey method, we first perform the calculation of "DlogR" using the formula provided in equation (4.11) (Passey, et al., 1990).

$$\mathrm{DlogR} = \log\left(\frac{\mathrm{ILD}}{\mathrm{ILDbase}}\right) + 0.02 * (\mathrm{DTC} - \mathrm{DTCbase}) \qquad (4.11)$$

ILD = deep resistivity in any zone (ohm-m)

ILDbase = deep resistivity baseline in non-source rock (ohm-m)

DTC = compressional; sonic log reading in any zone (µsec/ft)

DTCbase = sonic baseline in non-source rock (usec/ft)

DlogR = Passey's number from sonic (fractional)

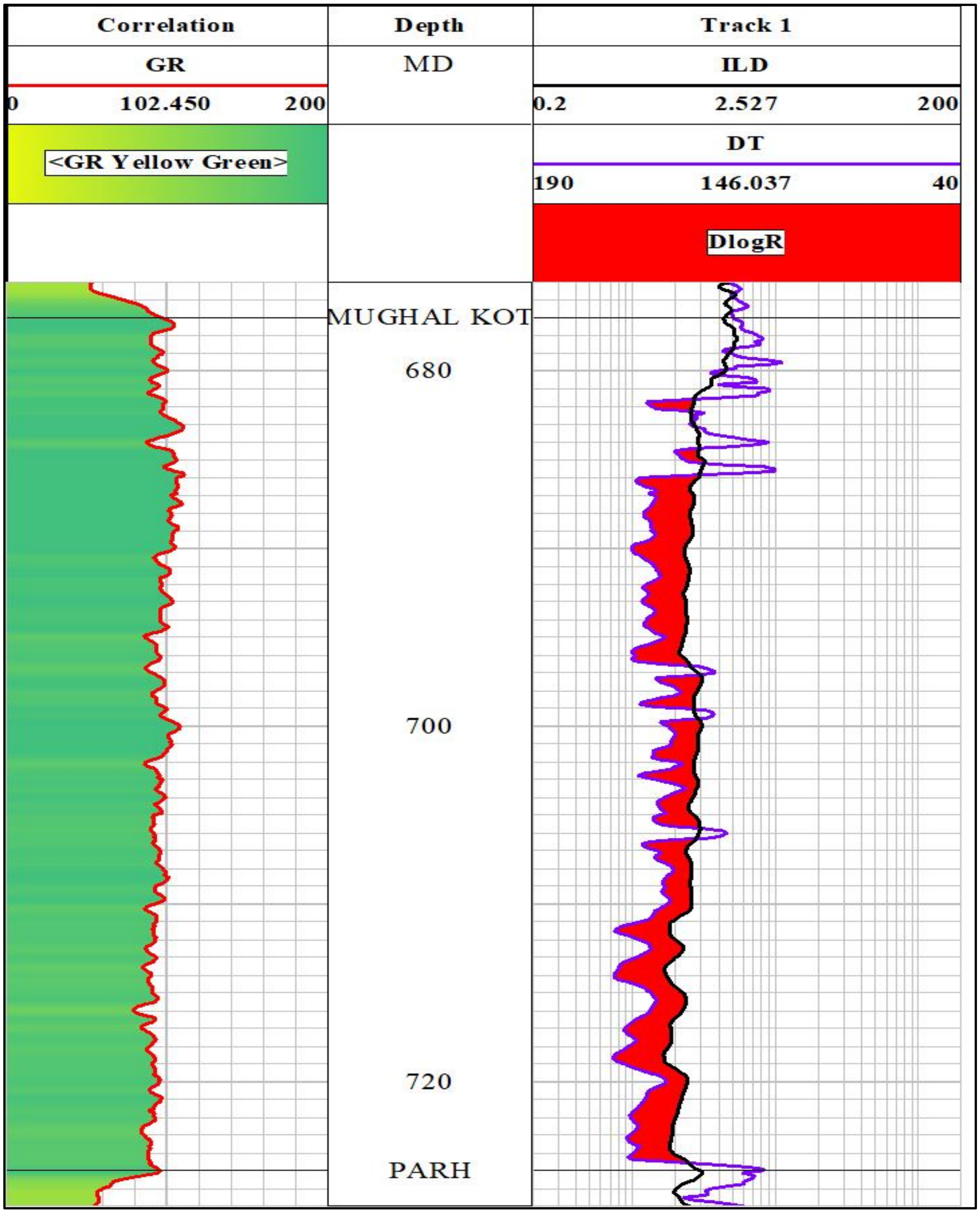

Figure 4.5 Raw log curves of Mughal kot formation of bijnot-01 well.

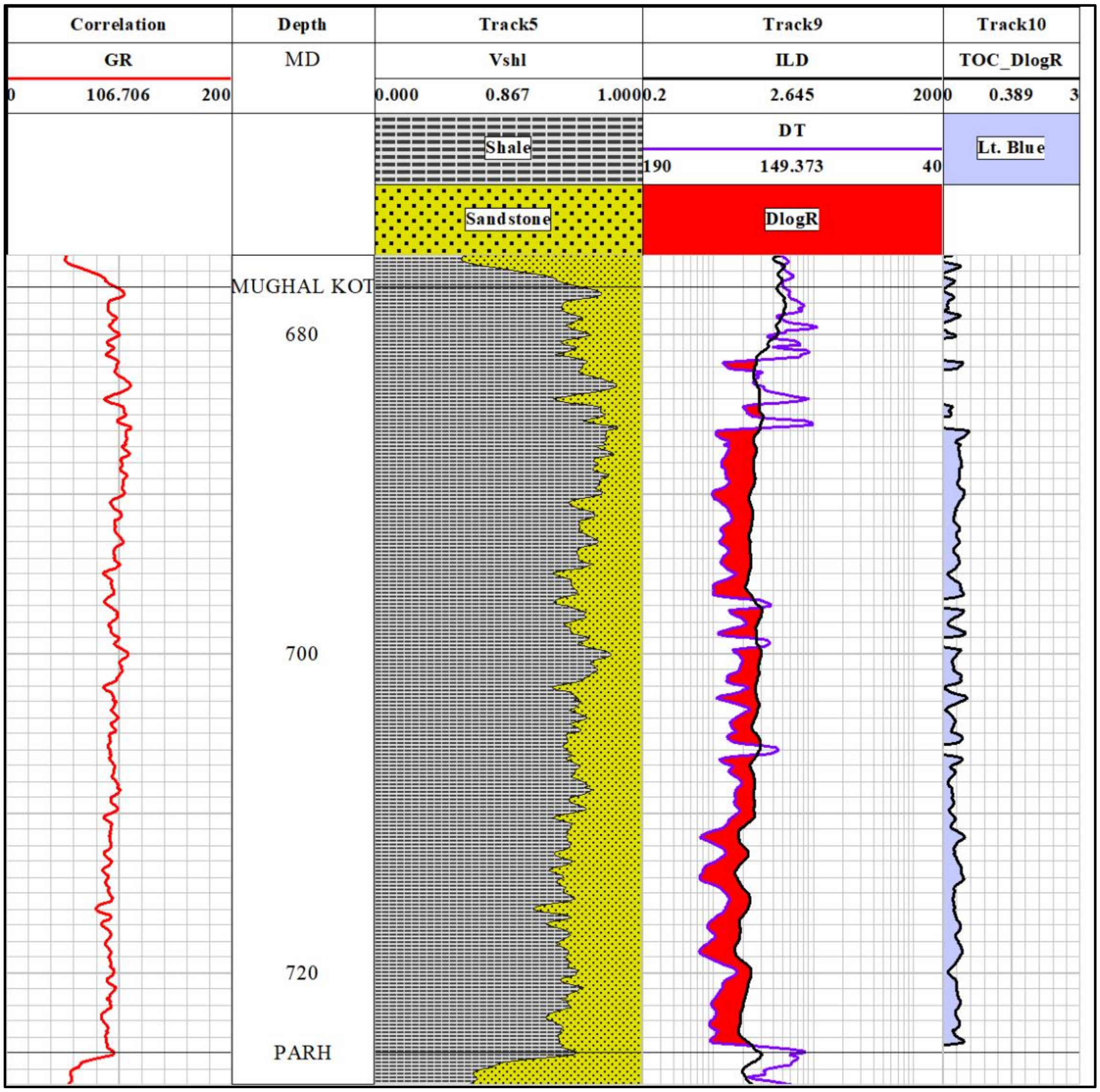

Figure 4.6 Interpreted curves of Mughal kot formation of bijnot-01 well.

The figure above shows the zone where the TOC tells about evaluating the potential of hydrocarbons present in the zone between Mughal kot and Parh limestone. The table shows the TOC minimum and maximum value. One zone of TOC has been evaluating from depth of 667m till 681.50m.

Table 4.2: TOC Evaluation Parameters

TOC Zone Depth (m)	Minimum Value	Maximum Value	Average Value
677-681.50	0.1	0.568	0.3322

CONCLUSIONS

1. The subsurface structural interpretation of the study reveals that the area is deformed by steeply dipping normal faults forming horst and graben structures.
2. Petrophysical evaluation of the Khewra Sandstone shows that the formation bears good effective porosities having average values of about 14% however, the fluid saturation revealed high percentage of water saturation ranging up to 98%.
3. Source rock potential of the Mughal Formation depicted that the formation bears low TOC values with and average of 0.33%.

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