PETROPHYSICAL ANALYSIS OF QADIRPUR-03 & QADIRPUR-11, LOWER INDUS BASIN, PAKISTAN

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ABSTRACT

Qadirpur Gas Field, located in Pakistan, has been a significant contributor to the country's natural gas production. This thesis presents a comparative analysis of two key wells in the field, namely Qadirpur-03 and Qadirpur-11 located at 28°2'49” N 69°21'47” E, with a focus on reservoir characterization and production optimization. By utilizing well logs, production data, and geological information, this study aims to evaluate and compare the reservoir properties for both wells. The well logs of Qadirpur-03 and Qadirpur-11 wells were acquired from Directorate General of Petroleum Concessions (DGPC). Petrophysical evaluation of these wells were carried out to mark the reservoir area which included the selection of zone of interest followed by Log interpretation. The zones of interest of study area were marked in Sui main limestone in both wells. Petrophysical analysis of two marked zones of Qadirpur-03 showed that there is 33.4% and 16.56% Vsh, 21.62% and 19% Sw 78.38% and 80.8% Sh and in Qadirpur-11 there is 64.1% and 16.01% Vsh,33.36% and 17.58% Sw 66.60% and 79.23% Sh in Zones 1 and 2 in Qadirpur-03 and Qadirpur-11 wells respectively. The value of Vsh is low and porosity is high which indicate it being producing wells.

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ABBREVIATIONS

Rt Resistivity of True Zone

Rw Resistivity of Water

Sh Saturation of hydrocarbons

Sw Saturation of water

Vsh Volume of shale

PHIA Average porosity

PHIE Effective porosity

PHIN Neutron porosity

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

Located in Sindh, Qadirpur ranks as the second largest gas field in Pakistan after Sui, with original recoverable reserves of about 4 Tcf.The Qadirpur gas field is currently one of OGDCL largest operated gas producing fields, accounting for 34%, 32% and 29% of OGDCL net gas production for 2012, 2013 and 2014.

Gas production on this field commenced in September 1995 by Prime Minister Benazir Bhutto after the installation of gas gathering facilities and processing plants. Of the 70 wells that have been drilled at this field, 57 are currently producing wells. Six have been abandoned, five are shut-in and two are water disposal wells Purified gas from the field is supplied to SNGPL while raw gas and condensate is sold to Liberty Power and Pakistan Refinery Limited, respectively. Besides, permeate gas is supplied to Engro Power Limited since March 2010.

1.2 LOCATION OF STUDY AREA

Qadirpur, situated in Sindh, holds the position of being Pakistan's second-largest gas field, following Sui. It is positioned approximately 8 kilometers (5.0 mi) away from Ghotki in Sindh Province, specifically at 28°2'49” N 69°21'47” E (Fig. 1.1).

The field is located 8 km from Ghotki, 70 km northeast of Sukkur and 100 km east of Jacobabad in Sindh province. It is located from main (90 km, sadiqabad = karachi, 540 km) highway road stop ahmed ki, 4 km away inside.

Qadirpur conventional gas field reserves accounts 0.04% of total remaining reserves of producing conventional gas fields globally.

1.3 OBJECTIVES

The objectives are as follows:

1. To delineate hydrocarbon potential and mark suitable reservoir zones in Qadirpur-03 and Qadirpur-11 wells.

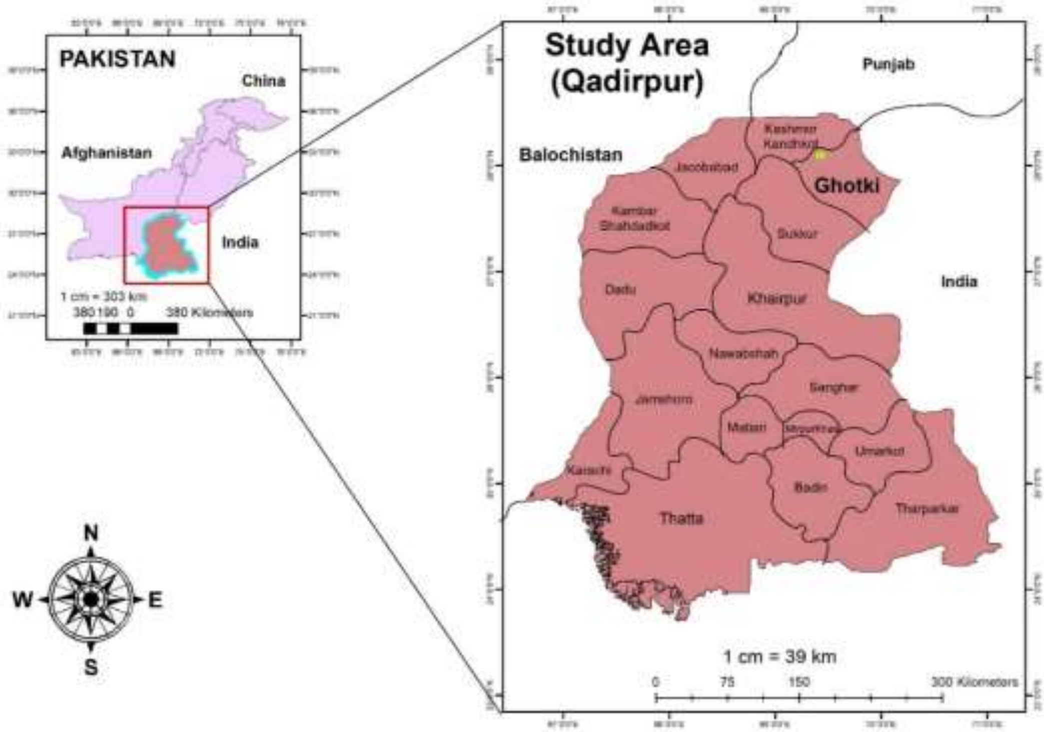

Figure 1. 1 Location area of Qadirpur (ArcGis).

1.4 DATA REQUIRED

The data for this research has been granted from Land Mark Resources (LMKR) Pakistan, and it includes: -

1. Resistivity log
2. Sonic log
3. Spontaneous Potential logs
4. Density log
5. Neutron log
6. Caliper log

1.5 METHODOLOGY

The steps for the petrophysical analysis (fig 1.2).

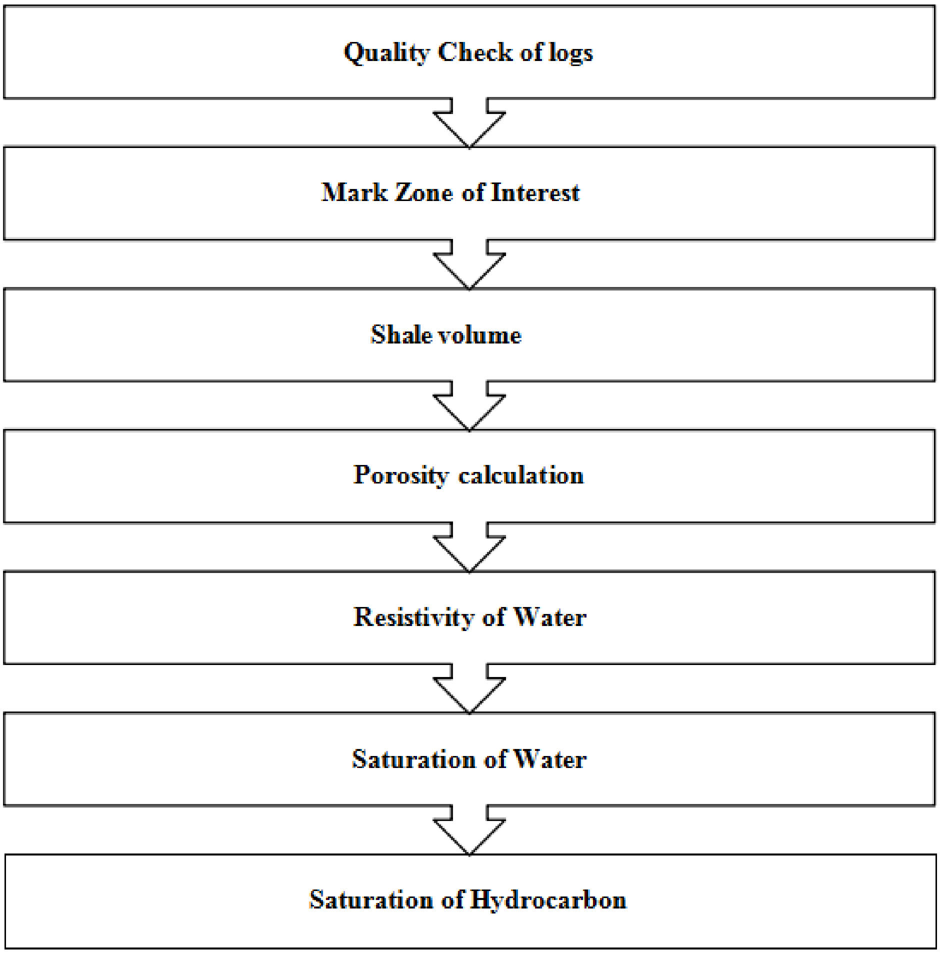

Figure 1. 2 Workflow of the current petrophysical analysis.

CHAPTER 2

GENERAL GEOLOGY AND TECTONICS

2.1 REGIONAL TECTONIC SETTING

Around 300 million years ago, the Earth's landmasses were fused together in a supercontinent known as Pangea. The region that would later become Pakistan was part of the Gondwana landmass, which included present-day Africa, South America, Antarctica, Australia, and the Indian subcontinent. Approximately 200 million years ago, Pangea began to break apart due to tectonic forces. This process led to the separation of Gondwana into multiple continents, including the Indian subcontinent. The landmass that would become Pakistan started to move northward. Around 50 million years ago, the Indian subcontinent, carrying the future land of Pakistan, began to collide with the Eurasian Plate. The northward movement of the Indian Plate at a rate of several centimeters per year initiated the formation of the Himalayan Mountain range. The ongoing collision between the Indian Plate and the Eurasian Plate resulted in the uplift and folding of the sedimentary rocks in what is now Pakistan. The Himalayas, Karakoram, Hindu Kush, and other mountain ranges were formed as a result of intense compression and folding of the Earth's crust. As the mountain ranges formed, the rivers in the region, including the Indus River, adapted to the changing topography. The Indus River and its tributaries, originating in the Himalayas and other ranges, cut through the mountains, carving deep valleys and creating a vast river system that played a significant role in shaping the landscape of Pakistan. Over the past millions of years, the tectonic forces in the region have continued to shape the land of Pakistan. Earthquakes, uplift, erosion, and deposition of sediments are ongoing processes that contribute to the current geological features and landforms in the country.

Pakistan, located in South Asia, possesses a diverse and complex tectonic setting due to its position at the junction of several major tectonic plates. The region is characterized by active tectonic activity, resulting in numerous earthquakes, mountain ranges, and geological features. Here, is provided a brief overview of the regional tectonic settings of Pakistan.

Collision Zone of the Indian Plate and Eurasian Plate: The most significant tectonic feature in Pakistan is the collision zone between the Indian Plate and the

Eurasian Plate. The Indian Plate, carrying the Indian subcontinent, is converging northward with the Eurasian Plate at a rate of about 37 millimeters per year. This ongoing collision has resulted in the formation of the Himalayan Mountain range, including the Karakoram, Hindu Kush, and Pamir ranges. These mountain ranges exhibit active tectonics and are home to some of the highest peaks in the world, such as K2 and Nanga Parbat.

Pakistan also experiences seismic activity due to the presence of active fault systems. The major fault line in the region is the Main Mantle Thrust (MMT), which separates the Indian Plate from the Eurasian Plate. This fault is responsible for the occurrence of large-magnitude earthquakes, such as the devastating 2005 Kashmir earthquake. Additionally, several other faults traverse different parts of Pakistan, including the Chaman Fault, the Kalabagh Fault, and the Salt Range Fault, contributing to the seismicity of the region.

The northern part of Pakistan is influenced by the Indus-Tsangpo Suture Zone. This zone represents the boundary between the Indian Plate and the Asian Plate. It is a tectonic suture where the remnants of the Tethys Sea, which once separated the Indian and Asian plates, have been squeezed and uplifted. This region is characterized by diverse geological formations, including ophiolites, melanges, and thrust sheets.

Pakistan's coastal areas along the Arabian Sea are shaped by a different tectonic setting. Here, the Arabian Plate is converging with the Eurasian Plate, resulting in compression and uplift. The Makran Coastal Range, located in southwestern Pakistan, is an example of a region affected by this tectonic interaction. It is prone to seismic activity and experiences occasional large-magnitude earthquakes.

The tectonic settings of Pakistan are influenced by the collision between the Indian Plate and the Eurasian Plate, resulting in the formation of the Himalayan Mountain range. The presence of active fault systems and the Indus-Tsangpo Suture Zone further contribute to the seismicity and geologic diversity of the region.

2.2 GENERAL GEOLOGY

The Jacobabad and Mari Kandhkot Highs, known as the Sukkur Rift, serve as a geographical demarcation between the Southern Indus Basin and the Middle Indus Basin. The Indus basin of Pakistan encompasses a significant area. of 533,500 km2 and consists of sedimentary layers spanning from the Precambrian era to the present time. This basin holds a significant amount of oil and gas resources. Various areas such as the Karachi depression, Sulaiman-Kirthar depression, and the folded regions within the Kirthar mountains and Sulaiman range have witnessed successful discoveries of oil and gas reserves (Fig 2.1).

Figure 2. 1 Divisions in the Indus Basin showing location of study area in the Southern Indus Basin (Awan et al., 2021).

The Indus basin is further broken down into: -

1. Upper Indus Basin
2. Lower Indus Basin (Central and Southern Indus Basin)

2.2.1 SUB-DIVISIOS OF SOUTHREN INDUS BASIN

The Southern Indus Basin is divided from the central basin by the Sukkur rift, situated in the southern part of the Lower Indus Basin. The eastern boundary of the Lower Indus Basin is defined by the Indian shield, while the western boundary is defined by the marginal zone of the Indian plate. It is worth noting that the Lower Indus Basin cannot extend further south due to the offshore Murray ridge Owen fracture plate limit (Kadri 1995).

The following five primary units make up the Lower Indus Basin: -

1) THAR PLATFORMS

The Thar platform, like the Punjab platform in the central Indus basin (Map 2:3), is a subsurface monocline with a gentle slope. As we move towards the Indian shield, which is evident at Nagar Parkar high, the sedimentary cover thins out. In contrast to the Punjab platform, the Thar platform displays buried structures that are created due to tectonic process resul from the recent anticlockwise movement of the Indian plate. This platform has witnessed highly successful development of the Goru Cretaceous Sands, which serve as oil reservoir and field gas (kadri 1995).

2) KARACHI TROUGH

The trough is characterized by its thick early Cretaceous sediments, which indicate its position as the final stages of marine sedimentation. It consists of a series of elongated and narrow anticlines that resemble chains, some of which contain oil and gas fields (Kothar, Sari & Hundi). Over the course of geological history, the trough has maintained its trough-like structure. The region boasts well-preserved rocks from the early, middle, and late Cretaceous periods. Particularly intriguing is the ongoing deposition of sediments at the Cretaceous/Tertiary (K/T) boundary (Kadri 1995).

3) KIRTHAR FOLD BELT

The Kirthar foredeep, oriented in a north-south direction, has gathered sediment deposits that reach a total thickness exceeding 15,000 meters. The boundary on its eastern side, where it meets the Thar platform, is characterized by faulting. Although the Upper Cretaceous layer is not present, the Paleocene layer is well-preserved in this region. The Kirthar foredeep holds great promise for the maturation of source rocks.

4) OFFSHORE INDUS

The region under examination is a passive continental margin that appears to have undergone two distinct geological periods: the Cretaceous-Eocene era and the Oligocene-Recent era. Kadri's observations indicate that sedimentation in the offshore Indus region began during the Cretaceous period (1995)

2.3 GENERALIZED STRATIGRAPHY

The research area's stratigraphy includes rocks from the Sembar Formation to the Siwaliks (Fig 2.2).

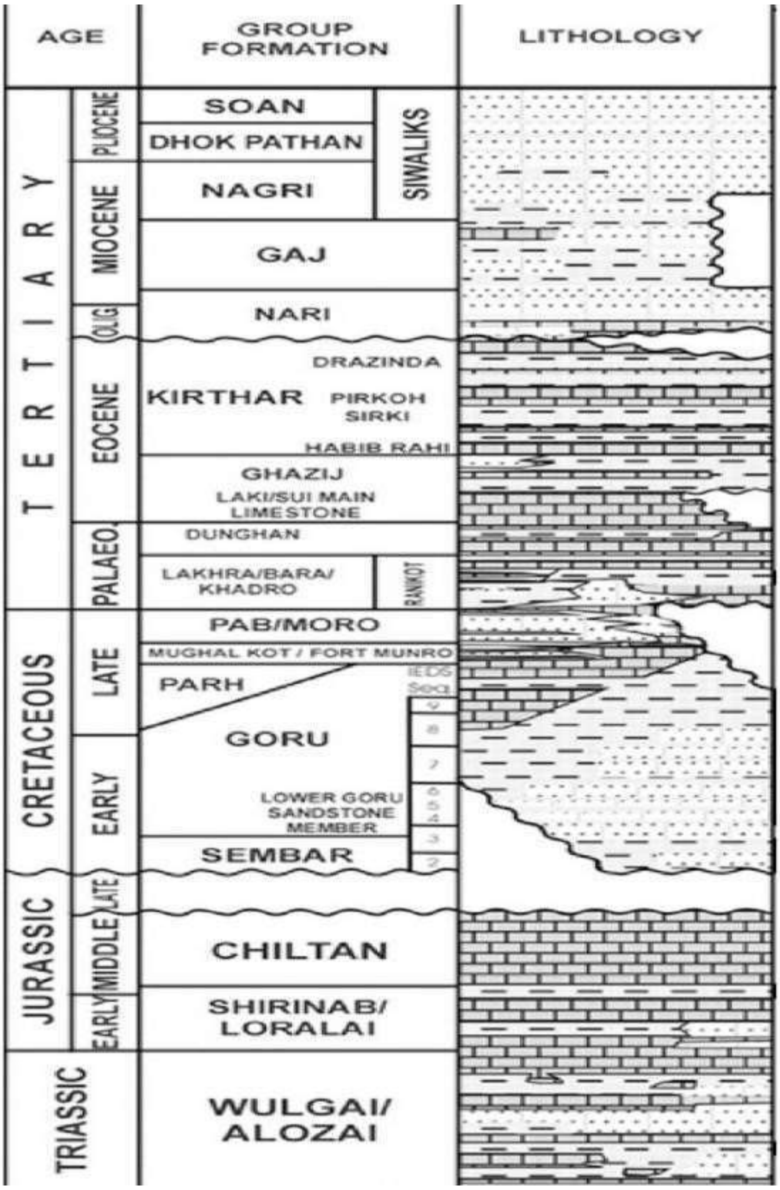

Figure 2. 2 Generalized stratigraphy found in wells Qadirpur-03 and Qadirpur-11

2.3.1 CRETACEOUS

The actual breakup of Gondwanaland occurred in the Early Cretaceous (Africa-South America). Approximately 120 Ma (Aptian), when Sembar/Goru were being deposited, Eastern Gondwanaland broke up to form what is now known as the Greater India. Thus, shallow seas were present during the whole Cretaceous period.

Early Cretaceous is a transgression period, whereas end of Cretaceous (Mesozoic Era) is a global regression, characterized by continuous sedimentation. As a result, it is easy to see the contact in the outcrops, ditch cuttings, and on wireline logs. Early Cretaceous sediments are known for their shaly response on logs.

An interesting phenomenon can be seen at the upper Cretaceous–Paleocene contact in Pakistan. It is significant economically because laterite, bauxite, coal, and iron reserves are found along the contact in various regions of Pakistan. Since the Basal Tertiary is often characterised by transgressive seas and the Top Cretaceous by regressive phase, their contact is very clearly visible on ditch cuttings and wireline logs (Kadri, 1995).

In the Lower Cretaceous rocks, black shale, siltstone, and argillaceous of the Sembar Formation extend up to 250 metres, and limestone with shale (interbedded), and sandstone (Lower Goru) extend up to 500 metres. In the Southern and Middle Indus Basins, and Sulaiman-Kirthar region, the Sembar is regarded as the principal petroleum source rock. Most of the reservoirs that are producing the Composite TPS of Sembar-Goru and Ghazij are found in Lower Goru sandstone reservoirs. The Parh carbonates, the Moghal Kot shales, sandstones, and limestones, and the Fort Munro limestones and shales are evidence of the shelf to shallow-marine environment that existed throughout the majority of the Late Cretaceous period (Wandrey et al, 2004).

i. SEMBAR FORMATION

The Sembar Formation comprises layers of silty shale (black) and interbedded siltstone (black), along with weathered, rusty, argillaceous limestone (nodular) layers or concretions. The glauconitic component in the formation exhibits a greenish tint due to weathering. The depositional environment of the Sembar Formation is deep marine, and it is known to harbor a variety of fauna such as Ammonites, Belemnites, and Forums (Fatmi 1977).

It is widely believed that the hydrocarbons found in the Badin Platform fields and the extensive gas accumulations in the Suleiman Province originate from the Sembar Formation. It is speculated that the Sembar Formation was deposit in a broad shelf with a gentle slope away from the Indian Shield towards the west.

The Sembar Formation acts as an excellent source rock, exhibiting evidence of oil and gas shows. These indications align with other signs and suggest the presence of reducing conditions. The sandstones within the formation also hold potential as reservoirs. Moreover, there appears to be a favorable likelihood of oil migration from the Sembar Formation into the underlying Jurassic Formation along fault lines.

ii. GORU FORMATION

The Goru Formation consists of sandstone, interbedded limestone, shale, and siltstone.The limestone exhibits colors ranging from light to medium grey or olive grey and is characterized by fine-grained texture and thin bedding. Both the lower and upper parts of the formation are predominantly composed of limestone. Near the type locality, the Goru Formation reaches a thickness of 536 meters. Fauna such as Belemnites and Forams can be found within the formation. The Goru Formation is in contact with the Parh Formation above and the Sembar Formation below, with both contacts being conformable (Fatmi 1977). The Goru Formation consists of two distinct members are:

1- Lower Goru

2- Upper Goru

a) UPPER GORU MEMBER

The Upper Goru Member is assigned to the Upper Cretaceous period. The upper boundary of the lower Goru is characterized by a transition from sandstone and claystone to marl and limestone. The marl is hard, subblocky, and exhibits a light to medium gray color, with silty properties. In some areas, the upper portion of the formation shows argillaceous or marly characteristics in the sand. The siltstone within the Upper Goru Member is subblocky, calcareous, and light gray in color. Shale, which is dark gray in color, is moderately hard, subfissile, and grades into calcareous claystone (Kadri 1995).

Given that shale is the predominant lithology in the Upper Goru Member, it lacks the potential to serve as a reservoir (Quadri and Shuaib 1986).

b) LOWER GORU MEMBER

The Lower Goru Member's upper boundary is marked by a change in lithology from marl to claystone.Shale within this member exhibits a dark grey color and has a firm to moderately hard texture. It is subplaty, subfissile, moderately calcareous, and occasionally contains carbonaceous material. The shale is also silty and can locally grade into siltstone.

Siltstone in the Lower Goru Member is characterized by a light grey color and a friable, calcareous nature. It often contains glauconitic content and may locally grade into very fine sandstone. The sandstone in this member displays a medium grey color and exhibits friability. It has a very fine grain size and is well cemented with calcareous cementation. The sandstone also possesses an argillaceous matrix, common lithic pieces, and traces of mica.

The Lower Goru Sand, found within the Lower Goru Member, holds significant petroleum potential due to its hydrocarbon content. It is responsible for containing the majority of hydrocarbon reserves in the Sindh Monocline, making it highly promising for petroleum exploration and production. (Kadri 1995).

The Lower Goru Formation is composed of three main components: upper sands, Basal and middle.These sand layers in underlain by lower shales and overlain by upper shales. The upper sands are particularly significant as they contain the primary zones for hydrocarbon production. Within the upper sands, there are four distinct subzones, namely A, B, C, and D, which are delineated by the presence of Turk, Badin, and Jhol shales, respectively (Quadri and Shuaib 1986).

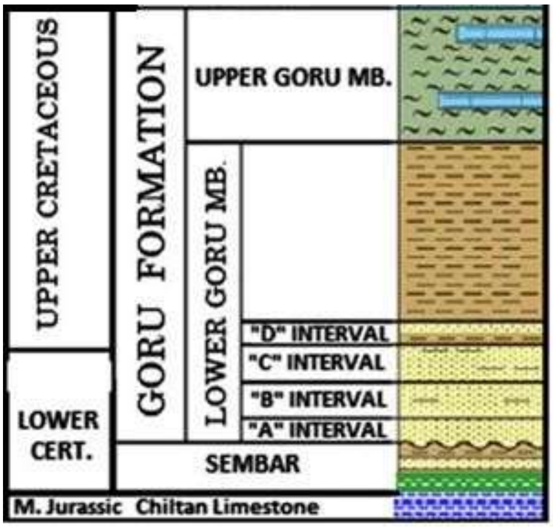

Figure 2. 3 The stratigraphic column showing the subdivisions of Lower Goru Formation into Sand intervals A, B, C and D (Ahmad et al. 2004).

2.3.2 TERTIARY

2.3.2.1 PALEOCENE

Except for a few sandstones and high-energy limestone, the Paleocene environment is predominantly characterized by low energy and anoxic conditions. This environment favors the accumulation and preservation of hydrocarbons. The Paleocene marks the transition from the Cretaceous to the Tertiary, coinciding with the northward movement of the Indian Plate, which accelerated during the Paleocene period (16 cm/year), (Powell 1988).

Paleocene (Danian) strata can be found in the Central Sulaiman Basin and a portion of the Kirthar Basin, while the rest of Pakistan also contains Paleocene deposits with some local unconformities.

Throughout the Tertiary period in the Lower Indus Basin, the collision between the Indian and Eurasian Plates resulted in the emergence of various local areas. Transgression and regression phases are evident in this basin. While some areas did not receive Danian sediments, the Central Sulaiman Basin (Tangi Sar/Drug Lahar, Rakhi Nallah sections) and the Kirthar Basin (Bara Nallah section) witnessed the incursion of the Khadro Formation during the early Paleocene (Danian). The Paleocene sediments were extensively distributed by the presence of the Jacobabad High. After the initial transgression, a rapid and short-lived regression occurred before the major Paleocene

(Ranikot) sea transgressed, eventually submerging the entire Indus Basin.

In the Central and Lower Indus Basin, the Paleocene rocks are mainly of marine origin, with limestone being the predominant lithology. Additionally, varying amounts of marls, shale, sandstone, and conglomerates are present. However, Kadri (1995) observed that certain regions in the Sulaiman Basin exhibit a more prominent shale lithology, indicating a significant rise in sea level in those specific areas.

i. RANIKOT FORMATION

Vredenburg established a distinction within Blanford's renamed "Ranikot Group" by dividing it into Lower Ranikot and Upper Ranikot, comprising sandstone and limestone respectively. This subdivision is still recognized and supported by the current report. Consequently, the group of Ranikot is characterized by three formations, listed in ascending stratigraphic order are;

- Formation of Khadro i.e., bed of Cardita beaumonti
- Formation of Bara i.e., Lower Ranikot Sandstone
- Formation of Lakhra i.e., Upper Ranikot Limestone

The lowest part of the group consists of the Khadro Formation, characterized by yellow-brown/olive-colored sandstone and shale, with interbedded limestone. This is followed by the Bara Formation, which is composed of variegated sandstone and fluvial shale. The upper portion is comprised of the Lakhra Formation, consisting of weathering brown/grey to brown sandstone and estuarine shale. The Kirthar Province exhibits the most extensive exposures of these formations.

The Pab Sandstone and the Moro Formation are believed to irregularly overlie the group, while the covering of the group by various units appears to be uniform but varies in different locations. The deposition of the group occurred during the Paleocene period, as evidenced by the fossils found in the Formation Khadro and Formation Lakhra. These groups share similarities with the Formation Dungan and Formation Rakhshani in western and lower Pakistan.

2.3.2.2 EOCENE

ii. KIRTHAR FORMATION

The Ghazij Formation is positioned below the Middle Eocene Kirthar Formation in a conformable transition. The upper contact of the Kirthar Formation is disconformable with the Nari Formation, which dates back to the Oligocene period. The primary components of the Kirthar Formation include fossiliferous limestone, along with minor amounts of marl and shale. In certain areas, there are thick-bedded limestone formations that exhibit a massive and nodular structure. The deposition environment of the Kirthar Formation was a shallow sea. This formation consists of four distinct members: Habib Rahi, Drazinda, Pirkoh, and Sirki (Kadri 1995).

a. DRAZINDA MEMBER

The Drazinda Formation, found in Rakhi Nala and Zinda Pir, has a thickness of over 380 meters and 300 meters, respectively. It predominantly consists of secondary marl and limestone layers, along with dark brown/greenish gray shale.

b. PIRKOH MEMBER

The Pirkoh Formation consists of consistently bedded, fine-grained limestone that is typically thin and light grey to chalky white, with variations in color from buff to brown. The limestone layers often contain clayey components. The formation is succeeded by the Drazinda Formation and the Domanda Formation, with temporary contacts between them. The middle and upper sections of the Pirkoh Formation are particularly abundant in fossils, including foraminifera, gastropods, bivalves, and echinoids. In terms of age, the Pirkoh Formation is classified as Middle Eocene.

c. SIRKI MEMBER

The Sirki member is classified as Eocene in age. The upper contact of the Sirki component is characterized as a shift from claystone and limestone lithology. The claystone is characterized by its soft to hard texture, dark bluish-green color, and mild calcareous nature. On the other hand, the limestone is relatively hard and exhibits a light yellowish-grey hue with traces of foramina (Kadri 1995).

d. HABIB RAHI MEMBER

The Habib Rahi Formation is composed of firm, buff, and greyish-brown limestone that weathers to a white color. It is primarily argillaceous, with thin bedding and fine-grained texture, occasionally transitioning into marl in certain areas. Cherty beds within the formation are limited to the upper layers, where Assilina-rich marl is prevalent. At Shinki Post in North Waziristan, the Habib Rahi Formation exhibits a significant upper portion, a thick bedded middle, and a massive bottom portion. In the Kohat District at Sirki Paila, the formation consists of five meters of higher marl, ranging in color from brown to plum, and also contains pure limestone.

The Habib Rahi Formation is present in North and South Waziristan, towards the eastern part of the Sulaiman Range. The Domanda Formation and Baska Formation are both uniformly overlaid and underlain over the Habib Rahi Formation in the Sulaiman Province. The Baska Formation, a transitional formation in Waziristan, is where the Habib Rahi Formation makes its lower contact. The formation dates from the Early to Middle Eocene.

iii. GHAZIJ FORMATION

The Ghazij Formation, dating back to the Early Eocene period, is primarily composed of shale, with subordinate claystone, sandstone, conglomerates, alabaster, and coal seams. With a thickness of 590 meters, it represents a deep marine depositional environment. The contacts of the Ghazij Formation are conformable, with its lower boundary conformably connected to the Laki Formation and Dungan Formation, and its upper boundary conformably connected to the Kirthar Formation. Within a three-meter interval, the Ghazij Formation contains fossilized remains of foraminifera, bivalves, gastropods, echinoids, and algae. Notably, the Laki Formation and Ghazij Formation exhibit a related nature, as established by Vredenburg in 1908.

iv. LAKI FORMATION

The Laki Formation, belonging to the Early Eocene period, is predominantly characterized by creamy grey limestone, accompanied by minor amounts of calcareous shale, marl, some sandstone, and laterite. It represents a shallow marine depositional environment, with a thickness of around 100 meters. The formation comprises two members: the upper Meting limestone and shale, and the lower Sohnari, which contains the Laki laterite at its base (Shah 1977). Fossils such as forums, bivalves, gastropods, echinoids, and algae have been discovered within the formation. The lower boundary of the Formation Laki is inconformable with the Formation Ranikot, while the upper boundary conforms to the Ghazij Formation, as determined by Vredenburg in 1908.

v. SUI MAIN LMESTONE

The Sui Main Limestone, found in this region, is dated to the Eocene period. The upper boundary of the Sui Main Limestone is identified by a transition from limestone to shale lithology. The limestone turn a pale gray-yellow identification color and may occasionally contain chert and remnants of crystalline calcite. The shale is subplaty, subfissile, firm to moderately hard, and somewhat calcareous. The marl, on the other hand, ranges in color from light to greenish gray and exhibits signs of foraminifera within subblocky portions. The argillaceous limestone in this area is hard, subblocky, chalky to microcrystalline, light grey to whitish in color, and contains traces of foraminifera (Kadri 1995).

2.4 BOREHOLE STRATIGRAPHY

Table 1.1 Borehole stratigraphy of Qadirpur-11 & Qadirpur-03.

	QadirPur-03			QadirPur-11		
Age	Formation	DEPTH	Thickness	Formation	DEPTH	Thickness
RECENT	ALLUVIUM	0	96	ALLUVIUM	0	82
MIOCENE-PLIESTOCENE-PLIOCENE	SIWALIK	96	404	SIWALIK	82	368
OLIGOCENE	NARI	500	204	NARI	450	255
EOCENE	DARAZINDA	704	69	DARAZINDA	705	58
	PIR KOH	773	107	PIR KOH	763	109
	SIRKI	880	50	SIRKI	872	53
	HABIB RAHI	930	84	HABIB RAHI	925	77
	GHAZIJ	1014	206	GHAZIJ	1002	205
	SUI UPPER LIMESTONE	1220	60	SUI UPPER LIMESTONE	1207	59
	SHALE UNIT	1280	53	SHALE UNIT	1266	48
	SUI MAIN LIMESTONE	1333	125	SUI MAIN LIMESTONE	1314	92

2.5 Petroleum System

The components of petroleum system are the active source rock, migration routes, reservoir rock, trapping mechanism and seal rock. For hydrocarbon accumulation and preservation, proper relative timing for the formation of these elements is necessary for the processes of generation, migration and accumulation. With respect to these parameters, the study area consists of source rock of Sember Formation, reservoir rock of Lower Goru Formation, Seal rock of Shales of Lower Goru Formation and trapping system which are Stratigraphic and Structural traps both. Lower Goru Formation is known for proven potential reservoir, and early Sember Formation is acting as proven source rock. Type 3-kerogen source rock information is evaluated after the oil and gas production from the studied area. The regional seal is provided by the shale unit of Lower and Upper Goru Formation for the Cretaceous Lower Goru reservoir.

2.5.1 SOURCE ROCK

The central Indus basin exhibits promising source rock potential within the Cenozoic sequences. Specifically, the Eocene Ghazij shale is known to contain oil shale, making it an excellent source of hydrocarbons in the Sibi area. The shales within the Ghazij Formation are considered to be the oil-prone facies, indicating their potential as good to rich source rocks for gas. In the Laki-Ghazij formations, characterized by gas and condensate, there are potentially favorable source rocks for gas. In offshore areas, Eocene sediments in the deeper parts of the trough may have undergone sufficient maturation to generate both gas and condensate. The Lower Eocene Ghazij shale and Sui main shale rocks are recognized as potential source rocks for hydrocarbon generation, (Qadri 1995).

2.5.2 RESERVOIR ROCK

The lower portion of the Habib Rahi limestone member and the Pirkoh limestone are identified as shallow shelf deposits, demonstrating remarkable reservoir qualities in the Mari field. The Habib Rahi limestone also serves as secondary reservoirs in the Qadirpur and Kandhkot fields, exhibiting 18% porosity at Kandhkot. Similar porosity characteristics are observed in the Pirkoh and Loti areas. These carbonate horizons are interbedded within thick shale and marly sequences. It is worth noting that the thickness of individual beds does not exceed 1 meter in any instance.

2.5.3 SEALS

Within the Central Indus basin, the reservoir rocks are overlain by extensive layers of younger and thick shale and claystone, which serve as effective seal rocks in the region. Specifically, the Sui main shale acts as a seal rock for the Sui main limestone, while the Ghazij shale acts as a seal rock for the Sui upper limestone. Additionally, the Siriki shale functions as a seal rock for the Habib Rahi limestone and sandstone (Qadri 1995).

2.6 PETROLEUM PLAY

2.6.1 SOURCE ROCK

The potential source rocks encompass various shale formations, including the Sembar Shales, shales within the Mughalkot Formation, shales within the Ranikot Formation, and Sirki Shales. These formations are considered to have the capacity to generate hydrocarbons in the region.

2.6.2 RESERVOIR ROCK

In the Qadirpur region, the main reservoirs for hydrocarbon production are the Sui Main and Sui Upper Limestone formations. These formations are recognized as the primary producers in the area. Additionally, the Habib Rahi Limestone is considered a secondary reservoir with the potential to contribute to hydrocarbon production in the region.

2.6.3 CAP ROCK

The Sui Main and Sui Upper Limestone formations are the predominant reservoirs for hydrocarbon production in the Qadirpur region. These formations are widely acknowledged as the primary sources of hydrocarbon extraction in the area. Furthermore, the Habib Rahi Limestone is identified as a secondary reservoir that holds significant potential for contributing to hydrocarbon production in the region.

CHAPTER 3

PETROPHYSICAL INTERPRETATION

Petrophysical investigations play a vital role in identifying the fluid occupying rock pores and assessing the qualities of reservoir rocks. Petrophysical analysis is of great importance in the petroleum industry as it serves as a crucial tool for both hydrocarbon exploration and reserve evaluation in any reservoir zone. The primary petrophysical characteristics examined in shale include volume determination, density porosity, neutron porosity, average porosity, effective porosity, and calculation of water and hydrocarbon saturation. Additionally, petrophysical analysis enables professionals to make rough estimations of the lithology of encountered rock units.

3.1 QUALITY CHECK OF LOGS

The calliper log has been consistently calibrated for most depth intervals, and the logging data obtained from the Qadirpur-03 and Qadirpur-11 wells exhibit good quality, particularly indicated by low gamma ray (GR) values. The logs themselves are of satisfactory quality and can be reliably interpreted.

3.2 LOG TRENDS

Track-01 displays lithology logs, specifically Gamma Ray and Spontaneous Potential logs, in addition to the caliper log and bit size information. (Figures 3.1 & 3.2) Conversely, the GR log exhibited fluctuations with both elevated and diminished peaks, characterized by undulations and gradual increases.

Track-02 illustrates resistivity logs, namely MSFL, LLS, and LLD. The resistivity logs are displayed using a logarithmic scale, revealing variations throughout the entire depth of the borehole. Furthermore, certain depths exhibit minimal differentiation between the MSFL and LLD logs. However, when considering potential hydrocarbon zones independently from other logs, a distinct distinction between MSFL and LLD becomes evident, with the following sequence: -

$$MSFL < LLS < LLD$$

Track-03 presents porosity logs, including Neutron, Density, and Sonic logs. The neutron and density logs were utilized to calculate the average porosity, while the sonic log was employed to determine the sonic porosity.

To verify the accuracy of the bulk density (RHOB), an additional track, specifically track 7, was introduced. In this track, a curve for density correction (DRHO) has been incorporated. The purpose of this curve is to assess the reliability of the RHOB data. It is considered reliable if the DRHO value is below 0.15.

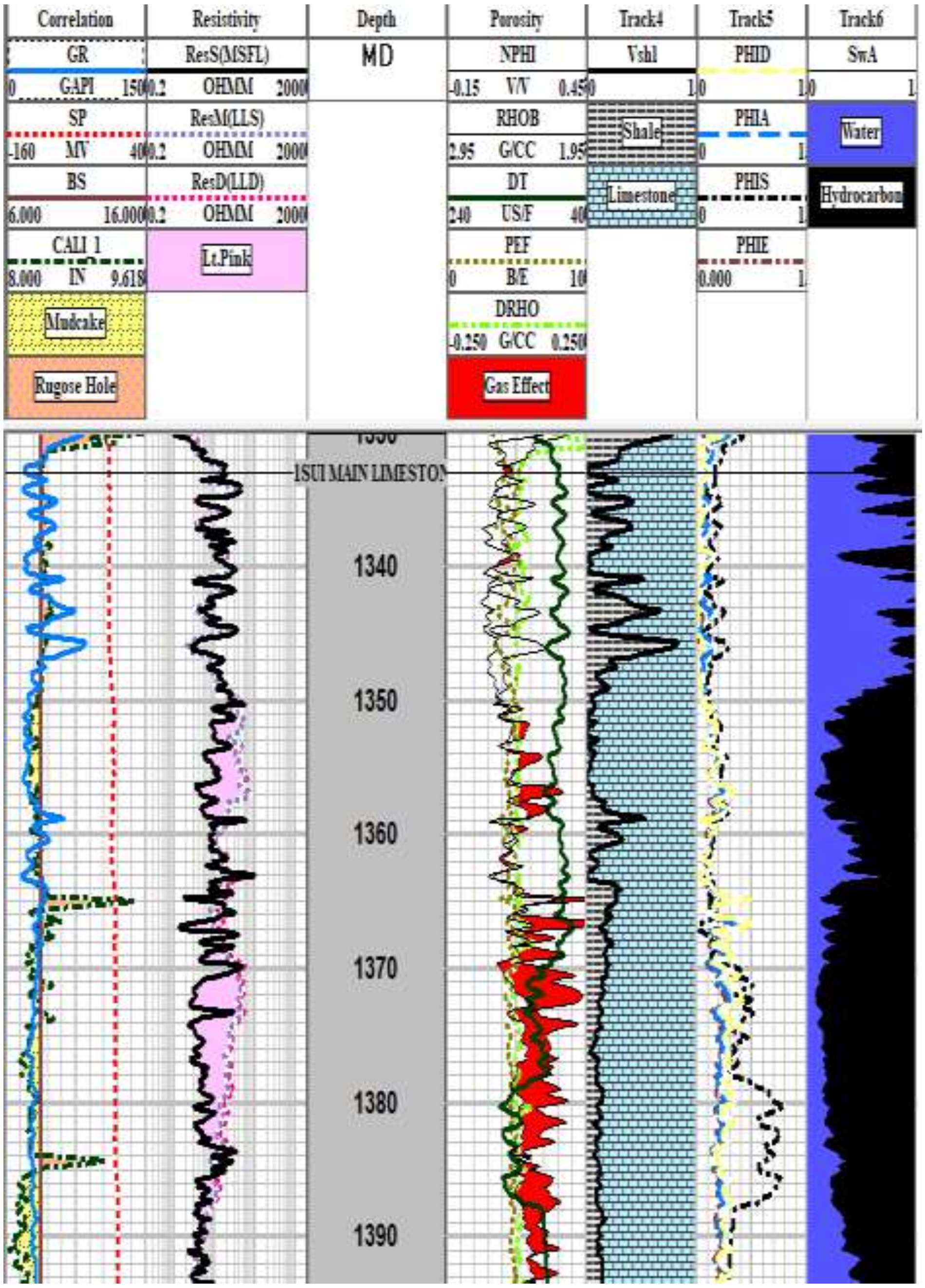

Figure 3. 1 Interpreted raw log curves of Qadirpur-03.

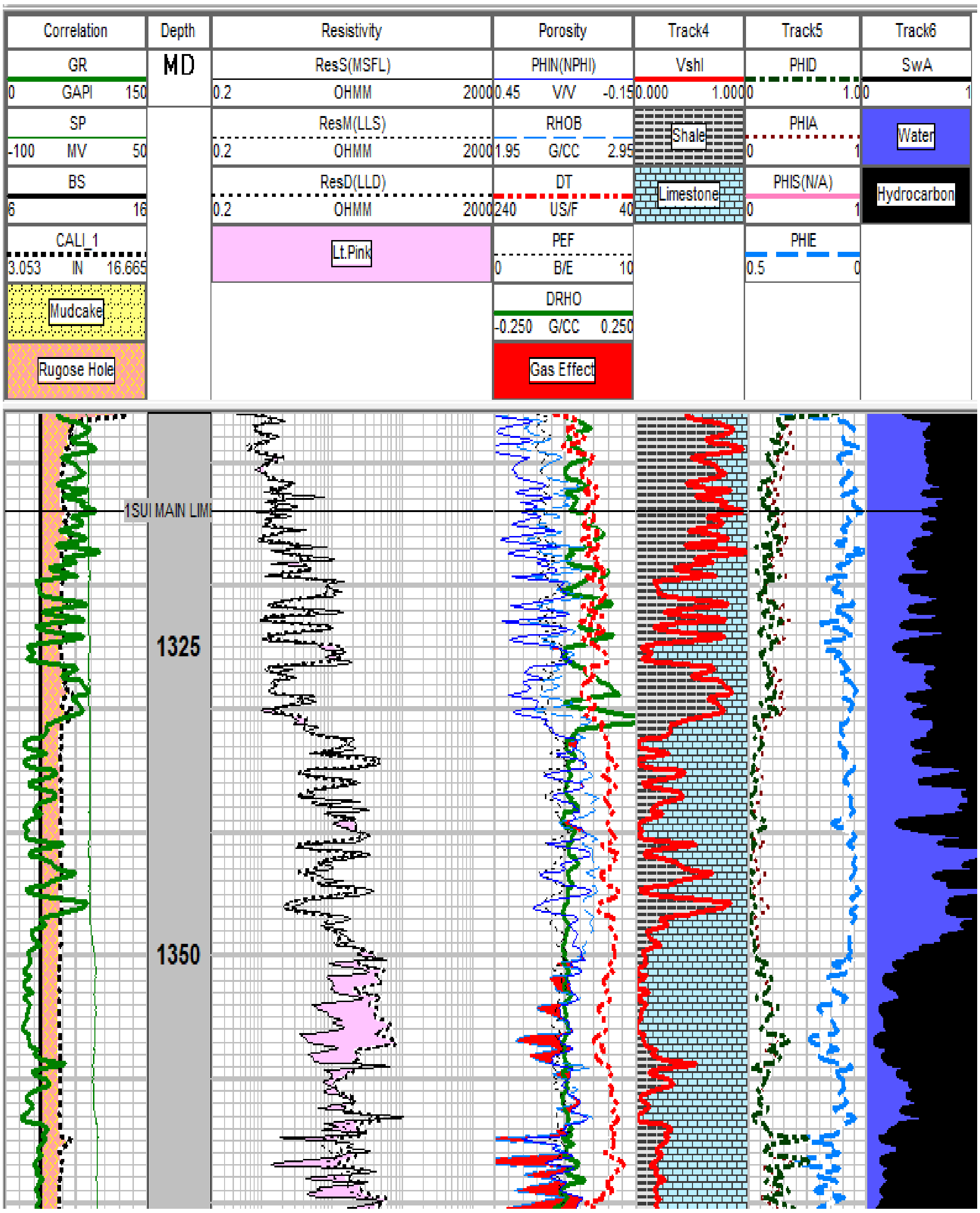

Figure 3. 2 Interpreted raw log curves of Qadirpur-11.

3.3 MARKING ZONE OF INTREST

The initial and pivotal stage of petrophysical analysis is identifying the zone of interest. This step holds paramount importance since accurate identification is crucial for meaningful calculations. Therefore, marking the zone meticulously using well log data is essential. Reservoir zones can be identified by closely examining the following parameters in the log data:

2 The zone of interest, as indicated by the caliper log, primarily falls within the

region of stable borehole geometry. The caliper log demonstrates a consistently maintained or slightly contracted response, suggesting that the reservoir zone is situated within a consolidated and permeable formation.

3 A lower gamma ray value signifies a lithological zone characterized by clean composition. Reservoir zones typically occur within such clean lithological zones, as they facilitate fluid movement and circulation.

4 An additional method to determine whether the drilling mud used is water-based is by examining the low values of shallow resistivity logs and high values of deep resistivity logs. This is due to the fact that hydrocarbons exhibit high resistance values, whereas saline water demonstrates low resistivity values.

5 The formation of a crossover between the neutron and density log curves, resulting from low values on both logs, serves as an indicator of the reservoir zone. A low neutron log value signifies a higher concentration of hydrogen atoms within the formation, indicating good porosity. Furthermore, a low-density log value provides further evidence of the reservoir zone as it suggests a highly porous formation.

QADIRPUR-03

Table 2.1 Zones of interest of Sui-Main Limestone of Qadirpur-03 well.

Potentional zone	Zone of reservoir	Start Depth	End Depth	Thickness
Zone 1	Sui Main-Limestone	1350	1358	8m
Zone 2	Sui Main-Limestone	1365	1390	25m

QADIRPUR-11

Table 2.2 Zones of interest of Sui-Main Limestone of Qadirpur-11 well.

Potentional zone	Zone of reservoir	Start Depth	End Depth	Thickness
Zone 1	Sui Main-Limestone	!348	1358	10m
Zone 2	Sui Main-Limestone	1365	1390	25m

Among these zones of interest, our target zones will be the ones with maximum thickness i.e., Zone 1, 2 in Qadirpur-3 well and Zone 1, 2 in Qadirpur-11 well. However, lateral extent of the zones also plays an important role in quantity of hydrocarbon production. In some cases, we also target less thick zones that have good quality hydrocarbons.

3.4 VOLUME OF SHALE (Vsh)

Gamma ray logs play a crucial role in identifying shale beds and quantifying the shale volume within a formation. These logs are particularly useful in detecting radioactivity, which is influenced by the presence of clay minerals in the formation. During the quantitative assessment of shale volume, the absence of radioactive elements in clean rocks is taken into consideration.

The calculation of shale volume involves the utilization of both the Gamma Ray (GR) log and Spontaneous Potential (SP) log. We rely on the gamma ray log to estimate the volume of shale, which is subsequently employed in determining various other reservoir properties. The formula commonly used to calculate the volume of shale is as follows:

IGR=Gamma Ray log - Gamma Ray min/Gamma Ray max – Gamma Ray min

Here,

I Gamma ray = volume of shale

Gamma Ray log = reading of Gamma Ray formation

Gamma Ray min = minimum Gamma Ray reading (sandstone)

Gamma Ray max = maximum Gamma Ray reading (shale)

3.5 CALCULATION OF POROSITY

Porosity refers to the fraction of a rock's volume occupied by pore spaces. Two types of porosity exist: primary porosity, which forms during the deposition of the rock, and secondary porosity, which develops during or after the alteration process.

$$ØD=(\rho ma-\rho b)/(\rho ma-\rho f)$$

(Poupon, A. and Leveaux, J. 1971)

3.5.1 NEUTRON POROSITY

The porosity log, commonly known as the neutron log, is influenced by the concentration of hydrogen ions within the formation. It provides a measurement of the liquid-filled porosity in a clean deposit, where the pore spaces are filled with water or oil.

The reactions observed in the neutron log vary depending on the type of detector used and the lithology of the formation, such as sandstone, dolomite, or carbonate. Typically, neutron porosity values range from 20 to 40%. The neutron log also helps determine the hydrogen index (HI) within the formation.

Given that hydrogen is present in all three fluids—water, oil, and gas—the neutron curve provides insights into the presence and concentration of these fluids. This allows us to gain an understanding of the fluid's composition through the neutron log.

3.5.2 DENSITY POROSITY

The formation density log is a porosity log that utilizes electron density measurements to determine the bulk density of the formation. This log is extensively utilized by professionals to analyze intricate lithology, hydrocarbon density, gas-bearing zones, evaporates, and minerals within the formation.

In the presence of high-density porosity values ranging from 60% to 80%, washouts are identified. These washouts indicate areas where the density porosity is significantly higher than the surrounding formation.

The formula commonly employed for the calculation of density porosity is as follows:

Here,

$$\Phi d = \rho ma - \rho b/\rho ma - \rho f$$

ρma = Density of the rock matrix

ρb = Bulk density of the formation

ρf = Density of the fluid occupying the pores

Φd = Density porosity of the rock

3.5.3 AVERAGE POROSITY

Average porosity, also referred to as total porosity, offers insights into the overall pore volume of a formation. It is determined by taking the average of density porosity and neutron porosity values. The calculation of average porosity can be expressed using the following formula:

$$\Phi_T = \sqrt{\frac{\Phi_D{}^2 + \Phi_N{}^2}{2}}$$

ΦA = Average porosity

Φ^2N = square of NPHI

Φ^2D = square of DPHI

3.5.4 EFFECTIVE POROSITY

Effective porosity is a term used to describe the interconnected voids within a rock, representing the total number of voids that contribute to fluid flow. The presence of connected pores determines the effectiveness of porosity, and it exhibits an inverse relationship with shale content. The calculation of effective porosity involves establishing a relationship between the average porosity of the shale volume and the effective porosity. The formula for determining effective porosity is as follows:

$\Phi E = \Phi A * (1 - Vsh)$

ΦE = Effective Porosity

ΦA = Average Porosity

Vsh = Volume of Shale

3.6 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. Three different methods are employed to calculate Rw, which include:

- Quick look method i.e., by directly using the equation.
- Pickett plot method i.e., on standard graphs.
- SP method, delivering the most reliable and accurate results.

We used Pickett plots to calculate Rw for Qadirpur-03 and Qadirpur-11(Fig 3.3 & 3.4).

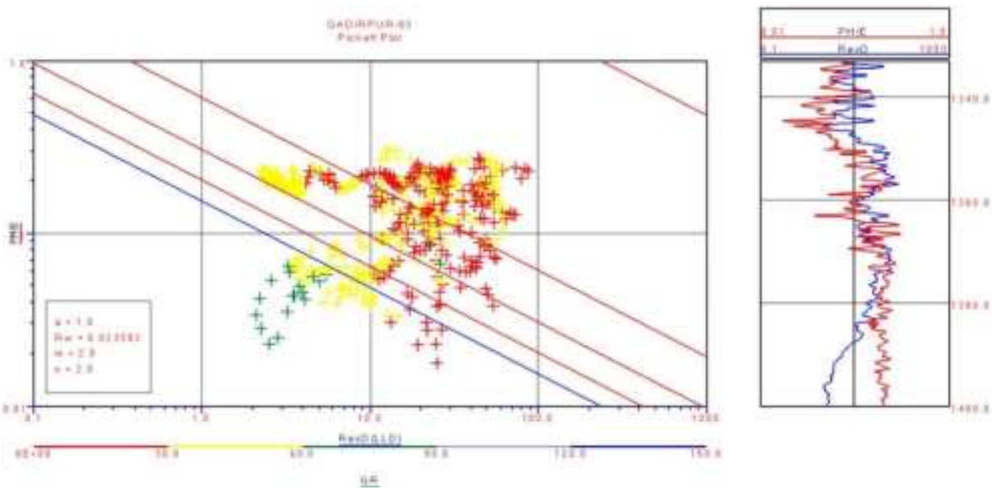

Figure 3. 3 Pickett plot of Qadirpur-03 of Sui Main Limestone.

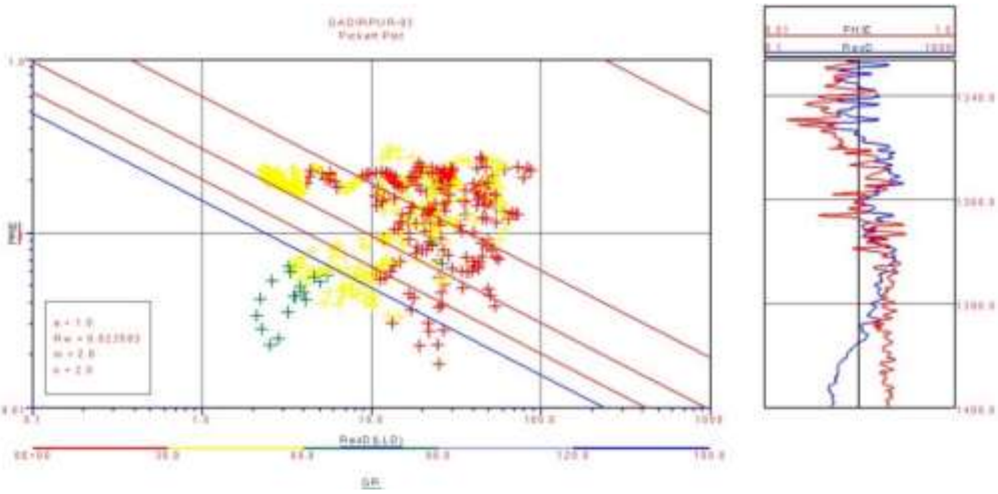

Figure 3. 4 Pickett plot of Qadirpur-11 of Sui Main Limestone.

3.7 SATURATION OF WATER

Water saturation represents the proportion of pore space occupied by water within a rock. It is denoted by Sw and provides insights into the presence of hydrocarbons. Sw values below zero indicate an excessive saturation of hydrocarbons. Conversely, if a formation shows 100% water saturation, it signifies the absence of hydrocarbons, rendering the zone commercially unviable.

To calculate water saturation in lithology that is not clean, the Indonesian equation is employed. This equation enables the determination of water saturation in such lithologies, and its formula is as follows:

Here,

$$Sw = \left\{ \sqrt{\frac{1}{Rt}} \Big/ \left(\frac{Vsh^{(1-0.5Vsh)}}{\sqrt{Rsh}} \right) + \sqrt{\frac{\Phi e^{m}}{\alpha . Rw}} \right\}^{(2/n)}$$

Sw = Water saturation of the uninvaded zone

Rw = Resistivity of the formation water

Φe = Effective porosity at water zone

Rt = True resistivity of formation

Rsh = Shale resistivity from LLD

Vsh = Volume of shale

m = Cementation exponent (usually around 2)

n = Saturation exponent (usually around 2)

α = Empirical constant (usually around 1)

3.8 SATURATION OF HYDROCARBON

Calculating the saturation of water is essential for determining a saturation for hydrocarbons. Water saturation and hydrocarbon saturation exhibit an inverse relationship. Consequently, a zone with low hydrocarbon saturation will have a high-water saturation. The calculation of saturation water can be performed by the formula:

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

Sh = Hydrocarbon of saturation

Sw = Saturation water of the uninvaded zone

3.9 RESULTS

After analyzing the log trends in the Qadirpur-03 and Qadirpur-11 wells, the following results were obtained: porosities, shale of volume, volume of clean, water of saturation, and hydrocarbon of saturation. The log curves were specifically available for the sui main limestone, which was studied in both wells.

3.9.1 RESULTS OF QADIRPUR-03

As mentioned earlier, the reservoir zones within the sui main limestone in Qadirpur-03 have been identified (Fig 3.5).

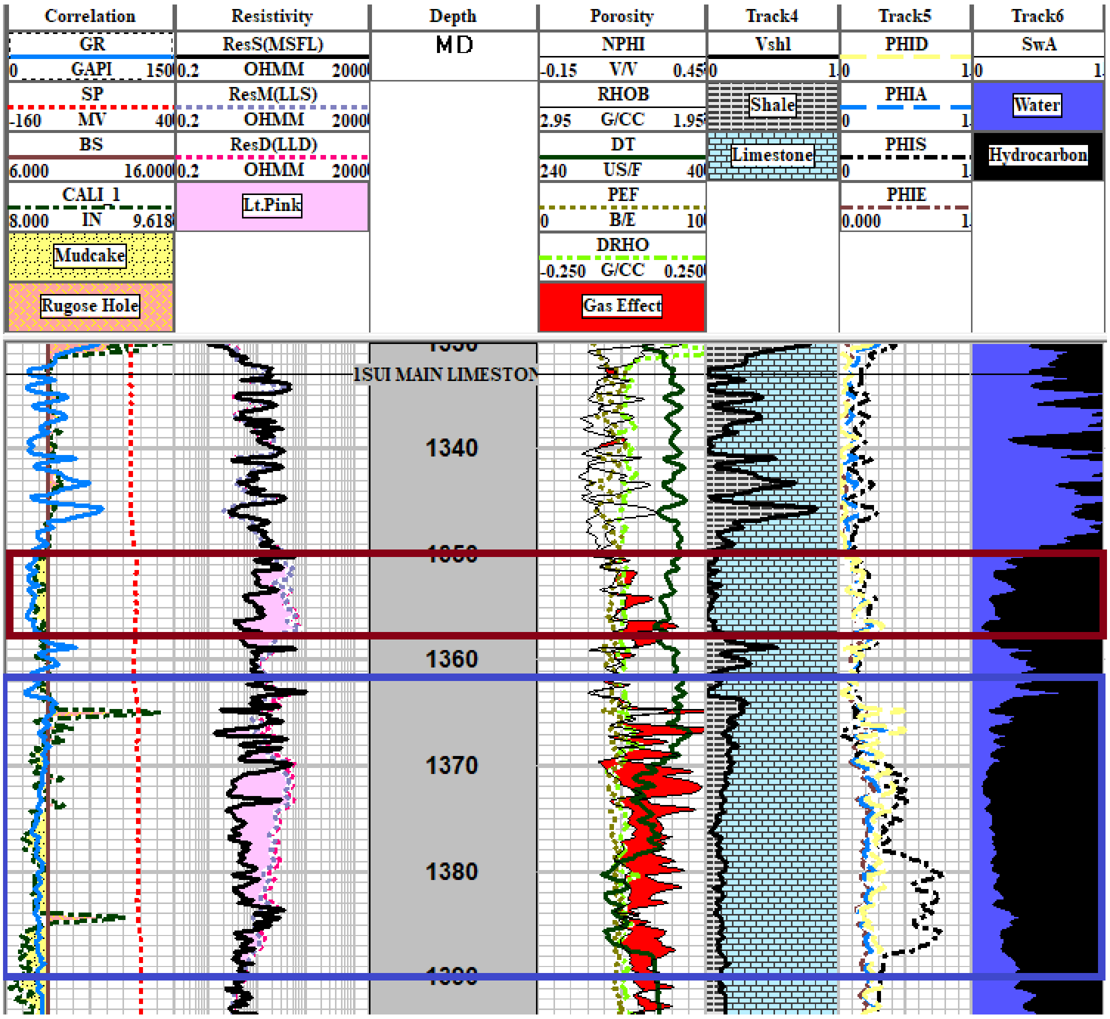

Figure 3. 5 zone 1 and 2 within Sui-Main Limestone of Qadirpur-03.

ZONE 1

Table 2. 3 Petrophysical results (%) of Zone 1 within Sui-Main Limestone of Qadirpur-03 well.

Depth (m)	PHIA (%)	PHIE (%)	PHIS%	Vsh(%)	Sw(%)	Sh(%)
1350	8.0	7.4	11.7	7.9	37.4	62.6
1352	15.5	15.4	23.4	2.6	17.1	82.9
1354	19.3	17.6	25.0	8.8	17.2	82.8
1356	15.1	14.2	20.8	5.5	19.2	80.8
1358	23.0	19.8	29.8	14.2	17.2	82.8
Average	**16.18**	**148.8**	**20.49**	**33.4**	**21.62**	**78.38**

ZONE 2

Table 2. 4 Petrophysical results (%) of Zone 2 within Sui-Main Limestone of Qadirpur-03 well.

Depth (m)	PHIA (%)	PHIE%	PHIS%	Vsh(%)	Sw(%)	Sh(%)
1365	37.4	26.9	13.5	28.2	15.7	84.3
1370	17.4	14	40.1	19.7	15.2	84.8
1375	22.3	20	43.3	10.2	16.5	83.5
1380	26.6	23.1	73.2	13.0	17.3	82.7
1390	18.6	16.5	59.3	11.7	31.3	68.7
Average	**24.46**	**20.1**	**45.88**	**16.56**	**19**	**80.8**

3.9.2 RESULTS OF QADIRPUR-011

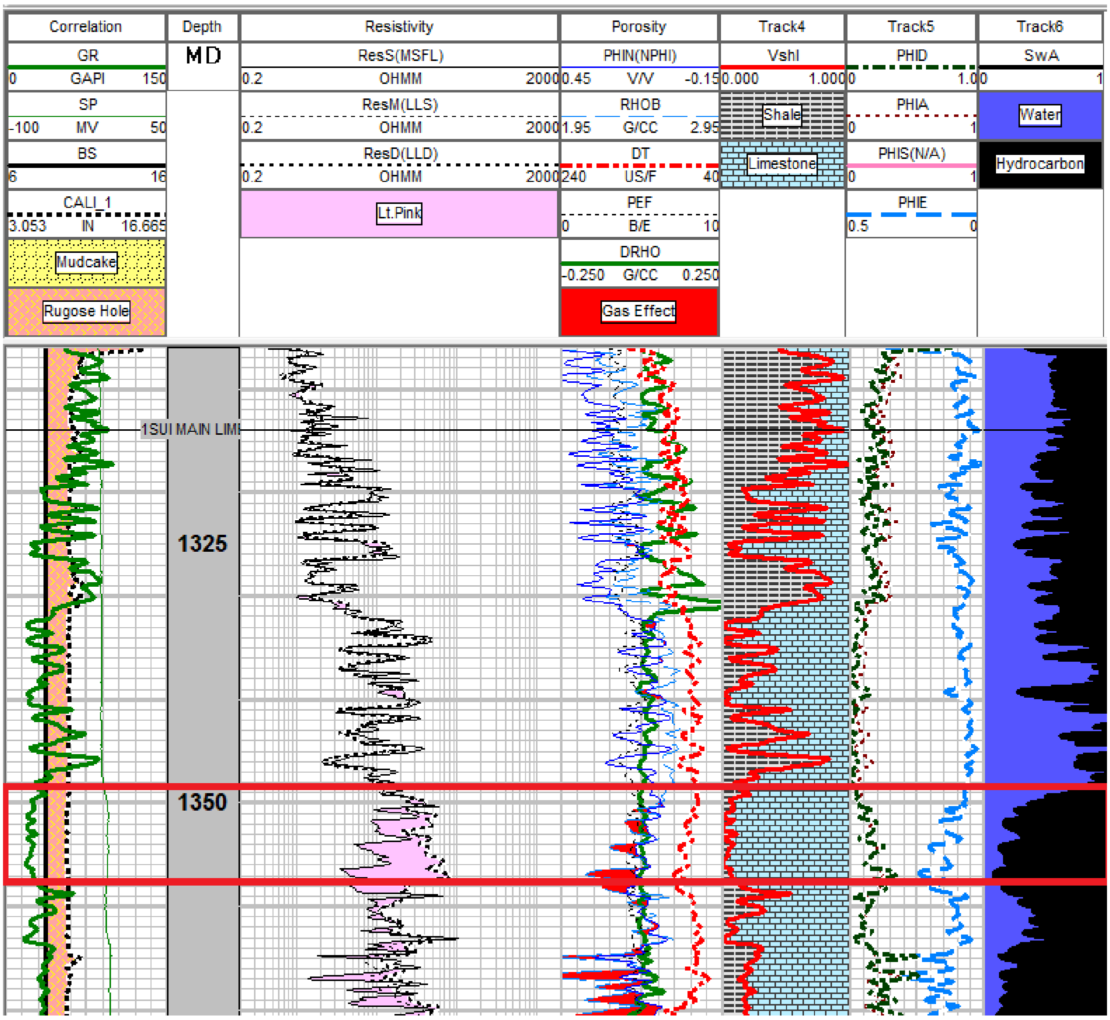

Figure 3. 6 Zone 1 within Sui-Main Limestone of Qadirpur-011

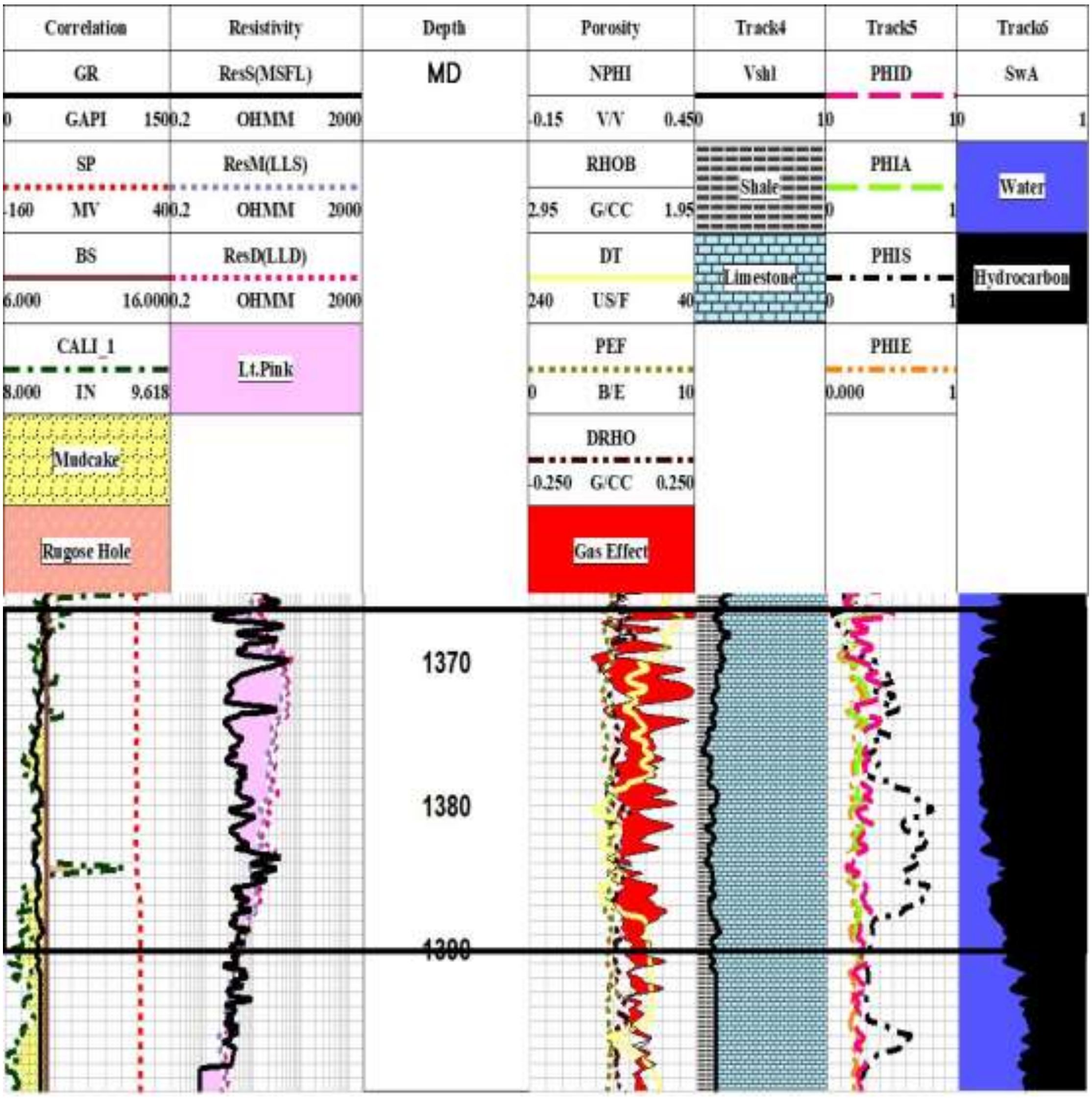

Figure 3. 7 Zone 2 within Sui-Main Limestone of Qadirpur-011.

ZONE 1

Table *2*. 5 Petrophysical results (%) of Zone 1 within Sui-Main Limestone of Qadirpur-11**.**

Depth (m)	PHIA (%)	PHIE%	PHIS%	Vsh(%)	Sw (%)	Sh(%)
1348	60	50	13.1	9.9	94.2	5.8
1350	80	7.4	11.4	7.9	35.3	64.7
1352	16.3	15.9	23.4	2.6	16.3	83.7
1354	19.3	17.6	25	8.8	16.2	83.8
1356	11.6	11.5	20.8	3	22	7.8
1358	23	19.8	29.8	14.2	16.2	83.8
Average	**84.2**	**77.2**	**20.58**	**64.1**	**33.36**	**66.50**

ZONE 2

Table 2. 6 Petrophysical results (%) of Zone 2 within Sui-Main Limestone of Qadirpur-11 well.

Depth (m)	PHIA (%)	PHIE%	PHIS%	Vsh(%)	Sw(%)	Sh(%)
1365	37.4	26.9	13.5	28.2	14.8	85.2
1370	17.4	14.0	40.1	19.7	14.3	85.7
1375	22.2	20.2	43.3	8.8	15.1	84.9
1380	26.6	23.1	73.2	13	16.3	83.7
1385	17.7	15.5	58.1	12.3	31.2	68.8
1390	24.1	20.7	32.5	14.1	32.9	67.1
Average	**24.23**	**20.06**	**43.5**	**16.01**	**17.58**	**79.23**

CONCLUSION

Sui Main Limestone acts as a hydrocarbon bearing reservoir in both Qadirpur-03 and Qadirpur-11 wells. In, Qadirpur-03 two specific reservoir zones have been identified & Qadirpur-011 well has also two marked reservoir zones. Among these zones, zone 2 of both wells has the highest potential for hydrocarbon.

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