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Formation Evaluation of Lower Goru Sands of Khipro Block, Lower Indus Basin, Pakistan

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Abstract: Formation evaluation is widely used in exploration and production in order to minimize the risk, uncertainty, and understanding of the detailed characteristics of potential reservoir rocks. This study is aimed to evaluate the Petrophysical characteristics of upper and lower basal sands of the Cretaceous lower Goru Formation in Niamat-01 and Siraj-01 wells and to focus on hydrocarbon exploration potential. These wells have been drilled in the Khipro block, lower Indus basin, which is the least explored for the reservoir quality evaluation. Present study characterized the lower Goru sands of the Khipro block. It is interpreted that the thickness of upper and lower Basal sands are 13m and 10m, respectively in Naimat Basal 01, whereas 9m and 17m, respectively, are reported in SirajSouth-01. The average effective porosity is 11% in upper Basal sands while 26% is interpreted for lower Basal sand in Naimat Basal-01. An average porosity of 11% is found for upper Basal sands in Siraj South-01 and 11% for lower Basal sand. Water saturation (Sw) calculated for upper and lower Basal sands are 22% and 19%, respectively. The hydrocarbon saturation (Sh) of 78% is interpreted for upper Basal sands and 81% hydrocarbon saturation reported for lower Basal sands in Naimat basal-01. However, 36% and 45% Sw have been recognized for upper and lower Basal sands, respectively. Whereas hydrocarbon saturations of 64% and 55% are reported for the upper and lower basal sands, respectively, in SirajSouth-01. Crossover effects in front of targeted formations confirmed the presence of hydrocarbons in the zone of interest. Lower sands of the lower Goru Formation in the Khipro block are favorable for hydrocarbon production and have potential for future hydrocarbon exploration activities.

Keywords: Formation evaluatrion, Goru Formation, well log data, lower Indus basin, Paksitan.

Introduction

The Khipro block is located between latitudes 25° 40′ - 26° 00′ and longitudes 68° 20′ - 69° 14′ (Fig. 1). It is surrounded by the Sukkur rift to the northeast, the Arabian Sea to the south, the Karachi depression is the westward extension, and it is bounded by the Kirthar depression to the northwest. The basin history of the Khipro block relates to Jurassic rifting and the breakup of Gondwanaland (Khan and Bibi, 2016). The Thar platform is a westward-sloping monocline, and its basement topography controls the geology of the Khipro block (Ali et al, 2016). Throughout the Tertiary, the Indian and Eurasian plates collided, causing tilting of the whole area (Powell, 1979). Jurassic rocks indicate rifting deposition. The rifting has produced typical faulting, horst, and graben structures. Early/middle Cretaceous sands (Lower Goru Formation) are the most significant sedimentary rocks in this region (Naeem et al., 2016). In the middle and lower Indus basin, the Bottom Goru Formation serves as a producing reservoir. Its top portion is mostly made up of shale, siltstone, and thin layers of shaly sand, while its lower portion is made up of reservoir-quality sandstones with interlayers of shale and limestone (Afzal, 2009). Lower Goru Formation's reservoir-quality sandstone has been further segmented into sand intervals A, B, C, and D (Kadri, 1995). In Sawan Miano, Kadanwari, and nearby gas fields, the sand intervals serve as potential gas reservoirs (Krois, et al., 1998). These sands are sealed by Goru marl and shale (Kazmi and Abbasi 2008). Naimat basal field is situated in the Khipro block of Sanghar district, 22km from Karachi. The field is an inclined fault with gas accumulations in the lower sands (Basal sands) of the lower Goru Formation. The lower Goru sands are key producing zone. Two wells were drilled on the structure and found gas and oil prospects (Fig. 2, 3). In 2004, one well produced 23.4 MMCF per day, the highest rate ever recorded in the field. Both wells were drilled in the Sindh Monocline for lower sands (upper and lower basal sands) of the lower Goru Formation. The Orient Petroleum Limited discovered the Khipro block by drilling the first exploratory well, namely Naimat Basal-01, in 2002. The Khipro block has a greater opportunity for future hydrocarbon exploration activities due to the least explored area yet, the lower Indus basin. The current study was intended to evaluate the reservoir quality and got better results with reference to hydrocarbon production capacity of the lower sands of the Cretaceous lower Goru Formation.

The Geology and Tectonics of the Khipro Block

The emergence of a major rift zone in the lower Indus basin as a result of tectonic activity during the Cretaceous marked the beginning of the evolution of the lower Indus basin (Kazmi and Jan, 1997). The study region is gently dipping towards the south, also known as the Sindh monocline. The Sindh monocline is a prominent feature of Pakistan's lower Indus basin. It is bounded to the west by the Indian shield (Nagar Parker granite) and to the east by the Karachi trough, where it combines with a tectonically distinct entity (Abbsi 2015). These include Khaskheli, Golarchi, Bhatti, Turk, TandoAlam, Bobby, and Pasakhi.

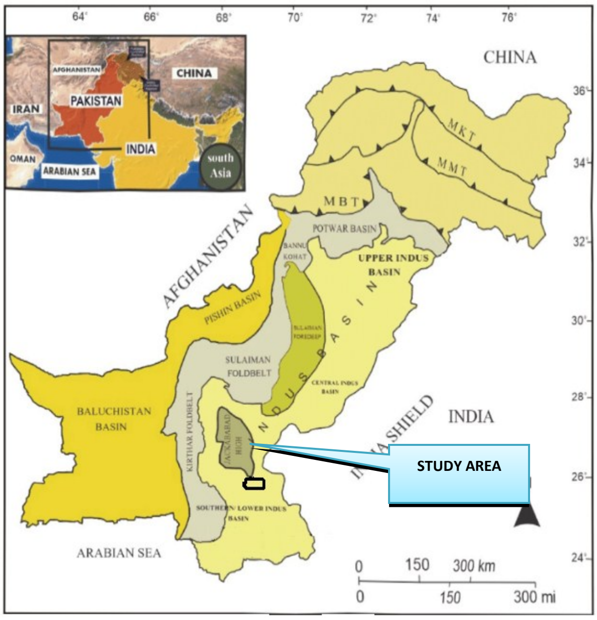

Fig. 1 Location map of the study area Khipro block, lower Indus basin.

The Khashkheli oil field was the first hydrocarbon exploration activity in the faulted structural traps (Solangi et al., 2016). Initially, stratigraphic reservoirs were overlooked due to abundance of structural traps and the increased risk of collapse associated with stratigraphic reservoirs. Since rock physics studies enabled geophysicists to locate source rocks, attention has turned to locating stratigraphic reservoirs. Characterizing

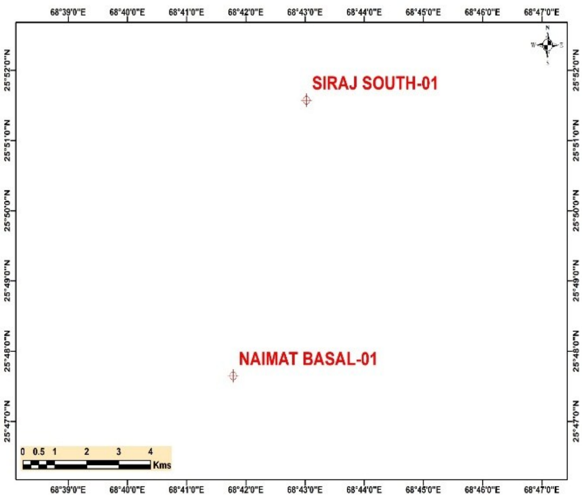

Fig. 2 Location map of the two studied wells.

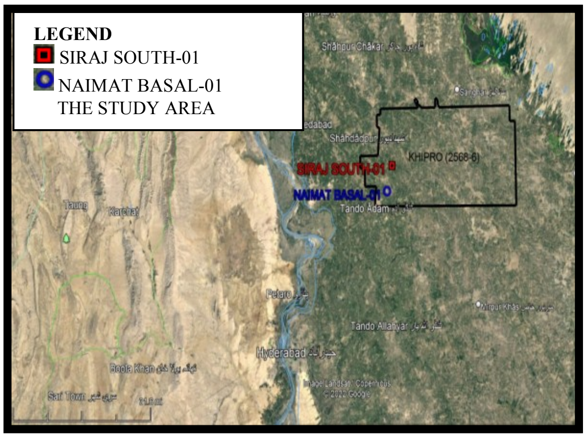

Fig. 3 Google earth image showing the location of the study area in Khipro field with respect to the Shahdadpur village unconventional reservoirs in terms of TOC, clay type, fracture orientation, etc. Sedimentary rock in study area is Cretaceous sands (lower Goru Formation) (Fig. 4), which operate as an excellent reservoir for hydrocarbons(Avseth and Odegaard 2004),(Ahmad, Fink, and Sturrock 2004). Sand packages are sealed by shale and marl (Upper Goru) (Kazmi 2008). The research area's stratigraphy is shown as follows.

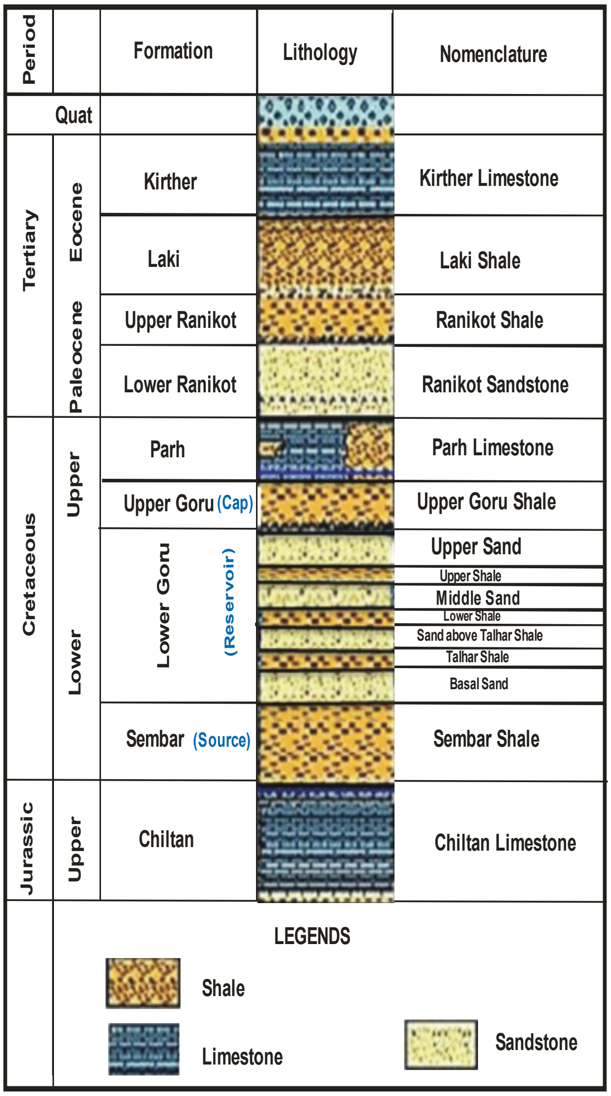

Fig. 4 Generalized stratigraphic column of the study area (Zaigham and Mallick 2000)

Zone of Interest

The zone of interest was determined based on clean formation, the lithology with the minimum shale volume, and the cross-over effect between the neutron porosity and density (Rhob) logs, which highlighted the hydrocarbon payable zone. It is recognized that two zones could be productive, including NPZ-1 (from 3398 to 3411 meters), known as upper Basal sands, and NPZ-2 (3487 to 3497 meters), called lower Basal sands. The Siraj South-01, both zones were interpreted in the lower sands known as lower Basal sands, with ranges of 3117 to 3125 and 3154 to 3171 meters, respectively (Fig. 5, 6).

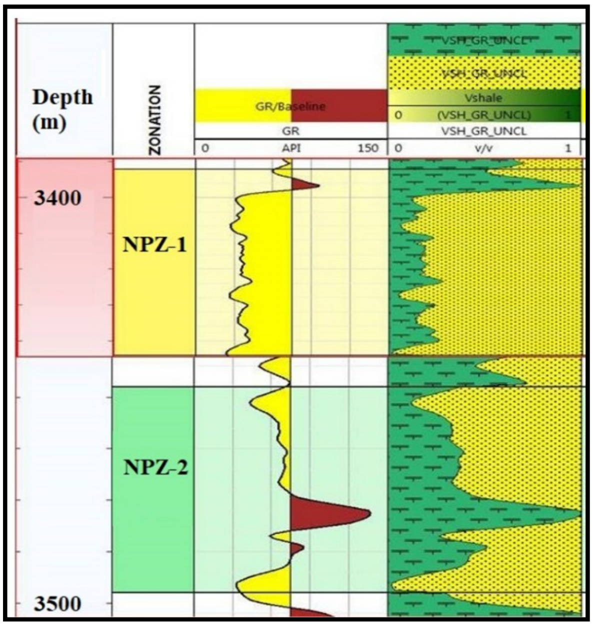

Fig. 5: Volume of shale in the interested zones of lower Goru Formation in Naimat Basal 01.

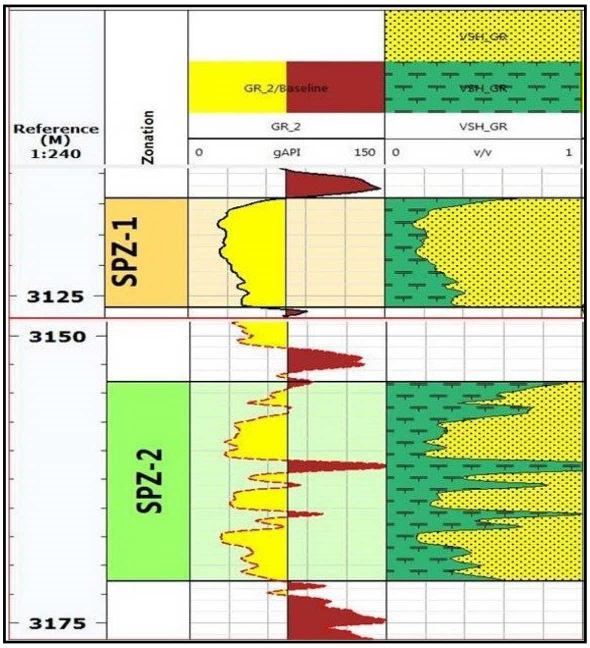

Fig. 6: Volume of shale in the interested zones of Lower Goru Formation in Siraj South-01 well.

Petrophysical Characteristics of Selected Zones

Petrophysical properties like total porosity, effective porosity, the volume of shale, and water saturation of the lower and upper Basal sands of the Cretaceous lower Goru Formation, have been determined in current research work by using Tech-log software.

Thickness of Reservoirs

The thickness of payable sand packages (upper and lower Basal sands) in both well namely Naimat Basal-01 and Siraj South-01 with the help of Gamma-ray logs. Thickness has been determined as upper and lower Basal sands are 13m and 10m, respectively in Naimat Basal 01, whereas, 9m and 17m are reported in Siraj South-01.

Volume of Shale (Vsh)

Following equation was utilized for the calculation of the volume of shale in the interested zones of the Lower Goru Formation (Fig. 3, 4).

$$Vsh = \frac{GR - GRcs}{GRsh - GRcs}$$

Whereas GR represents Gamma-ray log values, GRcs denotes clean sand (minimum gamma-ray value) and GRsh is for high shale concentrations (maximum gamma-ray value). Table 1 and 2 represented the volume of Shale that are interpreted by current study.

Density Porosity

Density derived porosity was computed by equation is given below;

$\Phi density = \rho m - \rho b / \rho m - \rho f$

Whereas, Φ represent the density porosity, ρm reveal density of matrix, ρb is bulk density of formation, ρf recognized the density of the fluid. Density of sandstone was taken 2.65g/cm3 and density of fluid like mud was 1.0g/cm3.

Sonic Porosity

Following equation has been used to estimate the sonic porosity;

$\Phi\text{-}s = \Delta tlog - \Delta tm / \Delta tf - \Delta tm$

Where Φ-s denotes the sonic porosity, Δt-log denotes the Formation's delta time, Δtm denotes the matrix transient time, and Δtf denotes fluid time. The time of the matrix, sandstone, was about 55 seconds per foot, fluid (fresh mud) was 189 seconds per foot.

Average Porosity

Average of the porosities of density and neutron is considered as the average porosity of the lower Goru

Formation. In this study the average porosity was calculated by using the following equation.

$$\Phi\text{-avg} = \Phi\text{-den} + \Phi\text{-neu} / 2$$

Whereas, Φ-avg represents the average porosity, Φ-den recognize the density porosity and Φ-neu reveal the neutron porosity of the formation

Net Reservoir Interval

The reservoir net interval has been determined by using Tech-log software through following equation;

$$\text{N-Res} = \Phi\text{-av} > \Phi\text{-Cut-off} \text{ while } \text{V-shale} < \text{V-sh Cutoff}$$

Whereas. N-Res is Reservoir net interval, Φ-Cut-off represents the Cut-off value that is applied on the effective porosity (Φ-effective) Vsh-Cutoff recognize the Cut-off value which is for V-shale (Tables 1,2).

Calculation of Water Saturation

Calculating the pay zone: The pay zone refers to the area of the reservoir where hydrocarbons can be found. This zone is characterized by the water saturation (Sw) and is validated within porous zones (Table 1,2).

Sw is determined by using the Archie's Equation, which is described further below.

$$Sw = [a / \Phi\text{-}m * R\text{-}w / R\text{-}t]$$

Where, a for the tortuosity factor which is equal to 1

Rw represent the resistivity of water, that is (0.015) ohm-m

Rt is the deep resistivity log (HLLD log)

m represents the cementation factor = 2

n was the factor of water saturation = 2

The porous and clean section of reservoir, the water saturation cut-off value used to define the pay zone equals 0.5. (50 percent). Finally, the zones that met the following criteria have been included as pay zone.

i. Φ-avg>Φ-Cutoff

ii. S-w<S-wCutoff

iii. V-sh<V-shCutoff

Hydrocarbon Saturation

For hydrocarbon saturation (Shc) calculation, the following equation is used as define by Shepherd, (2009).

$$SHC = (1 - Sw)$$

Whereas, Sw in fraction.

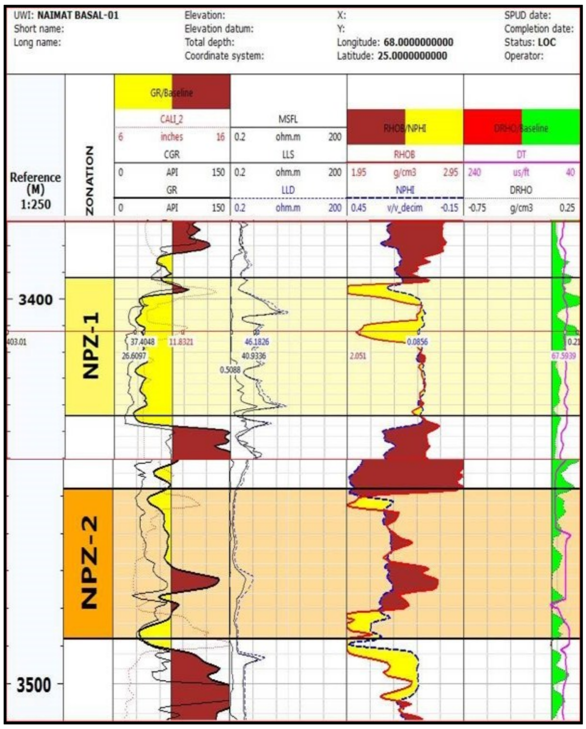

Fig. 7: Petrophysical properties of Naimat basal 01 well.

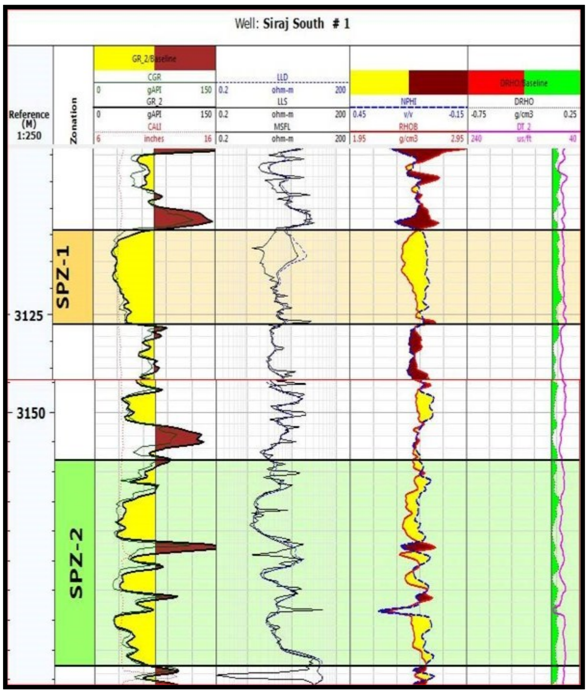

Fig. 8: Petrophysical properties of SirajSouth-01 well.

Cross over Effect

The interpretation of the lithology of targeted zones is derived from the integration of log responses and cross plots. Neutron and density logs have been used for evaluating the cross-over effect in order to confirm the reservoir pay zone lithology for both wells. The neutron density cross-over effect shows the dominant lithology of sand in the reservoir pay zones (Fig. 5, 6).

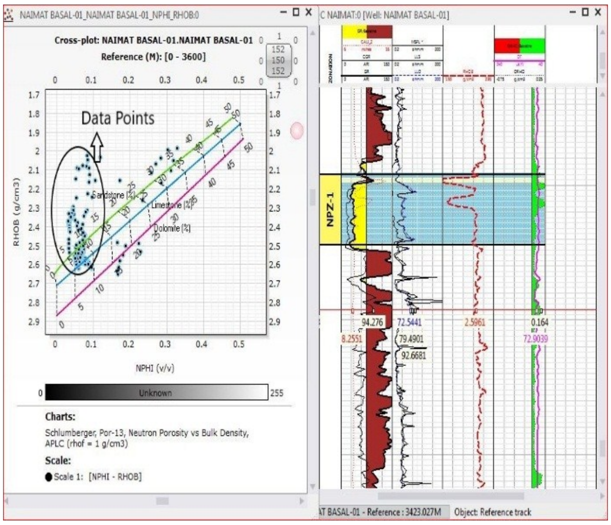

Fig. 9: Cross over effect in front of reservoir (producing) zone in Naimat Basal 01.

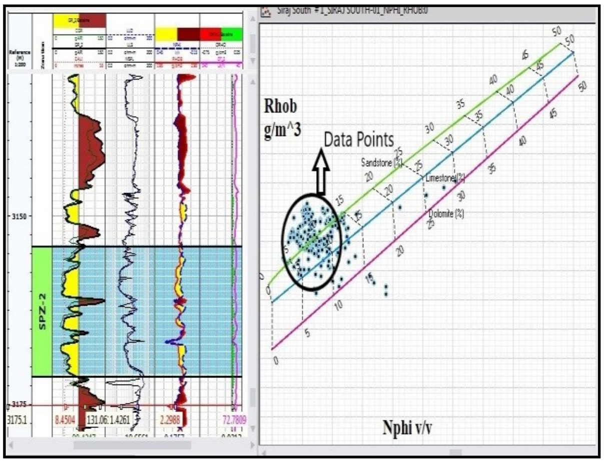

Fig. 10: Cross over effect in front of the payable zone of SirajSouth-01 well.

Hydrocarbon Profile

Hydrocarbon profile has been interpreted in lower sands of the lower Goru Formation in both wells (Fig. 7, 8). Resistivity logs including Msfl, LLs and LLd have been used for the recognition of hydrocarbon-bearing zones at the depth ranges from 3150 to 3175m. Such interpretation is also supported by the cross-over effect.

Results and Discussion

The results of petrophysics analysis showed that both reservoir zones had characteristics that are favorable for the extraction of hydrocarbons. These variables were calculated using rock Petrophysical equations to determine the volume of shale, porosity, and degree of saturation of the reservoirs for both Niamat-01 and Siraj-01 of Khipro block. Lower Goru Formation tops identified four sand packages, Upper sand package, Middle sand package, sand lying above Talhar shale, and Basal sand. Based on the results of petrophysical analysis, sand above Talhar shale, upper basal sands, and sand below Talhar shale (lower basal sands) show very good reservoir quality in terms of net reservoir thickness and net pay thickness. These two sand units in Naimat field contain significant accumulations of hydrocarbons. The delineated zones of interest in wells Naimat Basal-01 and Siraj south-01 have an average net sand thickness of between 8 and 13m, an average effective porosity in the range of 11–26%, and water saturation of between 19–45%, with a volume of shale ranging from 16 to 31%, which are favorable indicators for commercial hydrocarbon accumulation. The detailed study reveals that lower basal sands exhibit fair-to-good reservoir properties in comparison to upper basal sands. Further calibration of the log analysis parameters with core, test, and production data is necessary to verify the calculated values as the water saturation for sand below Talhar shale in Siraj South-01 is extremely high. Sand above Talhar shale having low porosity seems to be a tight sand reservoir in wells Naimat basal-01 and Siraj south-01.

Conclusion

The Lower and Upper Basal sands at the Khipro block in Pakistan's Lower Indus basin were evaluated using

Table 1: Summary of petrophysical analysis in Naimat Basal-01

S.No	Zone Name	Interval (m)	Gross thickness (m)	Net thickness (m)	Net Pay(m)	Vsh%	Φavg%	Sw%	Shc%
1	Upper Basal Sands	3398-3411	13	11.5	8.5	17	11	22	78
2	Lower Basal sands	3487-3497	10	9	8	31	26	19	81

Table 2: Summary of petrophysical analysis in Siraj South-01

S.No	Zone Name	Interval (m)	Gross thickness (m)	Net thickness (m)	Net Pay(m)	Vsh%	Φavg%	Sw%	Shc%
1	Upper Basal Sands	3117-3125	9	8	7.5	16	12	36	64
2	Lower Basal sands	3154-3171	17	13	12.5	24	11	45	55

porosity, shale volume, water saturation, gross and net reservoir thickness, and net reservoir pay zone analyses. Lower basal sands have good reservoir properties, with porosity ranging from 11 to 26%, shale volume ranging from 24 to 31%, water saturation ranging from 19% to 45%, and net pay thickness ranging from 8 to 12.5 meters. The Petrophysical analysis of the upper basal sands revealed reservoir parameters such as porosity ranging from 11% to 12%, shale volume ranges between 16% to 17%. The water saturation varies from 22% to 36%, and net pay thickness is from 7 to 8.5 meters. It is concluded that the upper and lower basal sands of the lower Goru Formation are productive. Further investigation based on core analysis and production data will enhance our understanding of the sand packages of the Lower Goru Formation.

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