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Reservoir Characterization of Sand Intervals of Lower Goru Formation Using Petrophysical Studies; A Case Study of Zaur-03 Well, Badin Block, Pakistan

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Abstract: Present study deals with petrophysical interpretation of Zaur-03 well for reservoir characterization of sand intervals of Lower Goru Formation in Badin Block, Southern Indus Basin, Pakistan. Early Cretaceous Lower Goru Formation is the distinct reservoir that is producing hydrocarbons for two decades. Complete suite of wireline logs including GR log, Caliper log, SP log, Resistivity logs (MSFL, LLS, LLD), Neutron log and Density log along with well tops and complete drilling parameters were analyzed in this study. The prime objective of this study was to mark zones of interest that could act as reservoir and to evaluate reservoir properties including shale volume (V_{sh}), porosity (ϕ), water saturation (S_w), hydrocarbon saturation (S_h) and net pay thickness. Based on Petrophysical evaluation three zones have been marked in Lower Goru Formation, A Sand (1890m to 1930m), B-sand (1935m to 2010) and C-sand (2015m to 2100m). The average calculated parameters for evaluation of reservoir properties of Zaur-03 well depicts an average porosity of 8.92% and effective porosity of 4.81%. Water Saturation is calculated as 28.54% and Hydrocarbons Saturation is 71.46%. Analysis shows that S_h in Zaur-03 well is high so the production of hydrocarbons is economically feasible.

Keywords: Lower Goru Formation, Badin block, petrophysics, reservoir evaluation, wireline logs.

Introduction

Petrophysical interpretation is the most sophisticated method employed for hydrocarbon exploration to evaluate the physical parameters of reservoir (Zinszner and Pellerin, 2007). Applications of well-logs are well developed in the petroleum industry for exploration, these logs are corrected with borehole environment to measure in situ properties. A precise petrophysical evaluation of a reservoir plays a key role in many aspects, especially in reservoir modeling, identification of pay zones, estimation of hydrocarbon volume and geophysical interpretations (Hosseini, 2018).

Present study deals with reservoir evaluation using well data of Zaur-03 well, Zaur Field, Badin-II block (Fig.1). The study area lies in Badin district, about 200 km east of Karachi in Sindh province. Geologically it is a part of Thar platform, a subdivision of southern Indus basin. Thar platform extends between N 24º06′ to N 25º02′ and E 68º11′ to E 68º47′. The dominant feature of the area is extensional tectonics that resulted in the creation of horst and graben geometries (Ehsan et al., 2018). To conduct this study a complete log suite of Zaur-03 well with corresponding data i.e. well tops and all drilling parameters were obtained. The Logs include GR log, Caliper log, SP log, Resistivity logs (MSFL, LLS, LLD), Neutron log, Density log and Sonic log.

Geological and Tectonic Framework of Area

Southern Indus basin lies between N 24° and N 28° and E 66° to E 68° E along southern eastern boundary of Pakistan (Qadri and Shoaib, 1986). It is bounded in the north by Jacobabad high, in the east by Indian shield rocks, in the west it merges into highly deformed Kirthar fold belt and the offshore Indus confines it from the south (Kadri, 1985) (Fig. 2). Southern Indus basin is subdivided into five units: Kirthar fold belt, Kirthar foredeep, Thar platform, Karachi trough and offshore Indus basin (Kadri, 1985, Khan et al., 2013). Thar platform is gently sloping monocline thinning towards Indian shield in the east (Fig. 2). Thar platform possesses thick Tertiary sedimentary deposits underlain by Mesozoic sequence and overlain by Quaternary Indus river floodplain sedimentary cover (Alam, 2002). Southern Indus basin exhibits extensional tectonics that prevail structures like tilted fault blocks, associated with normal faulting especially horst and graben (Wandrey et al., 2004). These faulted blocks possess great importance for exploration point of view. Such structures are present beneath the Paleocene unconformity within Cretaceous strata formed by northward drift of Indian plate during Late Cretaceous and Early Paleocene rift phase (Alam, 2002; Wandrey et al., 2004; Munir et al., 2014). Early Cretaceous Sembar shale has been identified as the primary source rock in the area (Sheikh and Giao, 2016). The overlying sands of Lower Goru Formation acts as principal reservoirs, intraformational shale beds of Lower Goru Formation act as effective seal for various sand intervals (Wandrey et al., 2004).

The Cretaceous strata, having a range of lithological heterogeneities, are widely distributed in the southern Indus basin, which is attributed to variations in

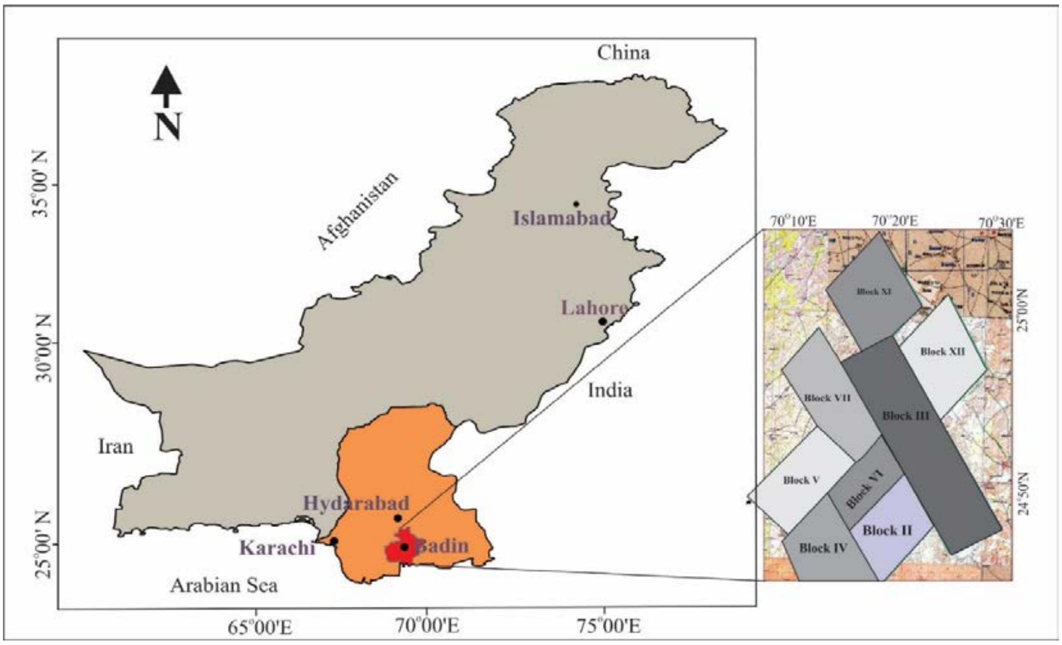

Fig.1 Map of Pakistan highlighting different sub-blocks in Badin block (Ahmed and Malick, 1998).

sediment supply and paleo-environmental conditions. The Goru Formation is composed of sandstone that is of significant importance in terms of reservoir characteristics (Tayyab et al., 2014). The upper part of formation has shale as dominant lithology, sandstone is rare in the upper part that is termed as Upper Goru. The name Lower Guru is used for the lower sandy part of the formation, which has sandstone lithology in abundance. It is further sub-divided in to various sand intervals (Ahmed et al., 2004; Tayyab et al., 2014). The generalized depositional environments of the formation appear to be relatively deep marine settings, however the Lower Guru may, represent barrier to deltaic environments (Kadri, 1995).

Table 1 Thickness of reservoir zone.

Zones of interest				
Formation	**Zone**	**Top (m)**	**Bottom (m)**	**Thickness (m)**
Lower Goru	A Sand	1890	1930	40
	B Sand	1935	2010	75
	C Sand	2015	2100	95

Materials and Methods

Methodology includes the import of Raw Log curves to GeoGraphix software, quality check of log curves, rescaling and correction of units and other necessary correction i.e. variable hole size effect, mud weight and acquisition conditions performed. After importing all log curves on GeoGraphix the lithological units were inferred that might be reservoir or non-reservoir. Zones where trend of GR log's curve is deflecting towards minimum, are marked as possibly reservoir zones. Cross over between Neutron and density, separation between curves of Lateral Log shallow (LLS), and Lateral Log deep (LLD) values indicates the presence of hydrocarbons in reservoir zone (LLD should be higher than LLS). Three reservoir intervals have been marked in Lower Goru Formation, these reservoir zones have been evaluated for their hydrocarbon's potential using different mathematical models and relations i.e. volume of shale determination using GR log and calculation of saturation of water using Archie's equation for quantitative interpretation of the well-logs.

Results and Discussion

Zone of interest

Clean zones were marked using GR log (high GR log values depicts dirty zone and low GR log values indicates clean zone). Cross over between Neutron and Density logs and separation between resistivity curves also confirmed the presence of hydrocarbons in zone. The marked reservoir zones and their thickness are mentioned in Table 1.

Volume of Shale (Vsh)

Volume of shale was calculated using GR log for evaluation of shale content in reservoir interval with the help of following equation (Schlumberger, 1972).

$$\mathbf{Vsh} = \frac{\mathbf{GR\ log - GR\ min}}{\mathbf{GRmax - GR\ min}}$$

Where:

- GRlog = Gamma ray log reading.
- GRmax = Maximum Gamma ray deflection in zone.

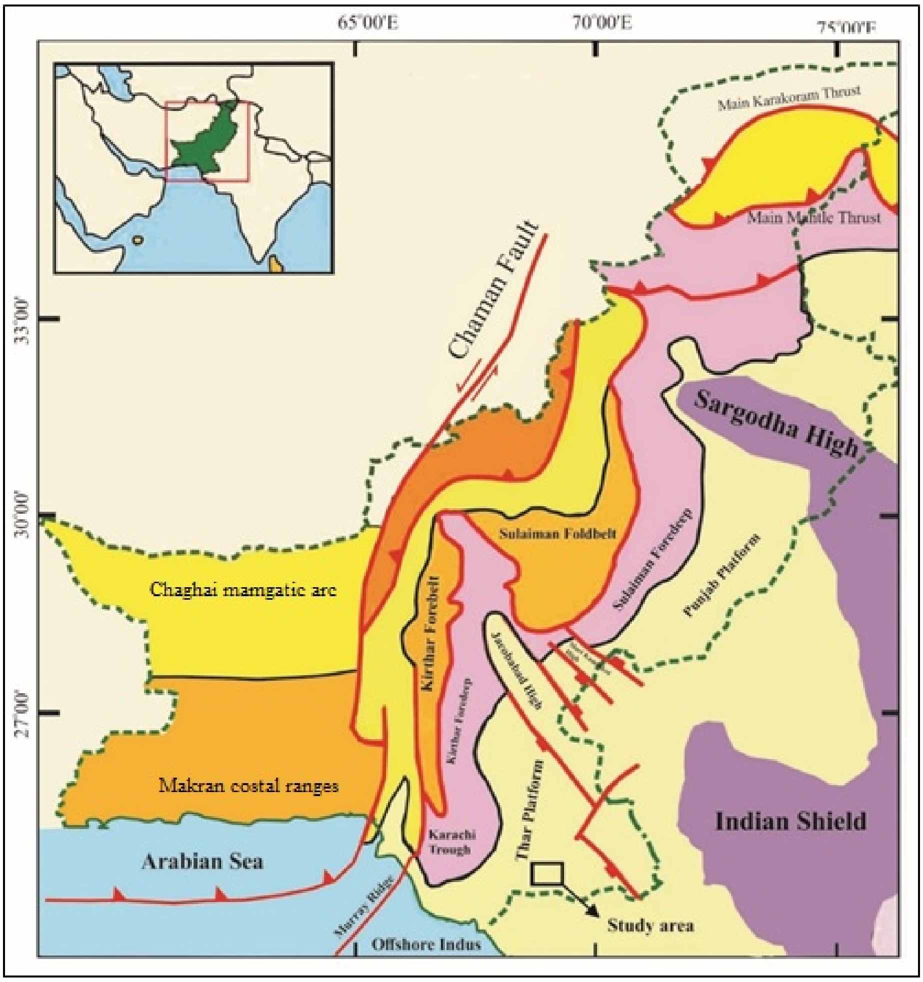

Fig. 2 Tectonic map showing subdivisions of southern Indus basin and study area (after Kazmi and Jan, 1997).

- GRmin = Minimum Gamma ray deflection in zone.

The average V_{sh} calculated for all sand intervals in Zaur-03 is 40%.

Table 2. Summation of estimated reservoir properties.

Zone (Lower Goru)	Depth (m)	V_{sh}%	$Ø_E$%	S_w%	S_h%	Net pay zone (m)
A-Sand	1890 – 1930	26	9	45	55	12
B-Sand	1935 - 2010	45	9	37	63	25
C-Sand	2015 – 2100	37	7	48	52	20

Porosity Calculations

Porosity (Ø) is the ratio of void spaces over total volume of rock. Neutron and Density Logs were used for porosity calculations (Moore, et al., 2011). Density log measures the electrons present in formation. Density log's values taken from density log's curve in reservoir zone at specific depth intervals and density porosity has been determined using following formula (Schlumberger, 1972).

$$\textbf{Density porosity} = ØD = \frac{\rho ma - \rho b}{\rho ma - \rho f}$$

Where:

- ρma = density of matrix (2.65 average value for sandstone lithologies)
- ρb = bulk density if formation (density log values from log curve)
- ρf = density of the fluid; mud filtrate (1.27, from log header)

Neutron porosity log measures hydrogen index in reservoir zone from pore spaces filled with water or hydrocarbons. Neutron log values measured directly from the log curve.

Neutron Porosity = Value of Neutron Log

Average porosity is calculated by combining neutron and density logs with following equation (Rider, 1996).

$$ØA = \frac{(ØD + ØN)}{2}$$

Where:

- ØN = Neutron porosity
- ØD = Density porosity

Effective porosity is defined as the sum of all the interconnected pore spaces. It is calculated from the

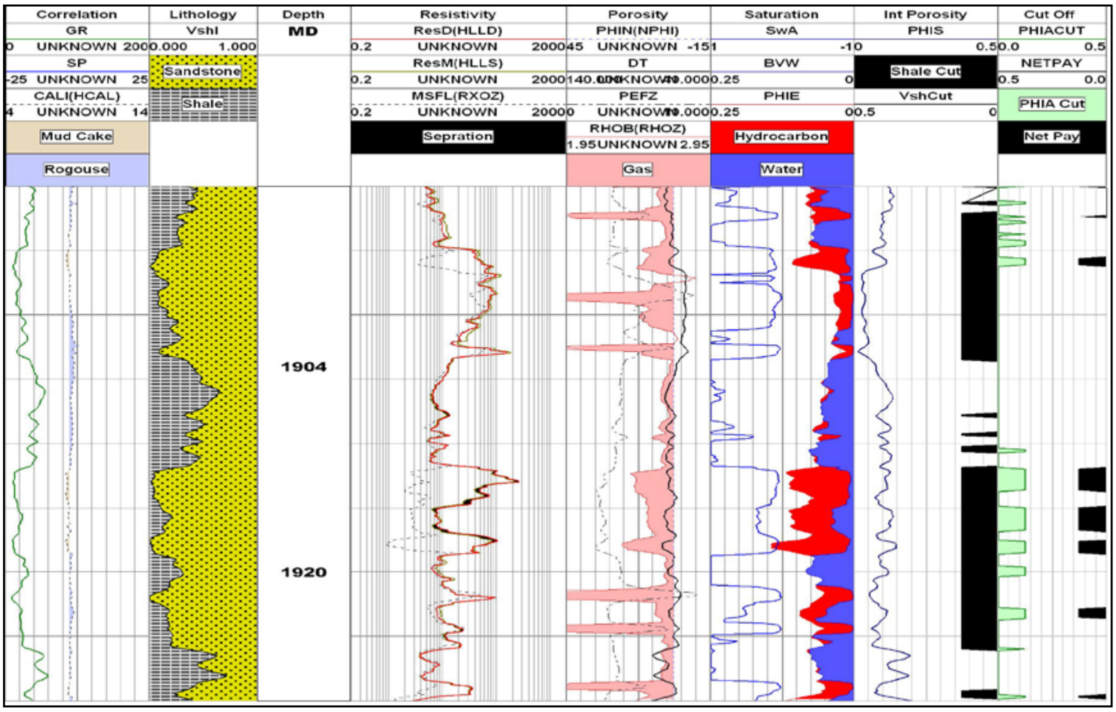

Fig. 3 Net Pay map for Lower Goru A-sand in Zaur-03 well.

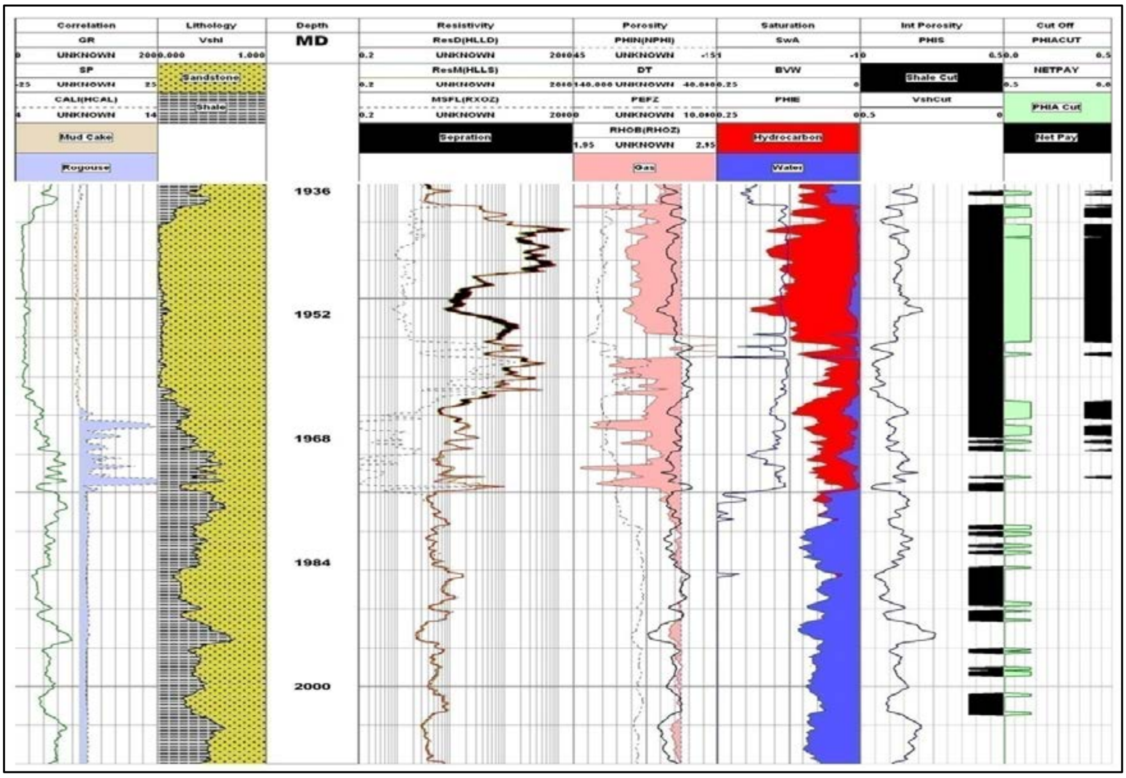

Fig. 4 Net Pay map of Lower Goru B-sand in Zaur-03 well.

total porosity corrected for shale fraction.

Effective porosity = $\emptyset E = \emptyset A * Vsand$

Where:

- $\emptyset_E$ = Effective porosity
- $\emptyset_{Avg}$ = Total porosity
- Volume of Sand= $1\text{-}V_{sh}$

Average porosity calculated for Zaur-03 is 8.92% and effective porosity is 4.81%.

Saturation of Water (S_w)

To calculate S_w for uninvaded zone water resistivity value at formation temperature was required. Apparent water resistivity was calculated from adjacent water bearing zone of the formation. This gave us a good match with picket plot. Archie's equation is applied from the calculation of S_w. (Rider, 2002).

$$\textbf{Saturation of water} = Sw^n = \frac{Rw}{\Phi^m * Rt}$$

Where:

- n = Saturation exponent, its value varies between 1.8 to 4.0.
- R_w = resistivity of formation water
- ∅ = porosity
- m = cementation exponent, its value varies between 1.7 to 3.0.
- R_t = resistivity of uninvaded zone

The average saturation of water is calculated as 28% for all sand intervals in Zaur-03.

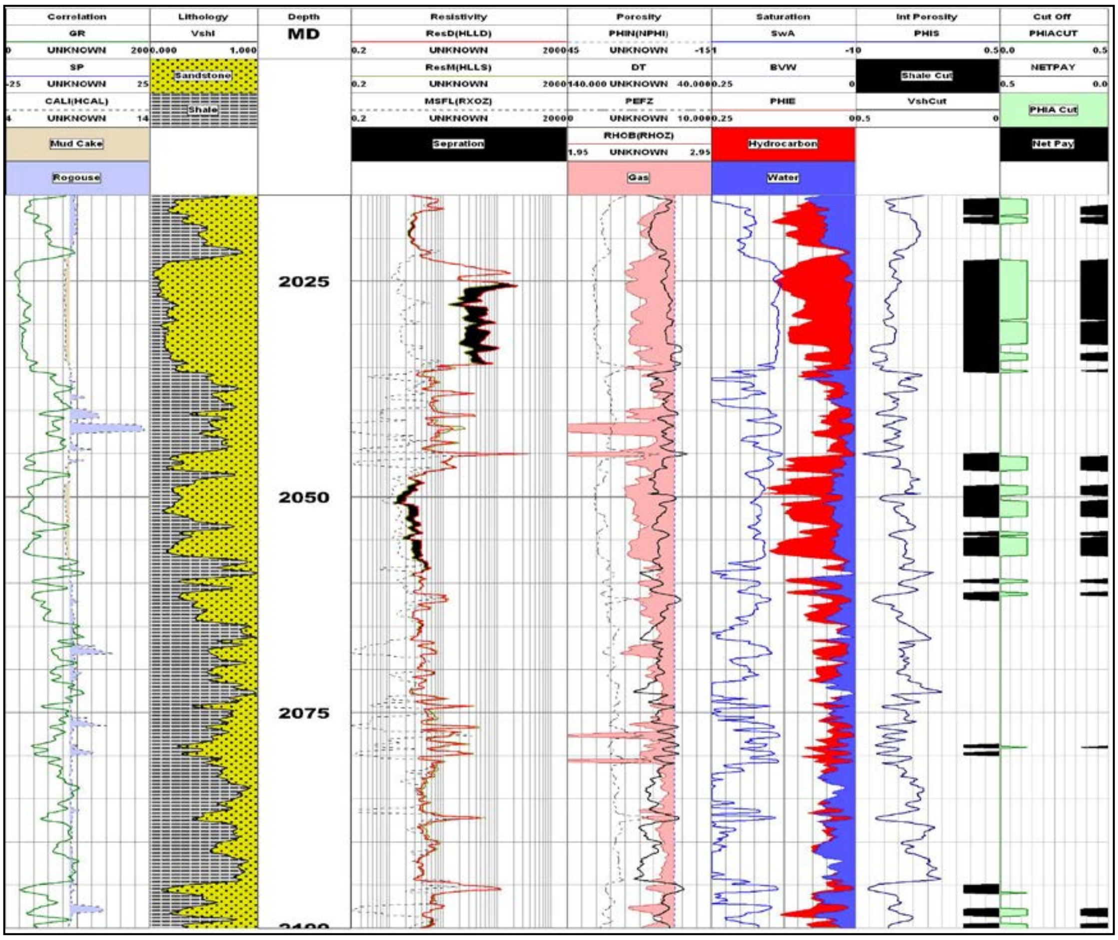

Fig. 5 Net pay map of Lower Goru C-sand in Zaur-03 well.

Saturation of Hydrocarbon (S_h)

Hydrocarbons saturation determination depicts the potential of reservoir to produce economically feasible hydrocarbons. It is calculated by following equation (Rider, 2002).

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

Calculated percentage of hydrocarbon's saturation in Zaur-03 is up to 70%, that shows it is favorable zone for production.

The Petrophysical analysis to evaluate reservoir properties of marked zones of Zaur-03 well infers that Lower Goru A-sand encountered in Zaur-03 well at depth 1890m to 1930m, having total thickness is 40m shows that the average V_{sh} is 26%. S_w is 45% and S_h is calculated as 55%. Various cut-offs are applied to get net pay thickness, V_{sh} cut off is applied at 25%, Effective porosity cut off applied at 8% and S_w cut off applied at 40%. Net pay is found to be 12m. The analysis shows A-sand in Zaur-03 is economically feasible for hydrocarbon production (Fig. 3; Table 2).

The petrophysical analysis of Lower Goru B-sand depicts that the zone starts from 1935m to 2010m.Total thickness of the zone is 75m (Fig. 4). Caliper log curve showing the hole is over gauge at 1965m to 1980m. Separation between LLD and LLS is also observed in 4th column at depth of 1940m to 1968m. The analysis shows that the V_{sh} is 45%. Porosity is 9%. S_w is 37%

and S_h is up to 63%. Net pay is calculated after applying V_{sh}, porosity and S_h cutoffs that is 25m at different depth intervals in B-sand. High volume of hydrocarbons (V_h) makes this zone favorable for hydrocarbons production (Fig. 4) (Table 2).

The analysis of Lower Goru C-sand shows that the zone starts from 2015m to 2100m, the total thickness is 75m (Fig. 5). GR log shows variations throughout the zone and Caliper log shows breakage in hole at multiple depths. Separations between LLD and LLS are observed at 2025m to 2035m and 2047m to 2058m. V_{sh} is calculated as 37%, effective porosity is 7% and S_h is estimated up to 52%. Net pay is calculated as 20m after applying various cut-offs (Fig. 5; Table 2).

Conclusion

Sand intervals of Lower Goru Formation in Badin area are the principal reservoir. The present study shows the average values calculated for Lower Goru Formation encountered in Zaur-03 well are;

- Volume of Shale (V_{sh}) is 40%.
- Effective porosity is 9%.
- Saturation of water (S_w) is 28%.

These values indicate that the Zaur-03 well is productive, as it has low saturation of water, although volume of shale and porosity values are high. From cutoff of shale, porosity and saturation of water, the economic value of hydrocarbon is to find out that how much the well is productive. It is concluded from the interpretation that the Lower Goru A-sand and B-sand are economically feasible for hydrocarbons extraction.

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