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# Evaluation of Reservoir Properties Using Wireline Logs of Well Sarai-Sidhu-1, Punjab Platform, Central Indus Basin, Pakistan

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## Abstract

The well Sarai Sidhu-01 is located on Punjab Platform, Central Indus Basin, Pakistan. Punjab Platform is the eastern part of Central Indus Basin, and tectonically it is the stable portion of Indus Basin, which was least affected during Tertiary Himalayan orogeny. This study attempts to decipher reservoir potential for hydrocarbon exploration. It aims to delineate a subsurface hydrocarbon bearing zone and to estimate the reservoir properties. A complete suite of wireline logs containing Caliper log (CALI), gamma ray log (GR), spontaneous potential log (SP), neutron log ($Ø_N$), density log ($Ø_D$), and resistivity logs (MSFL, LLS, and LLD) with all drilling parameters and well tops were utilized. The methodology adopted to accomplish this task includes the calculation of volume of shale ($V_{sh}$) by using gamma ray log and effective porosity ($Ø_E$) by using density and neutron logs. Resistivity of water ($R_w$) was calculated by SP method, and the saturation of water ($S_w$) and the saturation of hydrocarbons ($S_h$) is calculated with the help of Archie's equation. According to log signatures, Lumshiwal formation of early Cretaceous age encountered in well in the depth range of 5433 ft. to 5797 ft. was marked as a possible reservoir, and this zone was evaluated for its reservoir potential in detail using a set of equations. The average values calculated for different parameters are as follows: $V_{sh}$ = 30%, $Ø_E$ = 17%, $S_w$ = 46%, and $S_h$ = 54%. The analysis shows that $S_h$ is low, so it is inferred that Lumshiwal formation has a low potential and is economically not feasible for hydrocarbons production.

**Keywords:** Reservoir Characterization, Wireline Logs, Sarai Sidhu-1, Punjab Platform, Petrophysics

## 1. Introduction

Wireline logging is a practice to attain information about subsurface strata encountered in a borehole drilled for hydrocarbon exploration (Rider, 2002). Its key purpose is to evaluate the potential of a formation to act as a reservoir for accumulation and economical recovery of hydrocarbons.

The present study has been performed on well Sarai-Sidhu-1 located in tehsil Kabirwala, District Khanewal, Punjab province, Pakistan (Figure 1); geologically, it is a part of Central Indus Basin. Sarai

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Sidhu-1 was drilled by Amoco in 1973-74 on seismically delineated prospect up to TD 15303 ft., and initially low-quality gas was discovered in cretaceous sequence; now, it is an abandoned well (Quadri and Quadri, 1998).

The main objective of this study is the demarcation of hydrocarbon bearing zone and its evaluation for reservoir characteristics by interpreting wireline logs in well Sarai-Sidhu 01. Reservoir characterization includes the estimation of different physical parameters, i.e. the volume of shale ($V_{sh}$), porosity (∅), saturation of water ($S_w$), and hydrocarbons.

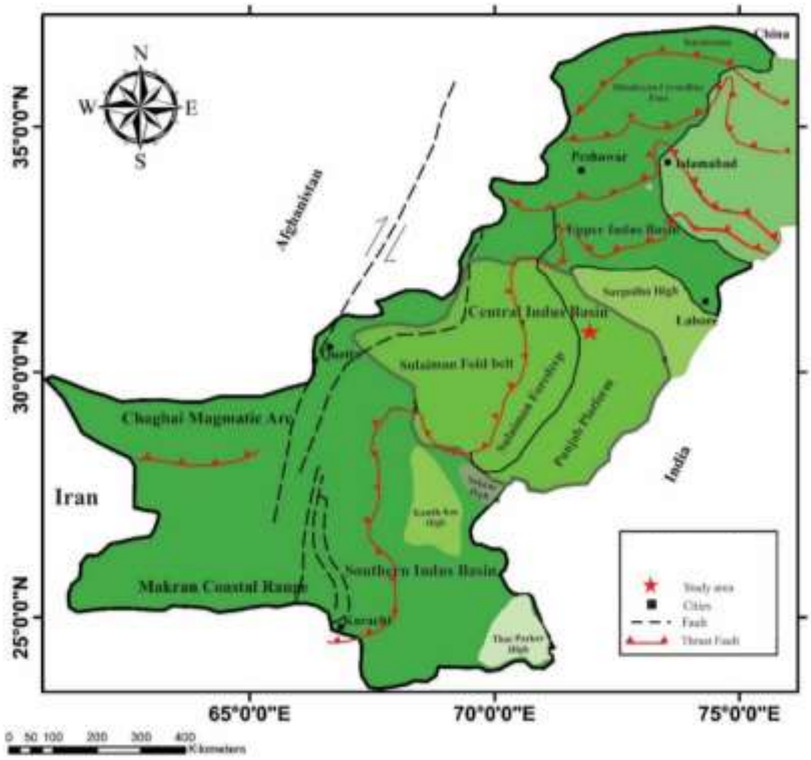



**Figure 1**
Tectonic map of the studied area (Kadri, 1995).

## 2. Regional geology and tectonic settings

The central Indus Basin from east to west comprises of three units (Figure 2); Punjab Platform, Sulaiman depression, and Sulaiman Fold belt (Raza et al., 1989). The well under study lies on Punjab platform (Figure 2). Punjab Platform marks the eastern segment of Central Indus Basin, and it is a broad monocline dipping gently towards Sulaiman depression (Kadri, 1995). In the north, Sargodha high separates Central Indus Basin from the Upper Indus Basin. Sukkur Rift comprises of Jacobabad and Mari Kandh-Kot, and highs are present in the south separating it from the southern Indus Basin. It is locked by Indian shield in the east and by the marginal zone of the Indian plate in the west (Shah, 1977). The area was relatively less affected by Tertiary Himalayan orogenic event because of its greater distance from the collision zone (Raza et al., 1989). The Punjab Platform is covered by thick unconsolidated quaternary alluvial deposits of sand, silt, and clay with the maximum thickness of about 1600 ft. (Kadri, 1995; Raza et al., 1989). The oldest rocks encountered in Punjab Platform through drilling are Infra-Cambrian Salt range formation (Kadri, 1995; Humayun et al., 1991). Table 1 shows the stratigraphy of the study area encountered in the borehole of Sarai-Sidhu 01. The Punjab Platform further extends towards east into India, where it is called Bikaner-Nagaur Basin; significant quantities of oil have been discovered from Infra-Cambrian evaporites therein (Aadil and Sohail, 2014). This discovery enhanced the exploration activities on Punjab Platform.

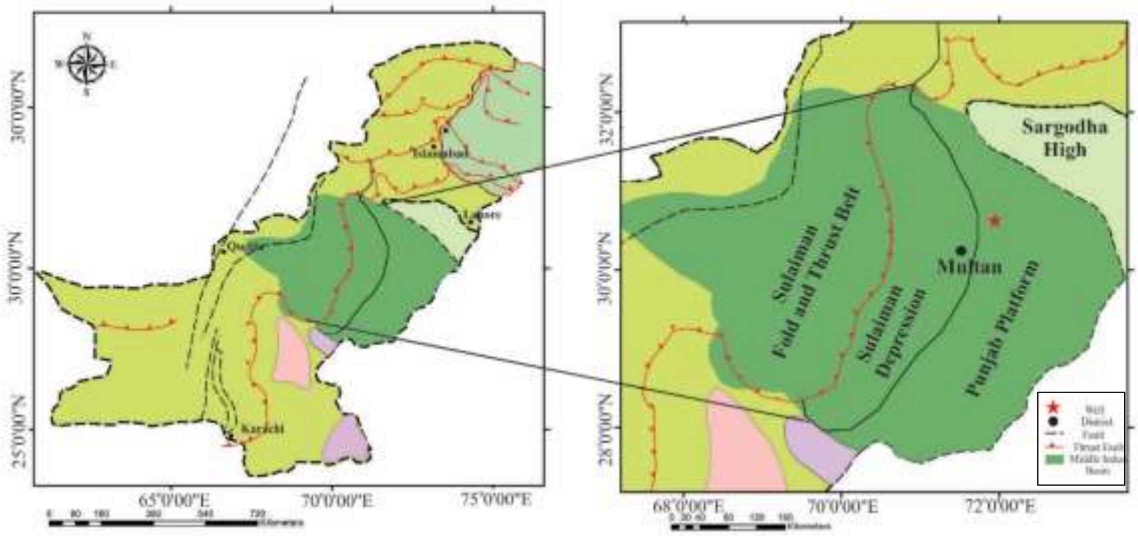



**Figure 2**
Tectonic map of Pakistan highlighting Central Indus Basin and its sub-divisions (Modified after Kadri, 1995).

**Table 1**
Borehole stratigraphy of Sarai-Sidhu-1.

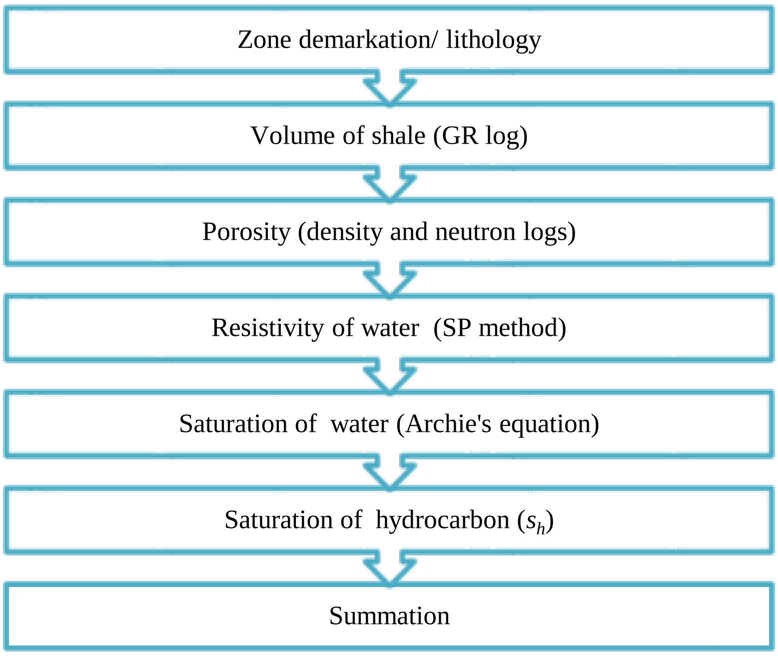
| Era | Period / epoch | Formation | Lithology description | Formation tops (feet) | Hydrocarbon system | | |
|---|---|---|---|---|---|---|---|
| | | | | | Seal | Source | Reservoir |
| CENOZOIC | PLIOCENE | NAGRI | Claystone, Siltstone | 00.0 | | | |
| | MIOCENE | CHINJI | Claystone, Siltstone | 2063.97 | | | |
| | EOCENE | SAKESAR | Limestone | 4373.68 | | | |
| | | NAMMAL | Shale, Limestone | 4582.67 | | | |
| | | GHAZIJ | Shale, Sandstone | 4681.75 | | | |
| | PALEOCENE | DUNGHAN | Limestone | 5178.80 | | | |
| | | RANIKOT | Limestone, Shale | 5291.99 | | | |
| MESOZOIC | CRETACEOUS | LUMSHIWAL | Sandstone | 5433.07 | | | |
| | | CHICHALI | Sandstone | 5797.24 | | | |
| | JURASSIC | SAMANA SUK | Limestone, Shale | 5985.56 | | | |
| | | SHINAWARI | Limestone, Sandstone | 6434.71 | | | |
| | | DATTA | Shale | 6746.71 | | | |
| | TRIASSIC | KINGRIALI | Sandstone, Shale | 6807.74 | | | |
| | | TREDIIAN | Sandstone | 7185.03 | | | |
| PALEOZOIC | PERMIAN | AMB | Limestone | 7355.64 | | | |
| | | SARDHAI | Clays | 7664.69 | | | |
| | | WARCHA | Sandstone | 8202.1 | | | |

## 3. Material and methodology

Data acquired to accomplish this study consist of open-hole wireline logs of well Sarai-Sidhu-01 and well tops. Data are provided by Land Mark Resources (LMKR) with prior approval of Directorate General Petroleum Concessions (DGPC) Islamabad, Pakistan; they include Caliper log (CALI), gamma ray log (GR), spontaneous potential log (SP), resistivity logs (LLD, LLS, and MSFL), neutron log ($Ø_N$), density log ($Ø_D$), and well tops along with all drilling parameters. The workflow adopted for logs interpretation is illustrated in Table 2.

**Table 2**

Methodology adopted for research work.




## 4. Results and discussion

The evaluation of the reservoir properties of well Sarai-Sidhu-01 was performed by the careful analysis of all the available wireline logs data. A zone is marked on the bases of GR log trend (Figure 3a) in a depth range of 5433.07 ft. to 5797.24 ft. as a possible reservoir. The total thickness of zone is 364 ft. Well tops of Sarai-Sadhu -01 (Table 1) confirmed this zone as Lumshiwal formation of a cretaceous age. Further analysis shows that the effective porosity calculated using neutron and density logs for the zone of interest is 17% (Figure 3c). The average saturation of water calculated using Archie’s equation is 46%, and the saturation of hydrocarbon is 54% (Figure 3c). After applying cut offs to minimum extractable hydrocarbons, net pay thickness is calculated 150 ft. for the whole zone in different depth intervals. Figure 3 shows the combined graphs of all the calculated parameters for the reservoir evaluation of Lumshiwal formation.

A zone of interest, having the fair potential to act as a reservoir for the accumulation of hydrocarbons, is marked with gamma ray log and correlated with the other logs in a depth range of 5433.07 ft. to 5797.24 ft. (Figure 3). This zone is tested for its hydrocarbon potential using a set of equations.

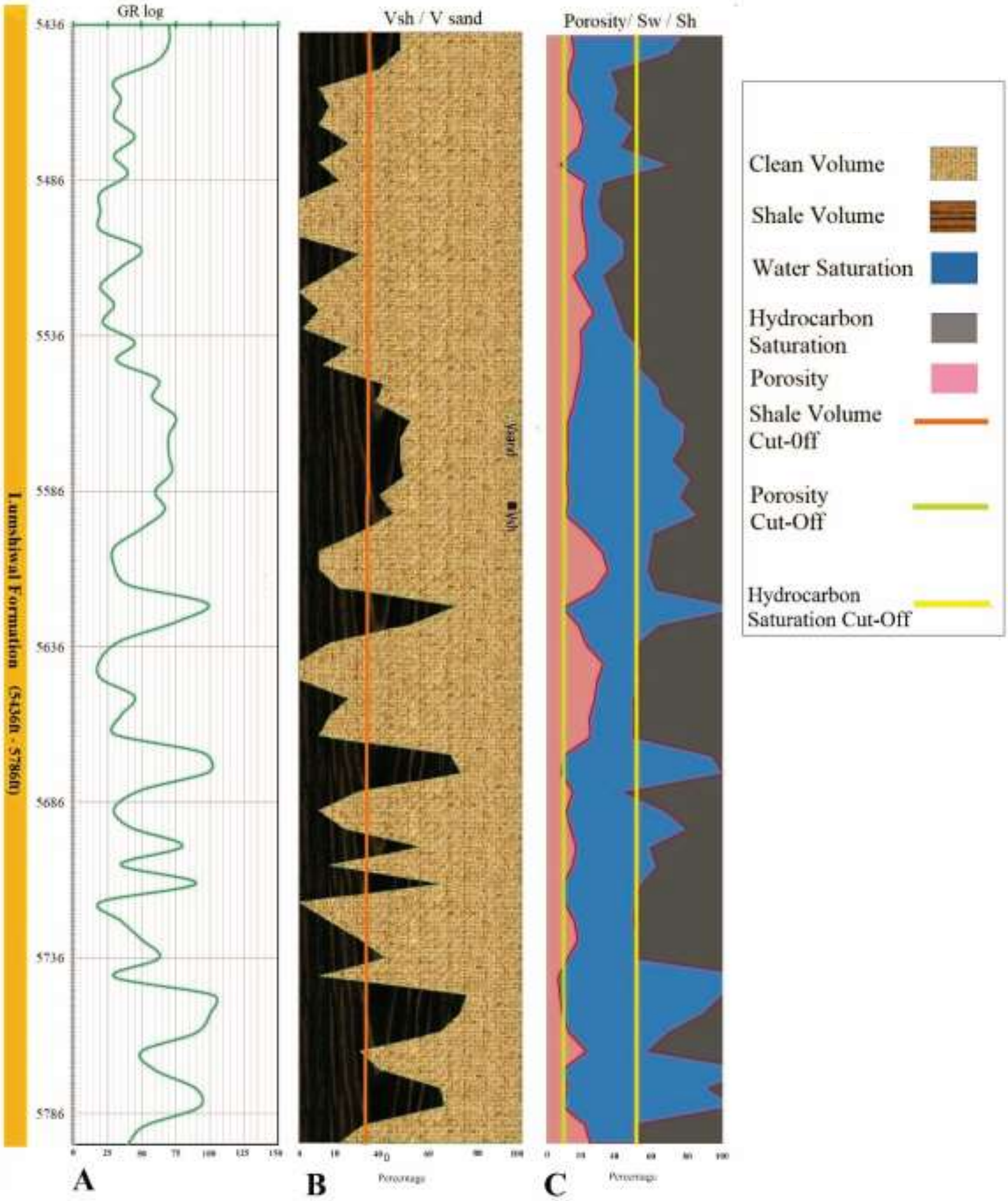



**Figure 3**
Composite graphs for the complete evaluation of our zone of interest; A) GR log curve in our zone of interest; B) the composite graph of $V_{sh}$ and $V_{sand}$; and C) the combined graph of porosity, $S_w$, and $S_h$.

### 4.1. Calculation of volume of shale ($V_{sh}$)

$V_{sh}$ is also known as the dirtiness of reservoir, and GR log is used for the calculation of $V_{sh}$ using the following equation (Rider, 1996).

$$V_{sh} = \frac{(GR\ \log - GR\ \min)}{(GR\ \max - GR\ \min)} \tag{1}$$

where,

- GR log = Gamma ray log reading.
- GR max = Maximum gamma ray deflection in the zone.
- GR min = Minimum gamma ray deflection in the zone.

## 4.2. Calculation of clean volume ($V_{sand}$)

$V_{sand}$ is the cleanliness of a reservoir, known as the net to gross ratio. $V_{sand}$ is obtained by subtracting 1 from $V_{sh}$. Equation is given below.

$$V_{sand} = 1 - V_{sh} \tag{2}$$

## 4.3. Porosity calculations

Porosity analysis is an important factor for reservoir evaluation. In the present study, neutron and density logs are used for porosity calculations. Neutron log ($Ø_N$) measures hydrogen ion present in formation, so it can be calculated directly from log curves; density porosity is calculated using the following equation (Rider, 1996).

$$Density\ Porosity\ \left(Ø_D\right) = \frac{\left(RHOM - RHOB\right)}{\left(RHOM - RHOF\right)} \tag{3}$$

where,

- $RHOM$ = Matrix density (constant values according to lithology)
- $RHOF$ = Fluid density (from log header)
- $RHOB$ = Bulk density (density log values from log curve)

Average porosity is calculated using combined neutron-density logs with the following equation (Rider, 1996).

$$Average\ Porosity = Ø_{N-D} = \sqrt{\frac{\left(Ø_N^2 + Ø_D^2\right)}{2}} \tag{4}$$

where,

- $Ø_N$ = Neutron porosity
- $Ø_D$ = Density porosity

$$Effective\ porosity = Ø_E = Ø_{Avg} \times \left(1 - V_{clean}\right) \tag{5}$$

where,

- $Ø_E$ = Effective porosity
- $Ø_{Avg}$ = Total porosity
- $V_{clean}$ = Volume of sand

## 4.4. Resistivity of water ($R_w$)

The calculation of $R_w$ is very sensitive because the saturation of water depends on it. Spontaneous potential (*SP*) method is adopted for the determination of $R_w$; calculations involve the determination of SSP, which is calculated directly from the *SP* log curve. Formation temperature is also determined by using Equation 6:

$$Formation\ Temperature\ = T_f = Ts + Df\left(BHT - \frac{Ts}{TD}\right) \tag{6}$$

where,

- *BHT* = Bottom hole temperature
- *Ts* = Surface temperature
- *TD* = Total depth
- *Df* = Formation depth

Bottom hole temperature (BHT) and the resistivity of mud filtrate at the surface temperature (*Rmf @ Ts*) were taken from the header of wireline log. To calculate the resistivity of mud filtrate at formation temperature (*Rmf @ Tf*) the Schlumberger Gen-9 chart was used. The *Rmf @ Tf* is converted to $Rmf_{eqv}/Rw_{eqv}$ using Schlumberger's SP-1 chart (Schlumberger, 2009). Using these values, *Rw* is determined by Schlumberger's SP-2 chart (Schlumberger, 2009). Table 3 shows the systematic approach to found parameters for determining $R_w$ by the SP procedure.

**Table 3**

Step by step parameters to be found for the determination of $R_w$.

| |
|---|
| Geothermal gradient (SP log) |
| Formation temperature *Tf* = *Ts* + *Df* (BHT - *Ts*/*TD*) |
| *Rmf* @ Formation temperature (Gen-9 chart) |
| *Rmf* equivalent (SP-1 chart) |
| *Rw* equivalent (SP-2 chart) |
| $R_w$ |

## 4.5. Saturation of water

Archie's equation is applied to the calculation of $S_w$ (Rider, 1996).

$$Saturation\ of\ water\ = S_w = n\sqrt{\left(\frac{a.\,R_w}{\varnothing_m \times R_t}\right)} \tag{7}$$

where,

- $S_w$ = Saturation of water
- *n* = Saturation exponent

- $a$ = Tortuosity factor
- $R_w$ = Resistivity of formation water
- $\emptyset$ = Porosity
- $m$ = Cementation exponent
- $R_t$ = Resistivity of uninvaded zone

$a$ is a tortuosity factor, which varies from 0.91 to 1.05, and it is normally taken as 1 (Elias and Steagall, 1996). $m$ is cementation exponent, which ranges from 1.8 to 2 for sandstones (Salem and Chilingarian, 1999b). $n$ value also ranges from 2.40 to 4.24 (Elias and Steagall, 1996).

### 4.6. Saturation of hydrocarbons

The determination of hydrocarbon saturation depicts the potential of reservoir to produce economically feasible hydrocarbons. It is calculated by Equation 8 (Rider, 1996)

$$S_h = 1 - S_w \tag{8}$$

Saturations of water and hydrocarbons (Figure 3c) are opposite to each other; in other words, where the saturation of hydrocarbons increases, the saturation of water drops. The saturation of hydrocarbons calculated for our zone of interest is 30%, which is very low for an economic recovery of hydrocarbons.

## 5. Cut off

Applying cut off is a manual practice for petrophysical evaluation. Cut offs are employed to find an average value in the zone of interest, where we find the least extractable volume of hydrocarbons. Cut off grades used to determine economically feasible zone for hydrocarbons production is 30% for $V_{sh}$, 10% for porosity, and 50% for saturation of hydrocarbons.

## 6. Conclusions

The analysis shows although the porosity is high, the saturation of hydrocarbon is least economically feasible for recovery. Therefore, it is concluded that Lumshiwal formation of early Cretaceous age has a low potential for an economic recovery of hydrocarbons due to the low volume of hydrocarbons present in pore spaces.

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## Nomenclature

| | |
|---|---|
| CALI | : Caliper log |
| GR | : Gamma ray log |
| LLD | : Laterolog deep |
| LLS | : Laterolog shallow |
| MSFL | : Micro-spherical focused log |

| | |
|---|---|
| $Rw$ | : Resistivity of water |
| $SP$ | : Spontaneous potential log |
| $S_w$ | : Saturation of water |
| $V_{sh}$ | : Volume of shale |
| $Ø_D$ | : Density log |
| $Ø_E$ | : Effective porosity |
| $Ø_N$ | : Neutron log |

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