

Evaluation of Reservoir Characteristics of Well Kot-Sarang-2, Potwar Plateau, Pakistan Using Geophysical Logs

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Received: 25 August, 2016

Revised: 10 October, 2016

Abstract: Present study deals with reservoir characterization of Kot-Sarang-2 well, located in central part of Potwar plateau of Upper Indus Basin, District Chakwal. The geological structure of the Potwar Basin is the product of the Tertiary Himalayan orogeny, which resulted in the formation of complex fold and thrust belt in this region. In the present work, an attempt has been made to delineate zones having fair shows of hydrocarbons accumulation. In addition to this, estimation of reservoir properties and formation evaluation using wireline logs is also the foremost objective of this study. Based on the wireline logging results, three zones have been marked. Paleocene Lockhart Limestone (3967m to 4045m), Permian Wargal Limestone (4160m to 4245m) and Permian Amb Formation (4246m to 4285m) are possible reservoirs encountered. Physical properties i.e. total porosity (ϕ), effective porosity (ϕ_E), resistivity of water (R_w), saturation of water (S_w) and saturation of hydrocarbons (S_h) are calculated. For the calculation of saturation of water (S_w) both Archie's equation (S_{wa}) and Indonesian equation (S_{wi}) are applied. Results show that Amb and Wargal formations are showing fair to good saturation of Hydrocarbons (S_h) i.e. 73% and 88% respectively, but this is due to high resistivity values of these formations and porosity log also giving very low values. Effective porosity for zones Lockhart, Wargal and Amb are 2.56%, 3.5% and 1.32% respectively. Based on these results it is inferred that these formations have low potential for an economically feasible production of hydrocarbons.

Keywords: Kot-Sarang, fold and thrust belt, wireline logs, porosity, Archie equation, Indonesian equation.

Introduction

The field of petrophysics has gained special attention for hydrocarbon exploration. It is a practice of making detailed record of subsurface geologic formations encountered during drilling a well (Rider, 2002). In the present work petrophysical analysis has been performed to evaluate rock properties and fluid saturation in our zones of interest, zones have been marked on the basis of combined response of all available geophysical log curves.

The study has been done on Kot-Sarang-2 well located at 33°2'14" N, 72°23'11" E that was drilled by OGDCL in Kot-Sarang field, Potwar Plateau, Upper Indus Basin in 1985 (Fig.1). Upper Indus Basin comprised of complex tectonics, it is dominated by structural and salt diapiric traps. In the study area, Central and Western Potwar, the thrust wedge has been transported southward as a coherent slab with little internal deformation and less than 1 km of shortening between NPDZ (north Potwar deformed zone) and Salt Range (Kazmi and Jan, 1997).

Data was acquired for this study from DGPC that consist of geophysical wireline logs (Caliper, Sonic, Gamma ray, Spontaneous Potential and Resistivity) and well tops. The zones were marked on the basis of Gamma ray, where it shows low values i.e. clean formation

and its correspondence to the other log curves and well tops. On this basis three zones have been marked, Paleocene Lockhart Limestone (from depth 3967m to 4045m) Permian Wargal Limestone (4160m to 4245m) and Permian Amb Formation (4246m to 4285m).

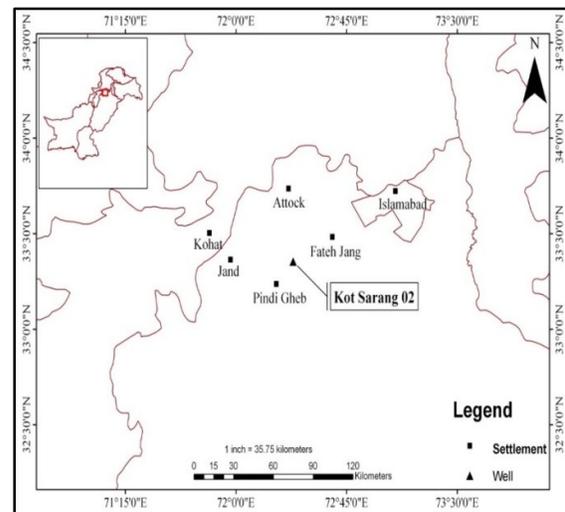


Fig. 1 Location map of the study area.

The parameters calculated from these log curves are Volume of Shale (V_{sh}), Volume of Sand (V_{sand}), Total

Porosity (ϕ), Effective Porosity (ϕ_E), Resistivity of Water R_w with the help of Schlumberger's charts (1997), Saturation of Water (S_w) with both Archie's (1942) and Indonesian equations and saturation of equation hydrocarbons. At the end, cut off grades have been applied for all three zones.

Stratigraphy and tectonics of area

The Potwar plateau is bounded in north by MBT, in south by Salt Range thrust, while the Sinistral Jhelum fault marks eastern and Kalabagh dextral fault marks western boundary (Mughal et al., 2007). Figure 2 shows the tectonics of study area.

Precambrian to Quaternary age sediments are preserved in Potwar Plateau. Cambrian age evaporites overlain by the platform deposits of Cambrian to Eocene age are relatively thin. Thick Miocene-Pliocene molasses overly these deposits. The Himalayan orogeny caused the deformation of whole section during Pliocene to middle Pleistocene (Mughal et al., 2007). Table 1 shows the stratigraphy encountered in borehole of Kot-Sarang-2 well.

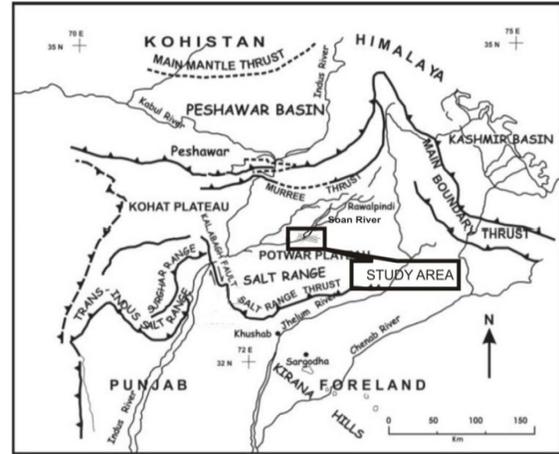
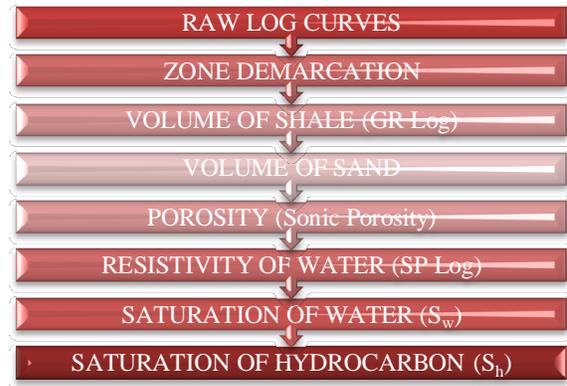


Fig. 2 Tectonic map of Northern Pakistan (after Kadri et al., 1995).

Methodology

A step by step procedure adopted for this study is following (Table 2)

Table 2 Procedure adopted for research work.



Subsurface knowledge primarily comes from drilling. Geophysical well logging offers an opportunity to determine various physical and electrical properties of subsurface and enables proper understanding. Geophysical logging tools used for this study are Gamma Ray (GR), Spontaneous Potential (SP), Caliper log, Resistivity log and Sonic log (DT). Based on the results, following formations have been marked as having fair potential for hydrocarbons (Table 3). Lithology has been confirmed by gamma ray log.

Table 3 Marked zones for petrophysical evaluation.

Zone	Starting depth(m)	Ending depth(m)	Total thickness(m)
Lockhart Limestone	3967	4045	+78
Wargal Limestone	4160	4245	+85
Amb Formation	4246	4285	+39

EON	ERA	EPOCH	FORMATION	LITHOLOGY	FORMATION TOPS (METERS)	HYDROCARBON SYSTEM		
						SEAL	SOURCE	RESERVOIR
PHANEROZOIC	CENOZOIC	EOCENE	BHADRAR	Claystone Siltstone	3645			
			SAKESAR	Limestone	3692			
			NAMMAL	Shales Limestone	3837			
		PALEOCENE	RANIKOT	Shale	3883			
			PATALA	Shale	3912	Yellow	Black	
			LOCKHART	Limestone, Shale	3967			Red
	MESOZOIC	LATE TRIASSIC	KINGRIALI	Dolomite Shale Sandstone Limestone	4086	Yellow		
			WARGAL	Limestone	4127			Red
				Sandstone Limestone Shale	4235			Red
			AMB	Shale, Sandstone, Siltstone	4283		Black	

Table 1 Borehole stratigraphy of well Kot-Sarang-2 along with hydrocarbon system of the area.

Calculation of Shale Volume

Volume of shale is calculated by Gama Ray log with following formula.

$$V_{sh} = (GR_{log} - GR_{min}) / (GR_{max} - GR_{min})$$

Where:

GR_{log} = Gamma ray log reading.

GR_{max} = Maximum Gamma ray deflection.

GR_{min} = Minimum Gamma ray deflection.

Calculation of Sand Volume

It is calculated by subtracting 1 from the shale volume.

$$\text{Volume of Sand } (V_{sand}) = 1 - V_{sh}$$

Where:

V_{sh} = Volume of shale.

Porosity Calculations

Porosity calculation is an important parameter to be calculated for reservoir properties evaluation.

Average total Porosity Calculation

In this research work, sonic log has been used for porosity calculation. It gives Interval transit time of formation ΔT.

$$\text{Sonic porosity} = \frac{\Delta T_{log} - \Delta T_{matrix}}{\Delta T_f - \Delta T_{matrix}}$$

Where:

ΔTlog = DT from sonic log

ΔT_f = Travel time of sound wave through fluid

ΔT_{matrix} = Travel time of wave through matrix

Effective Porosity

Average Total Porosity is multiplied by the volume of sand to get effective porosity.

$$\text{Ø}_E = \text{Ø}_{t_avg} * (1 - V_{sand})$$

Where:

Ø_E = Effective Porosity.

Ø_{t_avg} = Average Total Porosity.

V_{sand} = Volume of sand.

Resistivity of Water

It is the most sensitive parameter in the determination of water saturation (Rider, 2002). Spontaneous Potential (SP) procedure was used to determine the resistivity of water of reservoirs. Following steps show the parameters to be found out for the calculation of resistivity of water by SP procedure (Table 4).

Table 4 Procedure for calculating R_w.

Geothermal Gradient
Formation Temperature
R_{mf} @ Formation Temperature
R_{mf} Equivalent
R_w Equivalent
R_w

Different Schlumberger (Gen-9 and SP) charts are used to determine the above parameters, for the calculation of Resistivity of Water (Schlumberger, 1997).

Saturation of Water

It is calculated by the both Archie’s equation (1942) and Indonesian equation. The difference between both equations is that, Archie’s equation was developed for clean sandstone by a laboratory experiments. This is used in reservoirs, where clay mineral content is low. Indonesian equation is developed by field observations rather than laboratory experiments and it can give beneficial results for carbonate reservoirs, where secondary porosity often exists.

Archie’s Equation:

$$S_w = \sqrt{\frac{R_w}{R_t * \text{Ø}_a^2}}$$

Where:

S_w = Saturation of water

R_w = Resistivity of water

R_t = Resistivity of true zone

Ø_a = Average Porosity

Indonesian Equation:

$$S_w = \sqrt{\frac{1}{R_T}} / \left(\frac{V_{sh} * (1 - 0.5 * V_{sh})}{\text{Ø}_m} \right) / \sqrt{(R_{sh}) + \sqrt{\text{Ø}_m / (a * R_w)}}$$

Where:

R_T: True Resistivity of formation.

V_{sh}: Volume of shale.

R_w: Resistivity of water.

Saturation of Hydrocarbons

Determination of Hydrocarbon’s saturation is most important factor because it depicts the potential of reservoir to produce hydrocarbons. Formula for calculation of hydrocarbons is:

$$S_h = 1 - S_w$$

S_h: Saturation of hydrocarbons.

S_w : Saturation of water.

Cut Off s

For this petrophysical work, cut offs are applied for an average value in whole zone of interest where we find minimum extractable volume of hydrocarbons. Cut off applied for volume of shale was 40% and for porosity values were very low, so porosity cut off is applied as 3%.

Results and Discussion

Zone 1 (Lockhart Limestone)

This zone comprises of Lockhart Formation that is encountered at depth of 3967m to 4045m and total thickness is 78m. Following is the combined chart showing all parameters evaluated in this petrophysical analysis (Fig.3). The average volume of shale calculated for zone 1 is 36% and the volume of sand is 64%. Total porosity calculated using sonic log for this zone is as low as 4%. The effective porosity is only 2.56%. Saturation of hydrocarbons in this zone is 36% calculated using Archie’s equation. Gross thickness is 78m after applying cut offs (V_{sh} cut off, porosity cutoff, S_w cut off) the total thickness of Pay zone is 47m.

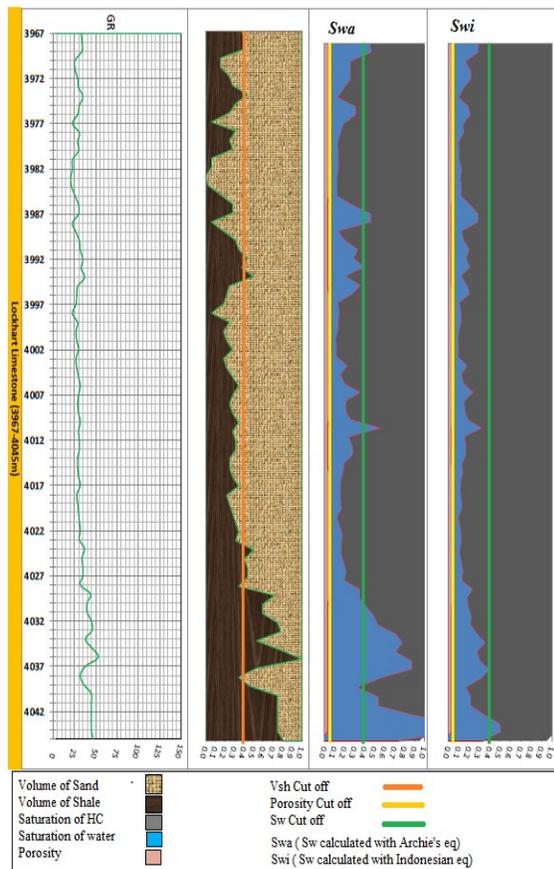


Fig. 3 Petrophysical parameters calculated for zone 1 (Lockhart Limestone).

Zone 2 (Wargal Limestone)

Zone 2 that is comprised of Wargal Limestone encountered in well at depth of 4160m up to 4245m. Total thickness for this zone is 85m (Fig. 4). Average V_{sh} calculated for Wargal limestone is 30% and V_{sand} is 70%. Total porosity is 5% and effective porosity is 3.5%. Cut off for V_{sh} applied at 35%, porosity cut off applied at 3% and S_w cut off applied at 35%. After applying cut offs, the total thickness of Pay zone is 51m.

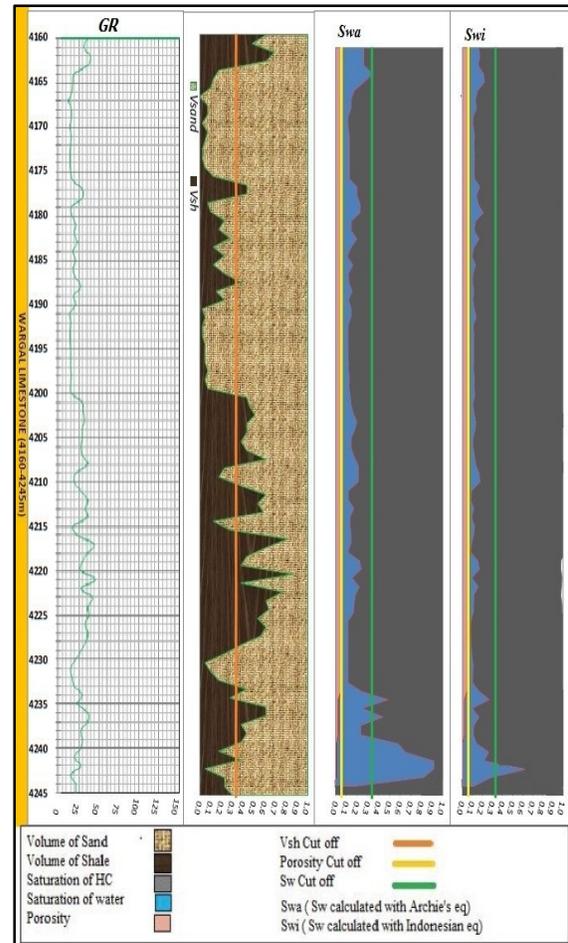


Fig. 4 Petrophysical parameters calculated for Zone 2 (Wargal Limestone).

Zone 3 (Amb Formation)

Amb Formation encountered in well at depth of 4246m up to 4285 m. Total thickness is 39m. Average V_{sh} calculated is 33% and V_{sand} is 67%. Total average porosity for Amb Formation is 4% and effective porosity is 1.32%. Saturation of hydrocarbons calculated using Archie’s method is 88%. Cut off for V_{sh} applied at 25%, for porosity cut off applied at 3% and for saturation of water cut off applied at 25%. The total thickness for Pay zone after applying cut off for Amb Formation remains 24m. Charts for Amb Formation are following (Fig. 5).

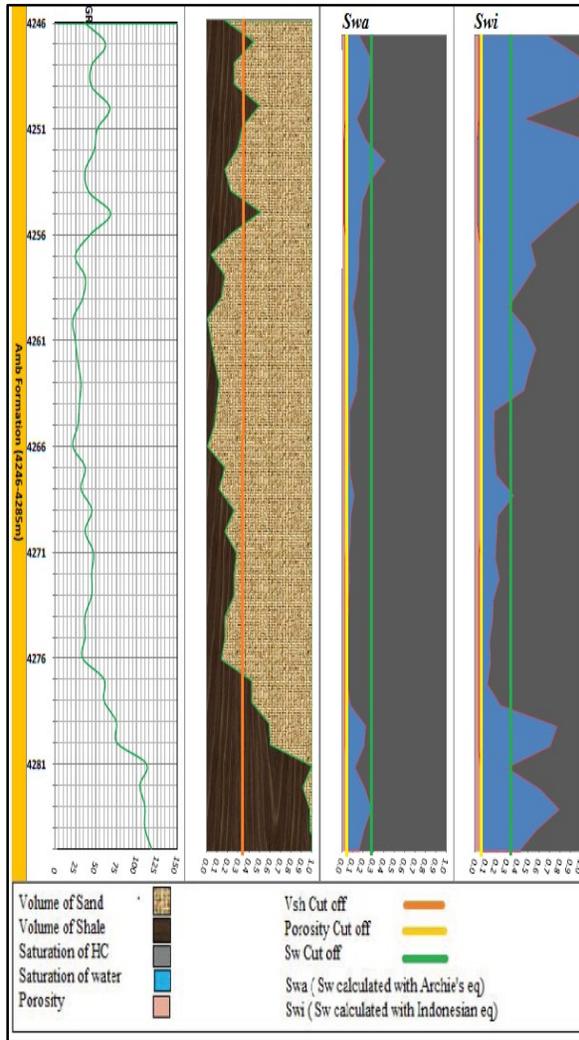


Fig. 5 Petrophysical parameters for zone 3 (Amb Formation).

Conclusion

Three zones have been marked on the basis of Gamma ray. Zone 1 consists of Lockhart Limestone, Zone 2 consists of Wargal Limestone and Zone 3 consists of Amb Formation. Out of these three formations only Wargal and Amb formations were showing fair to good concentration of hydrocarbons.

The Lockhart Limestone has dominant lithology of limestone with vuggy and crystalline type of secondary porosity that is very low porosity for production of hydrocarbons.

Hydrocarbons saturation is high due to high resistivity in these formations, as the calculated porosity values calculated from sonic log (as neutron and density logs were not available) was giving very low values ranging from 3to5 % in all three zones.

Therefore, keeping the above factors in mind, it is inferred that in fact these formations have the low potential for hydrocarbon accumulation.

Summarizing it, the logging tools are found to be quick, reliable and economic means for the evaluation of the properties of reservoir encountered in wells and wide application in the industry.

Acknowledgement

We are indebted to the Department of Earth and Environmental Sciences, Bahria University, Islamabad for guidance and moral support and especially thankful to Director General Petroleum Concession for giving approval to LMK Resources to provide us data for this research work.

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