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Petrophysical characteristics of lower goru formation (Cretaceous) in Sawan gas field, Central Indus basin, Pakistan

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Abstract

The study area lies in Central Indus Basin, District Khairpur, Sindh Province, Pakistan. The objective of the research was to study petrophysical parameters of the Lower Goru Formation in Sawan Gas Field to identify hydrocarbon bearing zones. In this study, data set of conventional well logs of Sawan-01 and Sawan-02 wells were used. The petrophysical interpretations revealed that the studied Lower Goru Formation has good reservoir characteristics with 12% effective porosity, 15% average volume of shale (Vsh), 38.62% water saturation (Sw) and 61.38% hydrocarbon saturation (Shc) with qualitative permeability in Sawan-01. Also the same formation in Sawan-02 is clean with 9% Vsh, 12% effective porosity, 46% Sw and 54% Shc. The lithology of the Lower Goru Formation is dominated by very fine to fine and silty sandstone.

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Introduction

The petrophysical parameters estimation from well logs is an important part of the hydrocarbon exploration and production which helps to understand the subsurface reservoir properties like porosity, permeability, water and hydrocarbon saturation etc. In 1927, Schlumberger brothers originally introduced wire line logging in Alsace, France. It can be practiced by visual examination of samples brought to the surface from subsurface (e.g. cuttings logs, core-logging or petrophysical logging) or by lowering the equipments into the borehole (Ofwona, 2010). There are three types of logging i.e. open hole logging, cased hole logging and production logging. Important logs include Gamma ray (GR), density (RHOB), sonic (DT), neutron (NPHI), resistivity, caliper log and cement bond log (Rider, 1996). The present research work is conducted by utilizing conventional logs run in the Cretaceous Lower Goru Formation penetrated in Sawan-01 and Sawan-02 wells of the Sawan Gas Field, Central Indus Basin, Pakistan. Sawan Gas Field is situated at latitude 26.98, 27.30 N and longitude 68.54, 68.58 E in Central Indus Basin, Khairpur, Pakistan (Figs. 1 and 2).

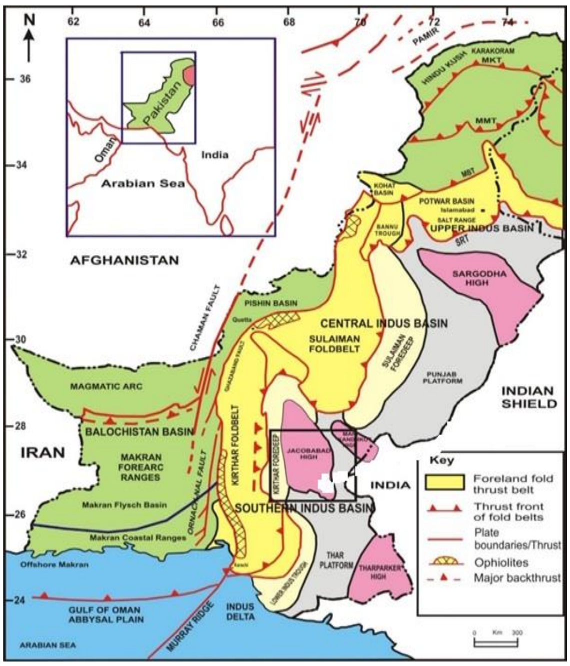

Fig. 1. Tectonic and sedimentary basin map of Pakistan (modified from Aziz and Khan, 2003). The studied wells belong to the black-lined box.

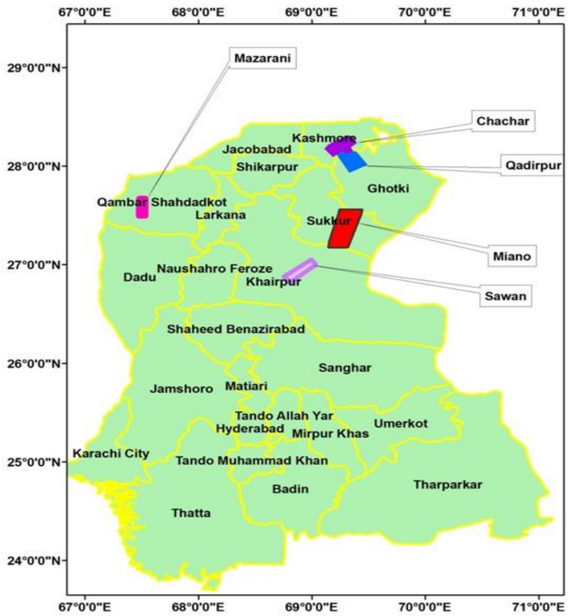

Fig. 2. Location map of the Sawan Gas Field (after Zaigham and Mallick, 2000).

The Central Indus Basin consists of Sulaiman Fold Belt, Sulaiman Foredeep and Punjab Platform (Fig. 1). It is surrounded by Sargodha High and Pezu uplift; Indian Shield; Indian Plate marginal zone and Sukkur Rift in the North, East, West and South respectively (Kadri, 1995). The Sulaiman Fold Belt is developed due to transpression alongside Chaman Fault and southward thrusted along the Indian plate western boundary (Jadoon *et al.*, 1994). Sulaiman Foredeep is a longitudinally leaning area of subsidence having arcuate and then perpendicular positioning towards its southern rim (Kadri, 1995). Punjab Platform is a wide monocline dipping towards West with no sedimentary surface outcrops and making up the eastern part of the Central Indus Basin. The Central Indus Basin consists of rocks ranging from Triassic Wulgai Fromation to Miocene-Pliocene Siwaliks (Fig. 3).

On the basis of lithology, the Goru Formation is divided into Lower Goru and Upper Goru (Kadri, 1995). The Lower Goru Formation mainly consists of basal, middle and upper sands unglued by lower and upper shales. Major hydrocarbon producing zones belongs to the upper sands. This zone consists of sub-zones i.e. A, B, C and D sands divided by Turk, Badin and Jhol shale respectively (Quadri and Shuaib, 1986).

The Upper Goru is dominated by shale and thus having no reservoir potential (Quadri and Shuaib, 1986).

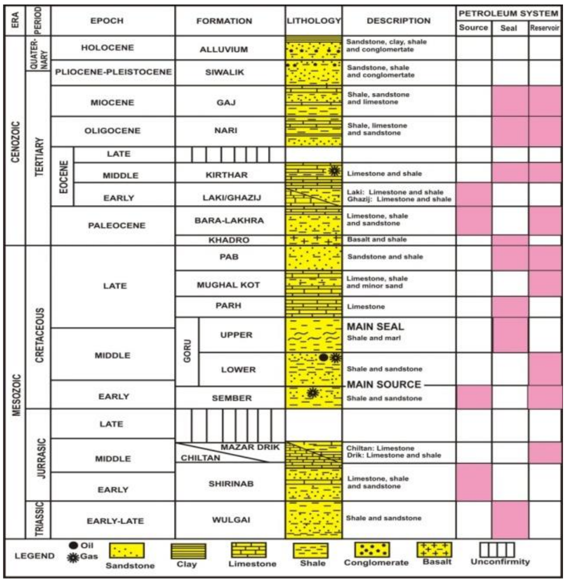

Fig. 3. Generalized stratigraphic column of the Central Indus Basin (modified from Raza *et al.*, 1990).

In the subsurface of the Southern Sindh Monocline (Lower Indus Basin, Pakistan), Solangi *et al.*, (2016) studied environments of deposition of Upper sands (B-sand) of Early Cretaceous Lower Goru Formation. They concluded that the Lower Goru Formation (B-sand) is a reservoir facies and deposited as barrier bar and transgressive facies in deltaic to shallow marine conditions. In Sanghar Block of the Lower Indus Basin, Nisar *et al.* (2016) evaluated the petrophysical properties of the Lower Goru Formation penetrated in Fateh-01 and Panairi-01 wells. According to them, the Lower Goru Formation is water-saturated in the drilled wells. Abbas *et al.* (2015) conducted the petrophysical characterization of the Lower Goru Formation in Sawan-03 and Sawan-07 wells and determined that the subject formation has good effective porosity but low water saturation. Sahito *et al.* (2013) worked out the sedimentological investigation of the Lower Goru Formation (upper sands) using ditch cuttings and geophysical logs penetrated in the Sindh Monocline, Southern Indus Basin, Pakistan. According to them, the sands are moderate to well sorted, sub-angular to well-rounded with mean sand grain size varying from fine to medium grained.

Through Poisson's ratio contour map, sands of the Lower Goru Formation are interpreted as gas saturated (Munir *et al.*, 2011).The present study is aimed to determine reservoir properties i.e. volume of shale, porosity, qualitative permeability, water saturation, hydrocarbon saturation, movability of hydrocarbons and lithology of the Lower Goru Formation of Cretaceous age in the Sawan Gas Field.

Materials and methods

The data set used in this study includes complete suite of wireline logs (GR, density, neutron, resistivity, sonic, SP and caliper logs) of Sawan-01 and Sawan-02 wells. Geophysical logging defines the constituents, changeability and physical characteristics of the rocks nearby the well bore thus aiding to understand the subsurface reservoirs at a cheaper cost. Geographix software of Landmark Resources (LMKR) was used for interpretations of logs.

Clay Volume

The fundamental use of Gamma Ray Log (GR) is calculation of volume of shale (Vsh) in a formation versus depth. For clay volume calculation, the given below linear equation was adopted (Rider, 1996):

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Where, V_{sh} = volume of shale; GR_{log} = GR log reading; GR_{max} = maximum GR log; and GR_{min} = minimum GR log

Porosity

The primary porosities of a formation like Density porosity (Φ_D), Sonic porosity (Φ_S), Average porosity (Φ_A), Effective porosity (Φ_E) and Neutron porosity (Φ_N) were calculated using the following formulae (Asquith and Gibson, 1982; Crain, 1986; Rider, 1996):

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}$$

$$\phi_A = \frac{\phi_N + \phi_D}{2}$$

$$\phi_E = \phi_A \times (1\text{-}Vsh)$$

Where, ϕ_D = density porosity; ρ_b = density from log; ρ_{ma} = matrix density and ρ_f = fluid density; ϕs = sonic porosity; Δt log = interval transit time from log; Δtma = interval transit time of matrix, and Δtf = interval transit time of fluids; ϕ_N = neutron porosity; ϕ_A= average porosity; ϕ_E = effective porosity

Permeability

The spontaneous potential log measure the ionic movement in a formation which is the indication of permeability because the impermeable zone not allow this movement, so deflection of SP log (positive or negative) is used to detect permeable zones in a reservoir. Similarly the formation of different invaded zones adjacent to well bore are also good indicators of permeability (Asquith and Gibson, 1982; Crain, 1986; Rider, 1996). The lower Goru Formation is observed as good reservoir in terms of permeability in the studied wells as shown in Fig. 4.

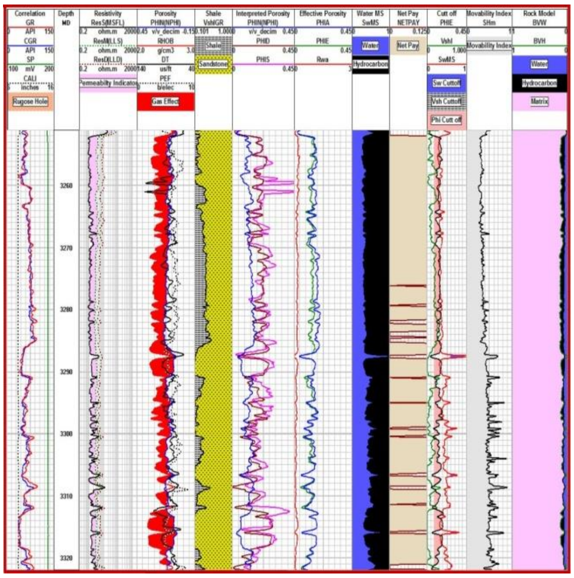

Fig. 4. Logs interpretation of the Lower Goru Formation in well Sawan-01.

Formation water resistivity (Rw)

The formation water resistivity (Rw) for the Lower Goru Formation is calculated by apparent resistivity method (Rwa) (Rider, 1996).

Water and Hydrocarbons saturation

The water saturation (Sw) in the formation was calculated by using Modified Simindox equation and hydrocarbon saturation (Shc) was calculated by the following equation (Rider, 1996):

$Shc = 1 – Sw$

Bulk Volume of Water (BVW)

The bulk volume of water (BVW) is the portion of the entire volume of rock filled by water. BVW values indicate grain size variation in clastic sedimentary rocks (Fertl and Vercellino, 1978). It is determined by the following formula (Asquith and Gibson, 1982; Crain, 1986):

$BVW = \phi_E \times Sw$

Movability of Hydrocarbons

The Moveable Hydrocarbon Index (MHI) is the proportion of water saturation in uninvaded zone to the water saturation in flushed zone (Sw/Sxo). It is utilized for the evaluation of movability of fluids in the reservoirs, and also gives information about the qualitative permeability of a formation. If Sw/Sxo value is greater than 1 then the hydrocarbons are not moved during invasion even if formation contains hydrocarbons or not. But if it is less than 0.6 then hydrocarbons are moveable (Asquith and Gibson, 1982). The MHI was used to interpret the movability of hydrocarbons in the Lower Goru Formation. The results have been shown in Fig. 5.

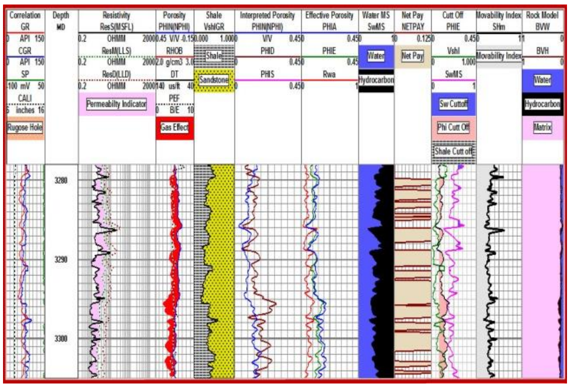

Fig. 5. Petrophysical interpretation of the Lower Goru in Sawan-02.

Net pay

The following cut-offs of the petrophysical parameters were applied for Net pay evaluation in the Lower Goru Formation of the studied wells:

$Vshl < 0.40$; $\Phi E > 7$, and $Sw < 0.50$

Results and discussions

Sawan-01

The Lower Goru Formation encountered in Sawan-01 ranging in depth between 3252 to 3322 m was evaluated for hydrocarbon potential (Fig. 4).

It has thickness of 70 m in Sawan-01. The average Vsh, ϕ_E, Sw and Shc is 15.25%, 12.58%, 38.62% and 61.38% respectively (Fig. 4).

Based on very low clay volume and high effective porosity, the Lower Goru Formation is clean and permeable implying hydrocarbon will move easily during production. The water saturation as interpreted by different logs behavior is low, so this formation in Sawan-01 well has economical potential for hydrocarbons.

The borehole conditions are good in the whole studied zone of the formation depicting no rugosity was observed.

Due to lack of cavities/cave-in the interpreted parameters are reliable. These calculated petrophysical parameters indicate that the Lower Goru Formation is clean having good primary porosity with high potential of hydrocarbons. Movability of hydrocarbon is important factor during production from the well. As the moveable hydrocarbon index (MHI) value is greater than 0.6 throughout the formation, so the hydrocarbons are also movable. Based on well logs interpretation, lithology of the Lower Goru Formation in Sawan-01 is dominated by sandstone (Fig. 4). According to BVW values, sandstone of the Lower Goru Formation in Sawan-01 varies from fine to very fine grained sandstone (dominant). The interpreted petrophysical parameters are given in table 1.

Table 1. Petrophysical results and BVW-derived grain size of the Lower Goru Formation in Sawan-01.

Depth interval (m)	Vsh %	PHID %	PHIN %	PHIA %	PHIE %	SwMS %	ShMS %	BVW	Grain size
3252-3257	13.06	12.50	07.96	10.23	08.84	36.80	63.20	0.0376	fine
3257-3262	17.94	23.46	11.08	17.27	14.17	32.63	67.37	0.0564	very fine
3262-3267	21.79	19.69	13.46	16.57	12.96	34.91	65.09	0.0579	very fine
3267-3272	10.65	21.97	12.44	17.20	15.37	31.53	68.47	0.0543	very fine
3272-3277	19.35	18.68	13.59	16.13	13.01	34.59	65.41	0.0558	very fine
3277-3282	19.74	22.73	14.15	18.44	14.80	33.54	66.64	0.0618	very fine
3282-3287	32.49	15.76	17.02	16.39	11.07	36.20	63.80	0.0593	very fine
3287-3292	07.59	21.03	09.04	15.04	13.89	38.05	61.95	0.0572	very fine
3292-3297	25.85	12.90	15.08	13.99	10.37	45.37	54.63	0.0635	very fine
3297-3302	05.84	16.27	12.12	14.19	13.36	42.20	57.8	0.0599	very fine
3302-3307	12.93	15.76	13.43	14.59	12.71	42.22	57.78	0.0616	very fine
3307-3312	0	14.41	08.38	11.39	11.39	50.49	49.51	0.0575	very fine
3312-3317	25.80	03.31	14.68	08.99	06.67	47.16	52.84	0.0424	fine
3317-3322	0	28.42	06.55	17.48	17.48	45.06	54.94	0.0613	very fine
Average	15.25	17.63	12.07	14.85	12.58	38.62	61.38	-	-

Sawan-02

One reservoir zone in the Lower Goru Formation was marked in Sawan-02 well having 25 meters thickness ranging between 3280 - 3305 m depth (Fig. 5). The average Vsh, ϕ_E, Sw and Shc is 9.7%, 12.11%, 46.61% and 53.39% respectively (Fig. 5). The borehole size is not disturbed and the formation is clean according to GR log interpretation. Different porosity logs were used for effective porosity calculation, which play a keen role in reservoir resulted sufficient porosity for hydrocarbon accumulation in the studied zone of the formation.

Separation between different resistivity logs of invaded and uninvaded zone is existing, clarifying the formation in Sawan-02 well is permeable. The hydrocarbon saturation is more than 50 % after applying suitable standard equation, so the reservoir has potential for storage of hydrocarbons. Based on well logs interpretation, lithology of the Lower Goru Formation in Sawan-01 is dominated by sandstone (Fig. 5). According to BVW values, the grain size of sandstone of the Lower Goru Formation in Sawan-02 varies from very fine (dominant) to silt size. The interpreted petrophysical parameters are given in Table 2.

Table 2. The average values of petrophysical parameters of the Lower Goru Formation in Sawan-02.

Depth interval (m)	Vsh %	PHID %	PHIN %	PHIA %	PHIE %	SwMS %	ShMS %	BVW	Grain size
3280-3285	11.05	16.78	11.13	13.95	12.41	49.96	50.04	0.0697	very fine
3285-3290	12.79	12.38	07.59	09.99	08.71	55.79	44.21	0.0557	very fine
3290-3295	05.66	17.17	08.56	12.86	12.14	45.83	54.17	0.0590	very fine
3295-3300	05.36	20.12	08.52	14.32	13.55	36.97	63.03	0.0530	very fine
3300-3305	13.64	17.83	13.96	15.90	13.73	44.52	55.48	0.0708	silt
3305	15.14	13.61	11.82	12.72	10.79	62.66	37.34	0.0797	silt
Average	09.70	16.86	09.95	13.40	12.11	46.61	53.39	-	-

Between the Lower Goru Formation of Sawan-01 and Sawa-02 wells, the Lower Goru Formation in Sawan-01 is comparatively a good reservoir having high average $\phi_E$and average Shc than Sawan-02 well, however, average Vsh is low in Sawan-02 well as compared to Sawan-01. The lithology of the Lower Goru Formation in either wells is identical with variation in grain size (Figs. 4 and 5).

Conclusions

Petrophysical evaluation confirms that the Lower Goru Formation is a good reservoir in the Sawan Gas Field having average effective porosity 12.58, 12.11%, Vsh15% and 9%, and saturation of hydrocarbons (Shc) is 61% and 53% in both wells i.e. Sawan-01 and Sawan-02 respectively. The lithology of the Lower Goru Formation is dominated by sandstone as worked-out from geophysical logs. In either wells, sandstone of the Lower Goru Formation is dominated by very fine grain size together with fine and silt size grains.

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Nomenclature

List of symbols and abbreviations used

Symbols	Descriptions
GRlog	gamma ray log value in the zone of interest, API unit
GRmax	gamma ray log value in shaly bed, API unit
GRcln	gamma ray log values in clean zone, API unit
Vsh	volume of shale
Δ t	travel transit time measured from log curve
Δ Tmat	travel transit time in matrix
Δ T f	travel transit time in fluid
Sw MS	water saturation using modified Simindox equation
ShMS	hydrocarbons saturation using modified Simindox equation
Sxo	water saturation in flushed zone
MHI	moveable hydrocarbon index
PhiD	density porosity
PhiS	sonic porosity
PhiN	neutron porosity
PhiA	average porosity
PhiE	effective porosity
BVW	bulk volume of water

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