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Reservoir Characterization of Paleocene Clastics and Carbonates in Chanda-01 Well, Kohat Basin, Khyber Pakhtunkhwa, Pakistan: A Petrophysical Approach

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ABSTRACT

The present study deals with the reservoir characterization of Paleocene reservoirs in Chanda-01 well drilled in the Kohat Basin, Pakistan. The petrophysical evaluation of the Paleocene Hangu Formation (clastics) and Lockhart Limestone (carbonates) have been carried out using conventional Petrophysical logs. The petrophysical parameters estimated include volume of shale (V_{sh}), density porosity (ϕ_D), neutron porosity (ϕ_N), sonic porosity (ϕ_S), average porosity (ϕ_A), effective porosity (ϕ_E), qualitative permeability, water saturation (S_w) and hydrocarbon saturation (S_{hc}). One possible pay zone with 14 m thickness has been marked in the Hangu Formation and one having 10 m thickness in Lockhart Limestone after detailed interpretations. In zone A of the Hangu Formation, average petrophysical values like V_{sh}, ϕ_A, ϕ_E and S_{hc} are 4%, 24%, 22% and 88%, respectively. The reservoir zone of Lockhart Limestone has the average values of V_{sh} 4%, ϕ_A 5%, ϕ_E 4% and S_{hc} 85 %. Between the studied Paleocene reservoirs Hangu Formation has high porosity, while the Lockhart Limestone has less porosity. Based on the ϕ_N and bulk density cross-plot, the lithology of Hangu Formation and Lockhart Limestone is dominated by sandstone and limestone, respectively.

1. Introduction

The well Chanda-1 well is located in Kohat Basin, Pakistan at 33° 13' 40.29" N; 71° 30' 50.93" E. The Upper Indus Basin is comprised of thick sequence of sedimentary rocks and has captivating structural deformation reflecting prospective precinct for generation and enmeshment of hydrocarbons [1, 2]. In the past 20 years, numerous hydrocarbons discoveries have been accomplished within this basin [3]. During 1990 to 1993, three wells (Tolanj-1, Kahi-1 and Sumari-1) have been drilled in the Kohat Basin by AMOCO Pakistan but there was no production. However, the different discoveries of oil and gas in the area such as Manzalai, Makori, Mela and Chanda reveal that this basin has high hydrocarbons potential.

The study well is situated in Chanda Field, Shakardara Block which is operated by the Oil and Gas Development Company Limited (OGDCL). In this Block the first well ‘Chanda-01’ was drilled in 1998 to a depth of 4,788 meters (m) and the second exploratory well Chanda Deep # 01 was penetrated to a depth of 5,102 m.

2. Tectonics

The Indian and Eurasian plate’s collision produced the Kohat-Potwar basins on the southern part of the Himalayan and Karakoram orogenic belt [4]. The Kohat Basin is ~70 km widespread in North-South direction and is a part of the North Western Himalayan Fold and Thrust Belt, Pakistan. It is bounded to the North, South, East and West by the Main Boundary Thrust (MBT), Surghar Range Thrust, Indus River and Kurram Fault respectively (Fig.1). The Kohat Basin merges into Bannu Basin towards the South-West [5]. In the Kohat Basin, the MBT transports Mesozoic and younger strata over Neogene molasses sediments. The Surghar Range and Salt Range Thrust are divided by Kalabagh right lateral strike-slip fault. It is the most conspicuous North-South oriented structural feature at the southernmost border of the Kohat-Potwar Foreland Fold and Thrust Belt [6]. The Indus River divides the Kohat and Potwar basins [6]. Many petroleum prospects are generated by the structural style (deformation) of the Upper Indus Basin, Pakistan [7]. The area under investigation belongs to south-eastern part of the Kohat Basin (Fig. 1).

3. Borehole Stratigraphy

The stratigraphy of Chanda-01 well begins from Jurassic Datta Formation and reaches up to Pleistocene Siwaliks group as shown in Fig. 2. Above the Jurassic sequence are Cretaceous rocks including Chichali and Lumshiwal formations. Lying above the Cretaceous sequence are Paleocene Hangu, Lockhart and Patala formations. The Eocene succession consists of Jatta Gypsum, Kuldana and Kohat formations. The Eocene rocks are followed unconformably by Miocene Rawalpindi group which consists of Murree and Kamlial formations, which is in turn overlain by Miocene-Pliocene Chinji and Nagri formations of Siwalik group.

4. Materials and Methods

The petrophysical analyses were performed using wireline logs. The logs used for the petrophysical analysis

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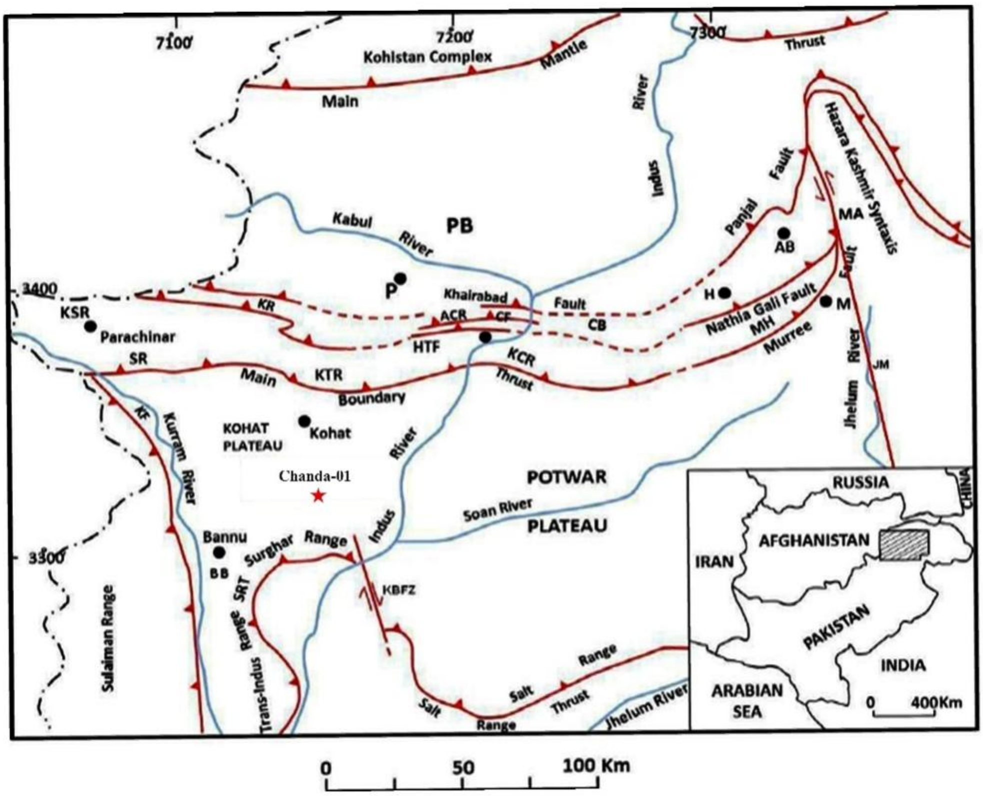

Fig. 1: Tectonic map of Northern Pakistan showing location of Chanda-01 well, Kohat basin [5].

of Chanda-1 well includes Bulk Density (RHOB), Gamma ray (GR), Neutron (NPHI), Resistivity, Sonic (DT), Spontaneous potential (SP) and Caliper (CALI). The GR log scale is 0-150 API, RHOB ranges from 1.95 to 2.95 g/cc, NPHI ranges from -0.15 to 0.45 v/v, SP scale ranges from 50 to -100 mV, the resistivity log scale used is 0.2-2000 ohm.m, and Caliper log scale is in the range of 6-16 inches. The petrophysical analyses were made to calculate volume of shale (V_{sh}), density porosity (ϕ_D), neutron porosity (ϕ_N), sonic porosity (ϕ_S), average porosity (ϕ_A), Effective porosity (ϕ_E), qualitative permeability, water saturation (S_w) and hydrocarbon saturation (S_{hc}). The above mentioned petrophysical parameters were calculated using the following formulae [10-12].

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \tag{1}$$

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \tag{2}$$

$$\phi_A = \frac{\phi_N + \phi_D}{2} \tag{3}$$

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \tag{4}$$

$$\phi_E = \phi_T \times (1 - V_{sh}) \tag{5}$$

Where, GR_{log} = GR log reading, GR_{max} = maximumGR log, GR_{min} = minimumGR log; ρ_b = density from log,

Age	Formation	Thickness (m)	Depth (m)	Lithology	Description
Miocene	Nagri	438	0000.000		Sandstone with minor clay
	Chinji	1604	0438.000		Clay and sandstone
Miocene	Kamlial	639	2042.000		Sandstone, shale and conglomerate
	Murree	1284	2681.000		Clay, sandstone and conglomerate
Eocene	Kohat	07	3965.000		Limestone and shale
	Kuldana	126	3972.000		Red clays
	Jatta	36	4098.000		Gypsum
Paleocene	Patala	134	4134.000		Shale and limestone
	Lockhart	207	4268.000		Limestone
	Hangu	50	4475.000		Sandstone
Cretaceous	Lumshiwal	18	4525.000		Sandstone
	Chichali	34	4543.000		Sandstone and shale
Jurassic	Samana Suk	85	4577.000		Limestone
	Shinawari	89	4662.000		Limestone, sandstone and shale
	Datta	37.7	4751.000		Sandstone
Legend	Limestone	Sandstone	Shale	Gypsum	Conglo-merate / Unconformi-ty

Fig. 2: Borehole stratigraphy of Chanda-1 well, Kohat basin, Pakistan (lithological description is adopted from [9]. The studied formations are highlighted by yellow color.

ρ_{ma} = matrix density, ρ_f = fluid density; Δtlog = interval transit time from log, Δtma = interval transit time of matrix, Δtf = interval transit time of fluids; ϕ_T = total porosity

(S_w) has been calculated through Archie equation as follows [12].

$$Sw = [(\frac{a}{\phi^m})(\frac{Rw}{Rt})]^{1/n} \quad (6)$$

Where, S_w = water saturation, ϕ = porosity,

R_w= formation water resistivity, R_t= true resistivity, a= tortuosity factor, m= cementation factor and n= saturation exponent. The hydrocarbon saturation (S_{hc}) has been assessed by the following equation [11].

$$Shc = 1 - Sw \quad (7)$$

The prerequisite (GR_{min}, GR_{max}, Rho_m, Rho_f, ΔT_m, ΔT_f and R_w) for calculating the petrophysical parameters are given in Table 1. The lithology is assumed to be pure sandstone and limestone for the Hangu Formation and Lockhart Limestone respectively.

Table 1: Petrophysical parameters values for the Hangu formation and Lockhart limestone.

Petrophysical parameters	Hangu Formation	Lockhart Limestone
GRmin (API)	30	30
GR max (API)	140	120
Rhom (g/cm)	2.64	2.71
Rhof (g/cm)	1.1	1.1
ΔTm (µs/ft)	55	47
ΔTf (µs/ft)	189	189
RwOhm.m	0.06	0.07

5. Results and Discussions

5.1. Marking Reservoir Intervals

The reservoir intervals were identified on the basis of different logs behavior such as low GR log values, high effective porosity and high resistivity and water saturation etc, with good borehole size as evaluated by caliper log. For assessment of porosity [12] the classification as given in Table 2 has been adopted.

Table 2: Qualitative assessment of porosity for a reservoir rock.

Average Porosity (%)	Qualitative Description
0 – 5	Negligible
5 – 10	Poor
10 – 20	Good
20 – 30	Very Good
> 30	Excellent

5.2. Petrophysical Evaluation of the Hangu Formation

The Hangu Formation is 50 m thick with depth ranges from 4475 to 4525 m (Fig. 3). One reservoir zone named zone A ranging in depth from 4490-4503 m having 14 m thickness has been marked as zone of interest in the Hangu Formation after detail interpretation (Fig. 3). In this zone the average volume of shale, density, sonic, neutron, average and effective porosities, water and hydrocarbon saturation are 4%, 16 %, 3 %, 32 %, 24 %, 22 %, 12 % and 88 % respectively as shown in Table 3. The qualitative description of porosity of zone A is called as very good as given in Table 2. This zone is the best reservoir with appreciably low volume of shale, very good average and effective porosity and high hydrocarbon saturation.

Table 3: Petrophysical summary of Zone A in Hangu Formation.

Petrophysical parametersValues	
Volume of shale (Vsh)	4%
Density porosity (ϕ_D)	16%
Sonic porosity (ϕ_s)	3%
Neutron Porosity (ϕ_N)	32%
Average porosity (ϕ_A)	24%
Effective porosity (ϕ_E)	22%
Water saturation (SwA)	12%
Hydrocarbon saturation (Shc)	88%

Table 4: Petrophysical summary of Zone A in Lockhart Limestone.

Average petrophysical parameters of Zone A in Lockhart formation	
Volume of shale (Vsh)	4%
Density porosity (ϕ_D)	7%
Sonic porosity (ϕ_s)	4%
Neutron Porosity (ϕ_N)	0.02%
Average porosity (ϕ_A)	5%
Effective porosity (ϕ_E)	4%
Water saturation (SwA)	15%
Hydrocarbon saturation (Shc)	85%

5.3. Petrophysical Evaluation of Paleocene Lockhart Limestone

The Lockhart Limestone in this well is 207 m thick ranging from 4268 m to 4475 m. The formation is comparatively with low porosity. Only one zone named as zone A has been finalized for hydrocarbon potential evaluation with 10 m net pay thickness ranges in depth from 4440 m to 4450 m having qualitative permeability. The average petrophysical values are shown in Fig. 4 and Table 4. By applying shale, porosity and water saturation cut off values as < 30%, > 3% and < 40% respectively a 10 m Net pay in Zone A has been determined.

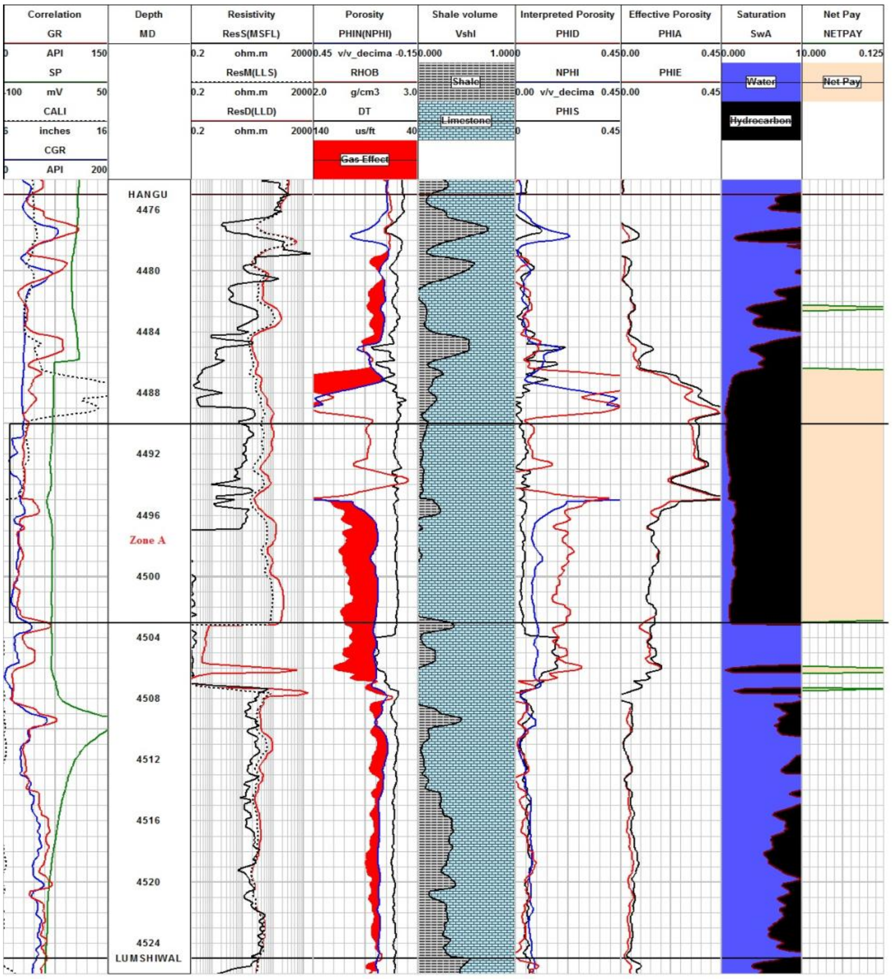

Fig. 3: Petrophysical interpretation of Zone A (4490-4503 m) in Hangu Formation.

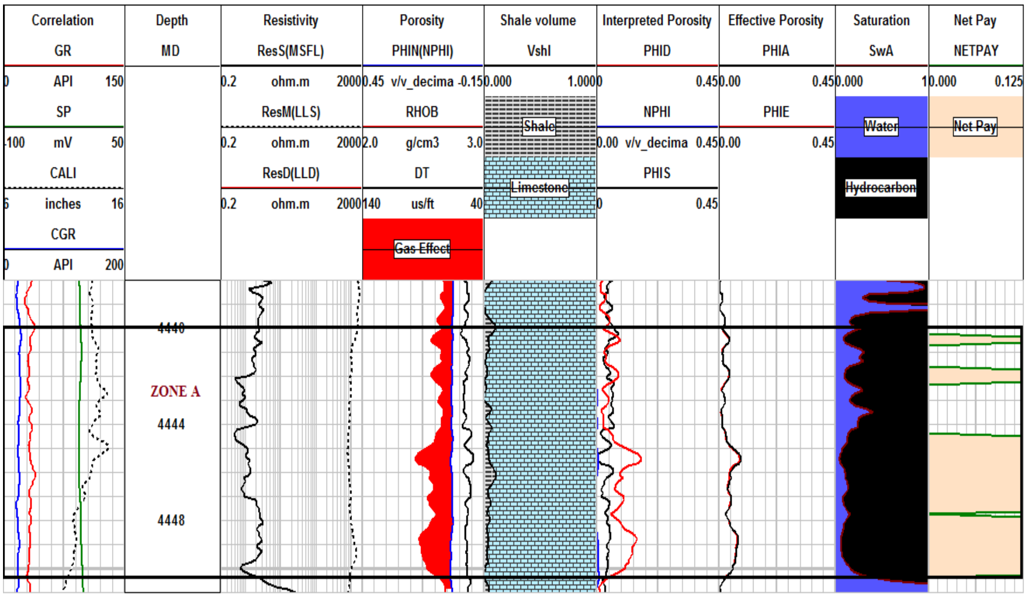

Fig. 4: Petrophysical interpretation of the Lockhart Limestone.

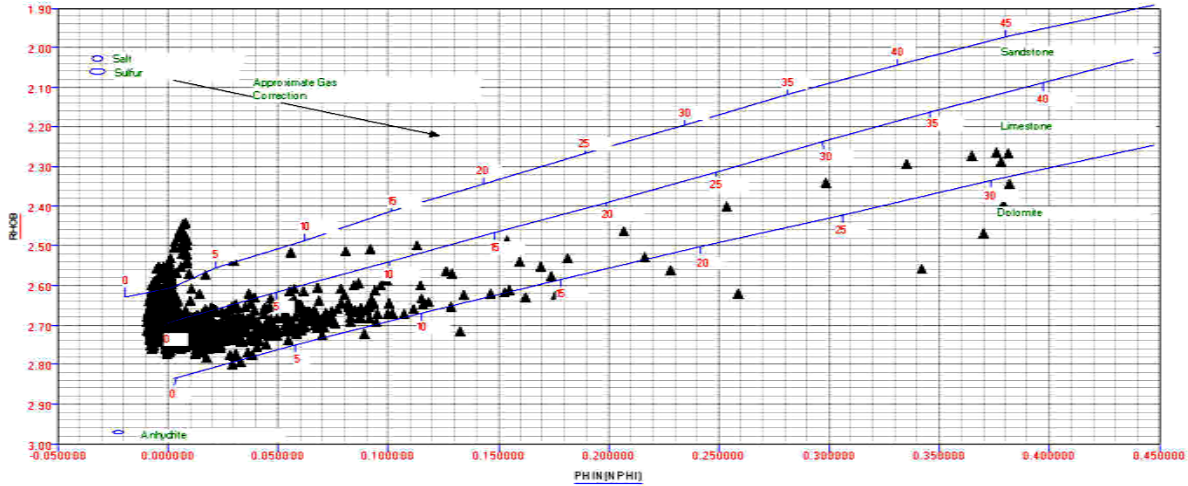

Fig. 5: NPHI-RHOB cross-plot showing lithology of the Lockhart Limestone modified after [13].

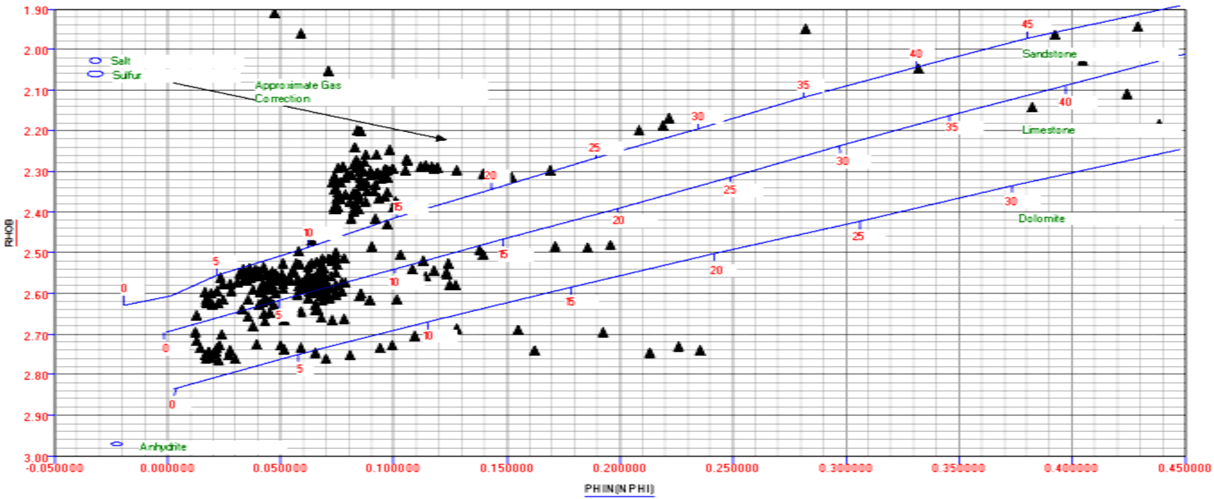

Fig. 6: NPHI-RHOB cross-plot showing lithology of the Hangu Formation modified after [13].

5.4. *Lithology Identification of the Studied Formations*

The lithology of the Hangu Formation and Lockhart formations has been constructed using the NPHI and RHOB cross-plot [13]. The lithology of the Hangu Formation is dominated by sandstone while that of the Lockhart Limestone comprised predominantly of limestone (Fig. 5 and Fig. 6). According to Babar et al and Shah [12 and 14], the lithology of the Hangu Limestone is sandstone and Lockhart Formation is dominantly limestone in Kahi-01 well of the Kohat Basin, Pakistan.

6. Conclusions

After petrophysical interpretations of the whole Hangu Formation one zone called Zone A has been finalized for hydrocarbon potential which is clean, permeable having very good average and effective porosities, with high hydrocarbon saturation. Zone A of the Lockhart Limestone has low primary porosity with low clay volume and water saturation, so it has good hydrocarbon potential. Rest of Lockhart limestone is water wet and has less porosity. Between the Hangu Formation and Lockhart Limestone, the former one has very high porosity but hydrocarbon saturation is almost same. Based on the ϕ_N and bulk density cross-plot, the lithology of Hangu and Lockhart formations have been evaluated as sandstone and limestone respectively. It is concluded that studied zones of Paleocene formations have high prospective for an economically practicable hydrocarbon production.

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