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Petrophysical Analysis to Map Geological Significance of Sawan Gas Field, Sindh, Pakistan

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ABSTRACT

This study is aimed to identify hydrocarbon-bearing zones and mapping of lithofacies in productive zones with the help of petrophysical logs. We have followed a systematic petrophysical examination of three wells Sawan-01, Sawan-05 and Sawan-07. Four gas-bearing zones have been identified in Cretaceous sands of Lower Goru Formation. Petrophysical logs are utilized for discrimination of lithological, porosity and fluid based characteristics of productive sand packages out of thick interbedded shales. The low response of Gamma Ray (GR) log discriminates sandstone beds from shale in the understudy zones. GR log also contributed to know the lithofacies distribution in the suspected productive gas zones (PGZ) which suggest the depositional environment of Cretaceous sands. The plots of neutron porosity (NPHI) and bulk density (RHOB) show the sampled point data density across the sandstone axis on NPHI-RHOB cross plots which validate the lithology and gas-presence in the reservoir zones. The reservoir traits (shale content, effective porosity, water saturation and respective gas potential of the zones) are estimated and ranked, accordingly. The best productive gas zone is identified in Sawan-5 well based on values of hydrocarbon saturation and effective porosity that is 0.86 % and 0.13% respectively.

Keywords: *Sawan, Petrophysical evaluation, Lower Goru, Cretaceous sands*

1. Introduction

Sawan gas field (SGF) is located in the Central Indus Basin, Pakistan which is contributing 61.7 mmscf per day in gas production of Pakistan [1]. There are other major gas fields such as Miano, Kadanwari and Mari located in the vicinity of SGF. Therefore, the study area is attractive for future exploration activities (Fig.1a and 1b). The Sawan concession area has been well-studied to model structural geometries using seismic surveys which helped in subsequent phases of exploration and exploitation [2, 3]. The interpretation and mapping of seismic data suggest that SGF can be geologically divided into two distinct parts, Sawan North and Sawan South. Both parts are separated by a north west–south east trending strike-slip fault [4] covering a regional extension of the block (212 km^2). Sawan North is a highly permeable and configured good quality sandstone reservoir, with maximum net pay over 100 meters [5]. SGF is affected by extensional tectonics, thereby the structural traps are enriched with hydrocarbons. The seismic interpretation by Ahmad and Khan [6] revealed that SGF and neighboring fields are characterized dominantly with normal faulting and associated strike-slip component (N-NW to S-SE). The faulting characteristics implicate in defining structural traps and distribution of Cretaceous sand along with the throw of these faults. It is evident from the earthquake studies and fault plane solution that the nature of Tertiary faults is trans-tensional [7]. The distribution of basin-fill deposits is spatially disturbed under the influence of tectonic episodes in the central and lower Indus Basin [6, 7].

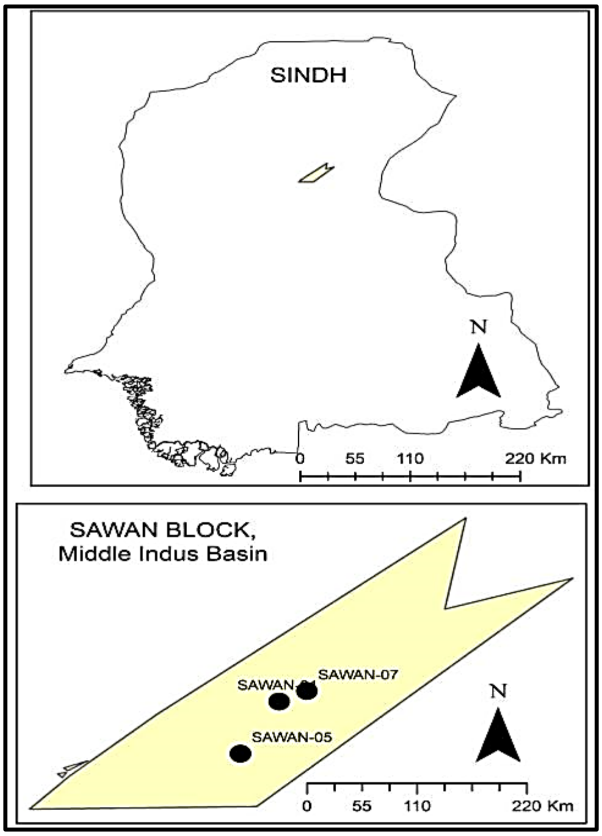

Fig. 1a: The geographical location of Sawan gas field in the maps and the wells used in the petrophysical examination of the Sawan gas field.

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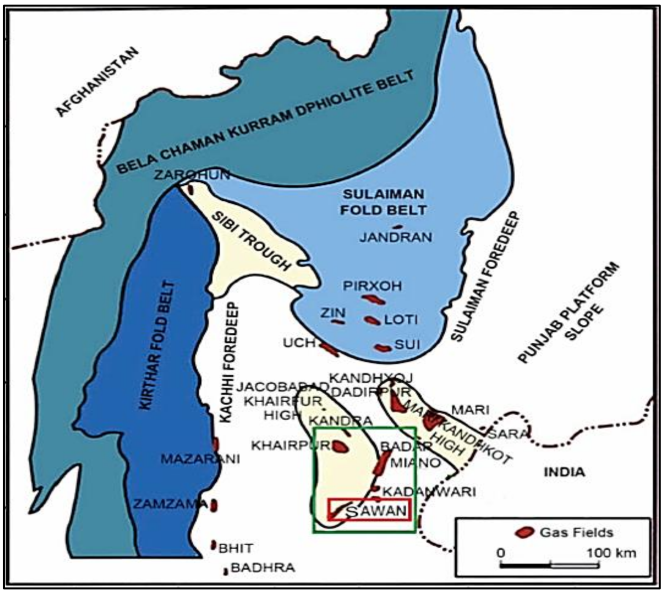

Fig. 1b: Location of Sawan gas field in the northeast of Sindh, Pakistan. Regional tectonic map of Sawan gas field in the Middle Indus Basin (After [6]).

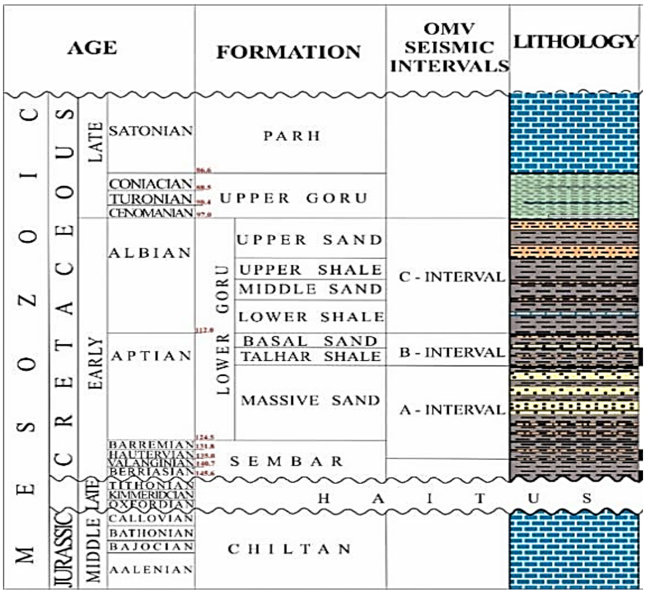

Fig. 2: Generalized stratigraphic sequence of Middle Indus Basin (adopted as [7])

The regional tectonic setting of the area depicts that SGF is bounded in northeast by Mari-High, Jacobabad-High in northwest, Tharparker-High in southeast, and Lower Indus trough in southwest (Fig. 1b). The geological architecture of SGF was influenced by three post-rift tectonic events: Late Cretaceous-uplift and erosion of rocks form high land areas, Late Paleocene-northwest trending wrench faulting (thick-skinned) and Late Tertiary to Recent-tectonic uplift of the Jacobabad-Khairpur High (northwest of SGF) [8]. This tectonic uplift halted the depositional influx of Goru Formation in proximal depositional systems positioned in structurally deep areas of the basin [9]. These areas contributed in the formation of structural/stratigraphic traps of multiple oil and gas producing fields including the Sawan field [10] by placing non-reservoir distal shales up-dip to form major structural and stratigraphic traps [11].

The stratigraphic succession of basin-fill deposits is shown in chronological order in Fig. 2. The Sembar Formation represents early Cretaceous strata (dominantly comprises organic-rich black shales and minor amounts of black siltstone, sandstone and nodular limestone which is thermally mature and fueled the gas in SGF and other established neighboring fields in the region [12-14]. Lower Goru Formation is underlain by the Sembar Formation, which is a distinct reservoir (medium to coarse-grained sand) of SGF (Fig. 2). The Lower Goru Formation was deposited in deltaic shallow-marine environments [2].

Petrophysical data analysis helps in petroleum exploration projects across the globe. A petrophysical log registers the rock response of physical characteristics like rock density, porosity, resistivity, radioactivity, etc., recorded along the depth axis of the borehole [7]. The petrophysical logs are essential for reservoir modeling based on volume of shale, effective porosity, pore-fluid type and hydrocarbons saturation. These estimates play a vital role in reservoir genesis, petroleum system modeling, prospect opportunities, risk assessment and production estimates [2, 15-17]. Petrophysical logs (such as Gamma Ray (GR), Sonic (DT), Self-Potential (SP), Latero Log Deep (LLD), Latero Log Shallow (LLS), Neutron Porosity (NPHI) and Bulk Density (ROHB)) can contribute to formation evaluation in absence of core data along with other types of logs [18]. Since the scale of seismic and Petrophysical logs are different, the petrophysical analysis seldom supports the multi-dimensional seismic signatures in hydrocarbon exploration [19, 20]. The objectives of this study are to evaluate petrophysical characteristics of Cretaceous sandstone deposits of Lower Goru Formation to delineate hydrocarbon potential and to understand the variations of lithofacies within productive zones in the SGF.

2. Dataset

The well log data of three wells namely Sawan-01, Sawan-05 and Sawan-07 are utilized in this study. The well logs data were provided by Directorate General of Petroleum Concessions, Pakistan. Table 1 summarizes the basic information of Petrophysical logs including GR, DT, LLD, LLS, NPHI, RHOB, and SP. These logs are interpreted for petrophysical evaluation of Lower Goru formation.

Table1: The well log data of understudy wells in SGF.

Basic dataset available	Sawan-01	Sawan-05	Sawan-07
Latitude (X)	26.99	26.95	26.99
Longitude (Y)	68.90	68.88	68.92
Gamma Ray Log (GR)	14.3 – 3503 (m)	50-3374 (m)	50-3395 (m)
Sonic Log (DT)	300-3500 (m)	1327-3372 (m)	328-3395.3 (m)
Bulk Density Log (RHOB)	3040-3502 (m)	3127-3372 (m)	3128-3410 (m)

Neutron Porosity Log (NPHI)	3040-3502 (m)	3127-3372 (m)	3130-3404 (m)
Deep Resistivity Log (LLD)	289-3494 (m)	3134-3374 (m)	330-3402 (m)
Shallow Resistivity Log (LLS)	289-3494 (m)	3134-3374 (m)	330-3402 (m)
Total Depth (m)	3505	3375	3412

3. Methodology

The Petrophysical logs are utilized for interpretation of geological layers particularly emphasized on Cretaceous sand bodies encountered in the understudy wells. Reservoir evaluation of these sand bodies is performed by estimating petrophysical properties which include: (a) shale content, (b) effective porosity, (c) saturation of water as a pore fluid and (d) hydrocarbon saturation. Estimation of shale contents help in the identification of clean sand beds [5-7, 19]. The shale content is calculated by utilizing GR log which discriminates the clean sand packages based on measured natural radioactivity of the targeted zones [20, 21. Reservoir porosity plays a significant role in productive reservoir characterization [21]. The porosity is estimated by using the neutron, density and the sonic log. Sonic porosity exhibits acoustic-based measurements whereas neutron porosity and density porosity estimated on nuclear-based measurements [19-22]. The effective porosity (ϕ eff) is calculated in the clean sand reservoir zones, which represent the interconnectivity of the pore spaces. The hydrocarbon saturation (Shc) is a function of water saturation (Sw). These petrophysical parameters are helpful to define productive sand reservoir zones [22].

4. Results and Discussion

Interpretational techniques were applied through well log analysis to choose the zones of interest and estimated probable chances for the presence of the hydrocarbons. The results of this study can be grouped in two sets: (a) Petrophysical examination and (b) Lithofacies modeling. Overall, GR log profile shows sand and shale intervals in the selected wells. The petrographic studies revealed mineralogical characteristics of various intervals of LGF. B and C-intervals of LGF are the main reservoir of SGF, which exhibit high porosity and permeability (at 3000 - 3500 meters); however, shales and siltstones of the upper Goru act as a regional seal.

4.1 Petrophysical Interpretation

The top and bottom of the clean sand reservoir zone is identified by critical analysis of petrophysical logs (GR, resistivity logs, NPHI and RHOB). We have interpreted four productive gas zones (PGZ) in potential wells. The prospective reservoir zone characterized with potential gas-bearing characteristics is named as PGZ-1 in Sawan-01 well. The zone ranges in depth between 3326 to 3328.5 m in Sawan-01, Fig. 3a depicts the analytical view of the zone of interest. It has a thickness of 2.5 m, the reservoir characteristics of this zone are evaluated based on petrophysical analysis. The average Vsh is 32.465%, average Sw is 19% and effective porosity is 10.3%. The average hydrocarbon saturation is calculated 81% (Table 2).

The productive gas zone, i.e., PGZ-2 is marked in well Sawan-05 having a thickness of 14 meters ranging between 3276 - 3290 m depth (Fig. 3b). The average saturation of water is 13%, hydrocarbon saturation is 87% and effective porosity is 12.86% (Table 2). Different porosity logs were utilized for effective porosity calculation, the separation between different resistivity logs of invaded and uninvaded zones showed that the sand beds in Sawan-05 well are permeable. Therefore, the gas potential is very high in sand beds of Lower Goru Formation.

Two productive zones, PGZ-3 and PGZ-4 are interpreted in Sawan-07 well, which lie between 3327-3330.5 meter and 3332-3335 meter, respectively (Fig. 3c). Petrophysical interpretation shows that the average hydrocarbon saturation in both the productive zones are 56% and 52% and effective porosities are 19.5% and 11.3%, respectively (Table 2). The Petrophysical results are more promising for Sawan-1 and Sawan-5 wells, having good hydrocarbon saturation, good effective porosity and low water saturation.

The cross-plots of NPHI and RHOB are presenting qualitative data of the respective zones which validate the presence of gas in the identified sandstone packages of the reservoir (Fig. 3d, 3e and 3f).

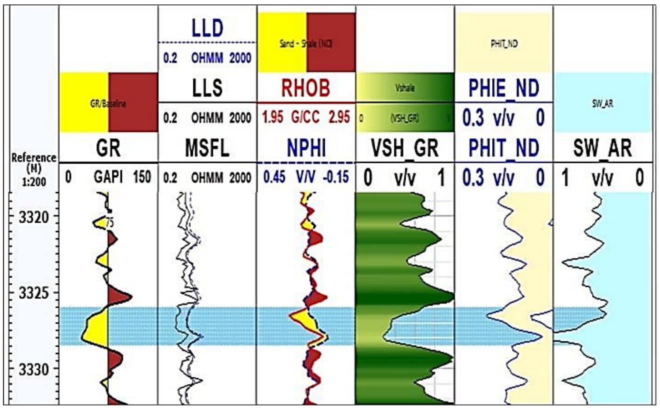

Fig. 3a: Selected zone of interest (shaded blue) in Sawan-01.

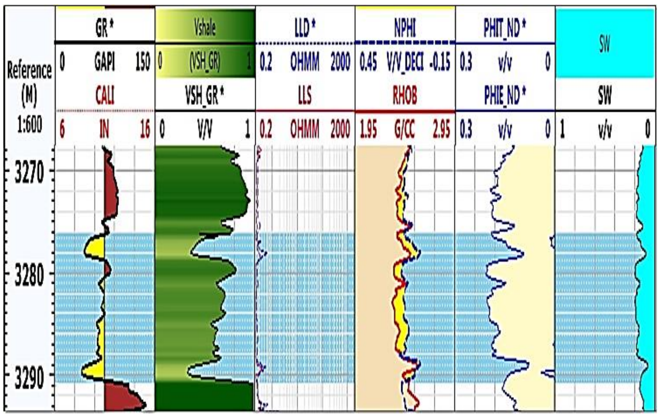

Fig. 3b: Selected zone of interest (shaded blue) in Sawan-05.

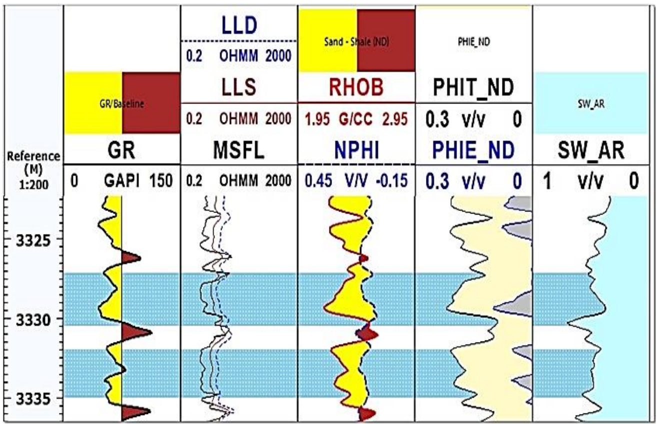

Fig. 3c: Selected zone of interest (shaded blue) in Sawan-07.

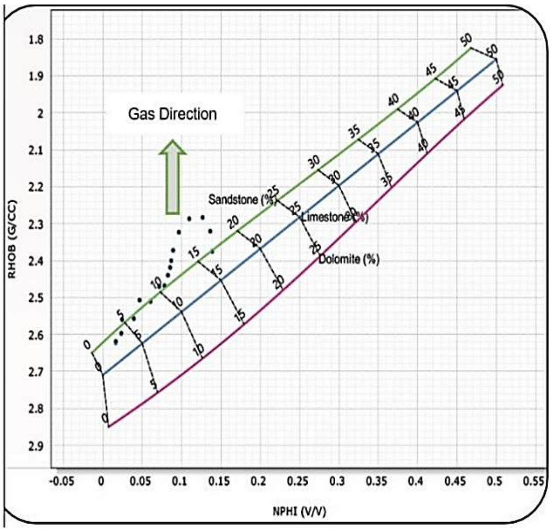

Fig. 3d: Cross Plot of NPHI and RHOB for selected zone in Sawan-01.

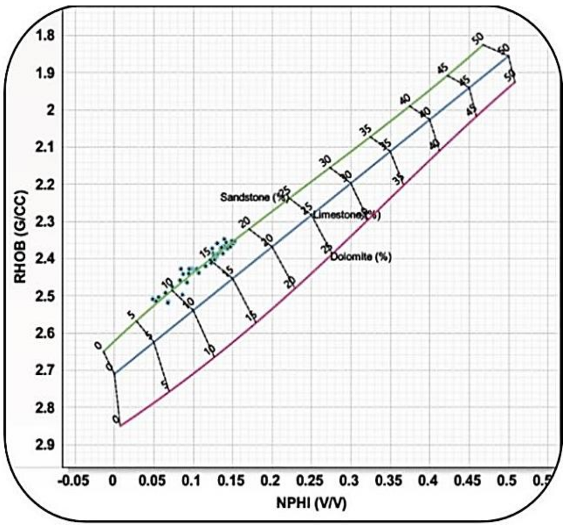

Fig. 3e: Cross Plot of NPHI and RHOB for selected zone in Sawan-05.

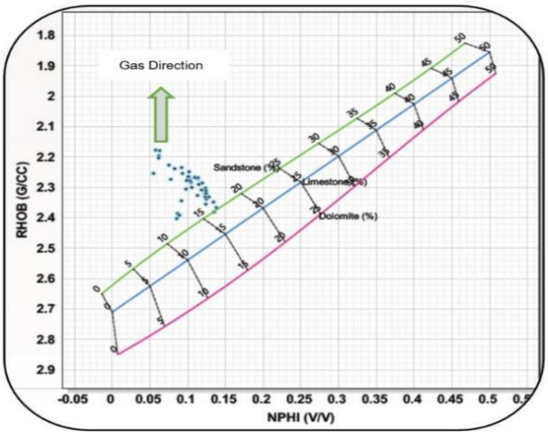

Fig. 3f: Cross Plot of NPHI and RHOB for selected zone in Sawan-07.

Table 2: Petrophysical evaluation of prospect zones in the understudy wells.

Proposed Gas Zone	Depth (m)	ϕ_{eff} (%)	S_w (%)	S_{HC} (%)	Thick. (m)
PGZ-1	3326-3328.5	10.3	19	81	2.5
PGZ-2	3276-3290	12.86	13	87	14
PGZ-3	3327-3330.5	19.5	44	56	3.5
PGZ-4	3332-3335	11.3	48	52	3

4.2 Facies Analysis

Geological facies are rock bodies having some specific characteristics which distinguish it from the others. Generally, facies are distinctive rock units, deposited under certain conditions of sedimentation and contemporaneous depositional environments, laterally and vertically as explained by Walther's law [23]. Thereby the interpretation of the lithofacies contributes to map the depositional environment of basin-fill sedimentary deposits, to get information about the successive sea-level changes, the interplay between sediment supply and accommodation space [16]. Under the influence of seal level changes, the shoreline deposits exhibit migration.

The differentiation between shale and sand has been a challenge for the geoscientists during the interpretation of Lower Goru Formation. In this process, the key task is identifying the facies, from logging and core data, and degree to which the shale content affects the reservoir properties [24]. Lithofacies modeling helped in marking sand beds within thick interbedded shales by utilizing GR log response. These sand beds can be correlated with the zones of interest which are identified during petrophysical interpretation. The Lower Goru Formation is a proven reservoir in the Sawan field as well as adjacent exploration and production (E&P) concessions. The Lower Goru Formation is composed of interbedded shale and sand packages [3]. The gamma-ray log behavior changes within sand beds having shaly concentrations. This lithological discrimination of sand and shale beds is known as lithofacies modeling.

The selected productive zones are further analyzed with respect to GR log for lithofacies modeling (Fig. 4a, b, c and d). The results of the gamma-ray show that facies modeling in respective wells which are helpful to interpret that the Lower Goru Formation was deposited in Sawan area under the falling sea level, i.e., during the period of regression. The regression conditions prevail when sediment supply exceeds the available accommodation space in the basin. As the accommodation space decreases, the further deposition of facies migrates toward distill side. These conditions result in the formation of an overall progradational sequence in which clinoform become thick and facies migrate from proximal to distill side. The sand deposition in the selected sequences (Fig. 4) validates the migration of sand bodies toward the proximal side and the shale towards the distill side. Coarsening upward, clayey-silty-sandy bodies and gas-bearing zones are characterized by low values of gamma-ray, high values of LLD resistivity log and crossover between neutron and density logs [23, 24]. These geological implications are identified as coarsening upward as indicated by GR log response. Changes in GR log response indicate the deposition of Lower Goru lithologies under eustatic control during geological times.

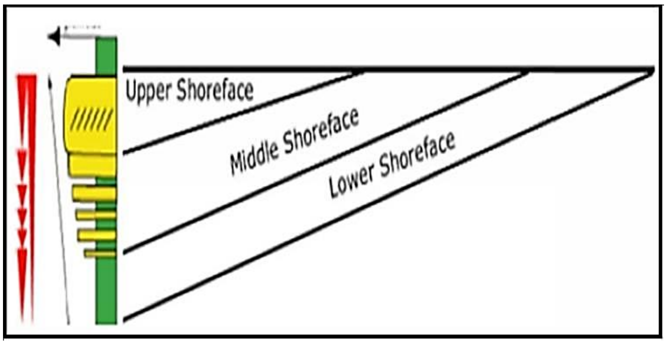

Fig. 4a: Schematic diagram of shore face distribution [24].

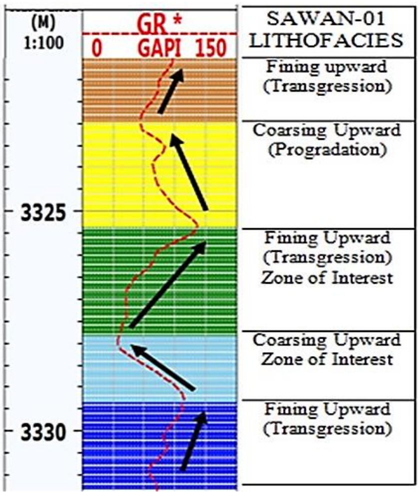

Fig. 4b: Interpretation of lithofacies distribution based on sequence stratigraphy using GR log motif in Sawan-01 well.

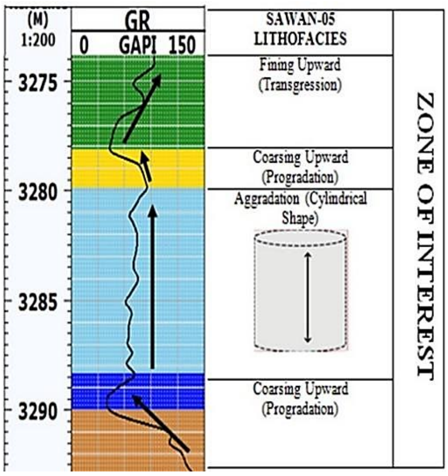

Fig. 4c: Interpretation of lithofacies distribution based on sequence stratigraphy using GR log motif in Sawan-05 well.

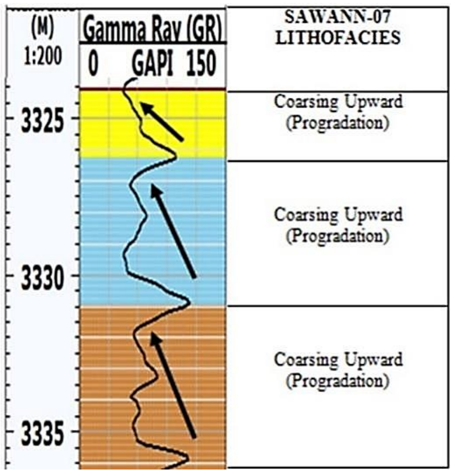

Fig. 4d: Interpretation of lithofacies distribution based on sequence stratigraphy using GR log motif in Sawan-07 well.

5. Conclusions

Gas-bearing sand beds have been identified in the Sawan field with the help of well logs response. Productive gas zones are identified in Sawan-1 and Sawan-5 wells which are promising zones due to good hydrocarbon saturation and high effective porosity. The best productive gas zone is ranked in Sawan-5 based on hydrocarbon saturation and effective porosity, i.e., S_{hc} 0.86% and 0.13%, respectively. GR log is used to interpret the lithofacies distribution in potential zones of Lower Goru Formation.

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