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Lower Goru Formation-3D Modeling and Petrophysical Interpretation of Sawan Gas Field, Lower Indus Basin, Pakistan

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ABSTRACT

Sawan Gas field is tectonically stable area as it is a part of Platform region and far away from collision zone. The present study deals with the interpretation of available seismic and well logs data to evaluate the subsurface structure to interpret the occurring of hydrocarbons in the study area of Lower Indus Basin. Seismic modeling (structural interpretations of seismic sections and 3D subsurface structure modeling) and petrophysical properties of reservoir were carried out in this work using the software SMT Kingdom Suite 8.3. Reflectors marked in all seismic sections are continuous with little folding there by indicating presence of subsurface stratigraphic-cum-structural traps. Petrophysical parameters point to presence of reservoir potentials at different depth in both wells due to low water saturation and good effective porosities.

1. Introduction

Sawan Gas field of Lower Indus Basin in Pakistan, is located (Fig. 1) in Khairpur district, Sindh province (26.98^0 N and 68.54^0 E).It was discovered in 1997 and became functional in July, 2003 with cumulative production of 850 bcf of Methane-rich gas accumulated in the C-Sand of Lower Goru Sands. In all, 15 wells were drilled and out of these, Sawan-7 well is producing most efficiently with a production of 130 Mmscfd [1]. Detailed information regarding the Sawan Field in the published literature is scarce.

Geologically, Pakistan is an important part of the world where ground mapping was carried out to evaluate structural models in the past. But, for subsurface investigations, drilling and seismic interpretation are used whereas petrophysical methods are applied to find rock properties and reservoir characteristics (like porosity, permeability, shale volume, etc.) to identify hydrocarbon traps. The present study deals with the interpretation of available seismic and well data to identify subsurface structure of the area for occurring of hydrocarbons in the study area, Lower Indus Basin.

Seismic modeling and petrophysical properties of reservoir were carried out in this work using the software SMT Kingdom Suite 8.3. In all, six seismic lines and well data were interpreted for evaluating hydrocarbon prospect and identification of petroleum plays in the subsurface of the study area.

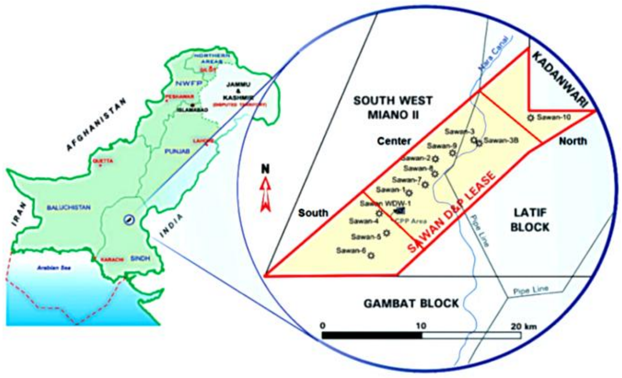

Fig. 1: Location of the Sawan Gas Field (modified after [2]

Following steps were performed during interpretation of results to visualize the results in 3-D using Kingdom Suite 8.3:

- Picking up reflectors of different formations or ages.
- Preparing time and depth contour maps.
- Adding wells in the software.
- Creating formation tops.
- Loading log curves in the softwares.
- Interpreting all yielded results listed above.

1.1 Tectonics

Pakistan is an active participant in ongoing collision of Indo-Pak and Eurasian Plates (55Ma) that involves continuous uplifting and erosion, transportation and

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Table 1. Stratigraphy of lower indus basin [10]

Period	Epoch	Formation	Lithology	Desciption
	Quateranry	Aluvium		Sandstone, Clay, Shale and Conlomerate
	Eocene	Kirthar		Limestone and Shale
		Laki		Limestone and Shale
Tertiary	Paleocene	Upper Ranikot		Shale and Sandstone
		Lower Ranikot		
		Parh		Limestone
	Upper	Upper Goru		Shale and Marl (Main Seal)
		Lower Goru		Shale and Sandstone (Main Reservoir and Source)
Cretaceous	Lower	Sember		Shale and Sandstone (Main Source)
JURASSIC	Upper	Chiltan		Limestone

Legend

Shale

Marl

Sandstone

Limestone

Conglomerate

deposition of the sediments. This collision has resulted in creation of a number of tectonic elements and structures in Pakistan and adjoining areas [3-4]. Indian Plate separated from Gondwanaland during Middle Jurassic and began to drift northward towards Eurasian Plate. Initial collision between Indian and Eurasian Plates took place at the end of Eocene. Indian Plate is still penetrating under Eurasian Plate and rotating anticlockwise slowly. Full scale collision during Oligocene resulted in second orogenic pulse in the Himalayas and caused uplift of Jacobabad and Mari Kandhkot Highs in the south. Marine sediments were restricted to a narrow but still rapidly subsiding trough in the Kirthar area [5].

Lower Indus Basin is bounded by the Sukkar Rift in the north, Indian Shield in the east, Murray Ridge-Oven Fracture Zone in the south and marginal zone of Indian Plate in the west. Chaman Transform fault separates Lower Indus Basin from Balochistan Basin. Middle and Lower Indus basins were same entity until Middle Cretaceous. The Jacobabad-Mari Kandhkot high became a positive area in Late Cretaceous and divided Middle and Lower Indus basins [6]. This is indicated by exposures of Chiltan Limestone (Jurassic) and Sembar Formation (Lower Cretaceous) across the High [7]. Southern Indus Basin is a vast sedimentary area (Fig. 2) and constitutes the southeastern part of Indus Basin. It has been divided into several physiographic units as from east to west [8] into Thar Platform, Karachi Trough, Kirthar Fore deep, Kirthar Fold Belt and Offshore Indus.

1.2 Stratigraphy

Lower Indus Basin is underlain by infra-Cambrian to Recent elastics and carbonates (Table 1). It remained passive margin until Late Cretaceous and then became a

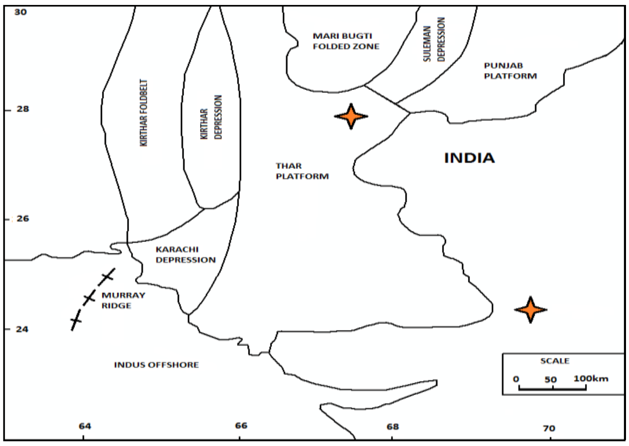

Fig. 2: Map showing division of lower Indus basin [9]

part of complex suture between Indian Plate and Afghan Block. Precambrian basement is exposed in S-E corner of the basin. Thickness of sediments increases to westward. Some important unconformities occur at base Permian and base Tertiary. In eastern part of Lower Indus Basin, Tertiary has direct contact with Jurassic sequence [10]. Table 1 is showing stratigraphy of the area.

2. METHODS

2.1 Seismic Data Presentation

Data in digital format was used for the interpretation of subsurface structure and petrophysical analysis. Seismic lines were in SEG-Y format which were used for subsurface structure analysis in the Kingdom Software. Navigation file (DAT file) was in text format used to attach the navigation to load the seismic lines. Information about well location was available in the header of the LAS file (a text file having some basic information of depth versus wire line logs values) of seismic data. Using this information, a well can be located on the base map. Data in the LAS file comprises of the header that gives basic information about the well and the values of different types of logs are present below the header. Different values of different wireline logs make it possible to generate the logs in a graphical pattern.

All seismic lines are given in Table 2. Seismic lines in the study area were not of good quality. Then, lines were selected that might have some prominent extendable reflectors suggesting possible structural patterns in the study area.

Table2 : Showing information about seismic and well data

Information about Seismic Lines			
S. No.	LineName	Trend	Used or not?
1	PSM96-114	Strike	Yes
2	PSM96-115	Dip	Yes
3	PSM96-129	Dip	Yes
4	PSM96-131	Dip	Yes
5	PSM96-133	Dip	Yes
6	PSM96-135	Dip	Yes
Information about Well Data			
S. No.	WellName	Status	Used or not?
1	Sawan-03	Development	Yes
2	Sawan-07	Development	Yes

3 Results and Discussion

3.1 *Project and Interpretation*

Base map of the project area located in the 42N zone of the Universal Transverse Mercator (UTM) system as shown in Fig. 3 having seismic lines defining their orientation, location and shot points of the seismic lines used.

Base map (Fig. 3) was constructed using six seismic lines which were imported in the software Kingdom 8.3. Then, some prominent reflectors were selected and extended following their lateral extensions in a seismic section. Reflectors that are picked from seismic sections vary in their elevation in the subsurface with respect to time. Reflectors marked on seismic lines using the software show structural variations along every line illustrated by different colors (Fig. 4).In order to delineate subsurface structures on seismic lines, reflectors were selected to represent lithological boundaries on the basis of their continuity, prominence and the petroleum importance in the study area. This line is dip line (Fig. 4) showing the TD scale with different stratigraphic units with depth as calculated from the sonic log to tie the well seismic with surface seismic data. In all, nine reflectors were interpreted and designated as Lower Goru, Upper Goru, Ranikot Formation, Sui Main Limestone, Ghazij Formation, Sirki Member, Pirkoh Member, Drazinda Member and Kirthar Formation. The data quality is fair, showing good reflector continuity which reveals that the

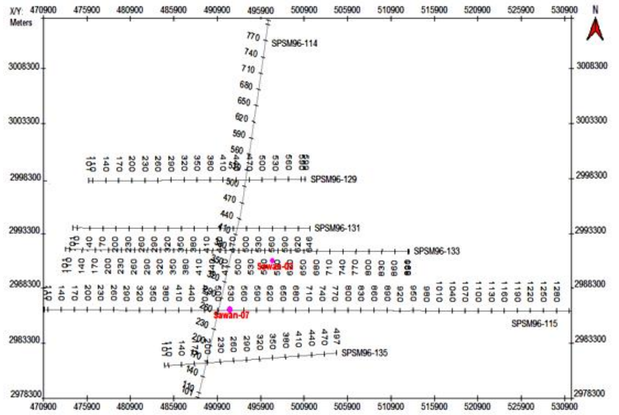

Fig. 3: Base map of the project

area is tectonically undisturbed. The traps in the area are structure-cum-stratigraphic. The Lower Goru reflector is continuous throughout seismic section with strong amplitude as shown in Fig. 4.

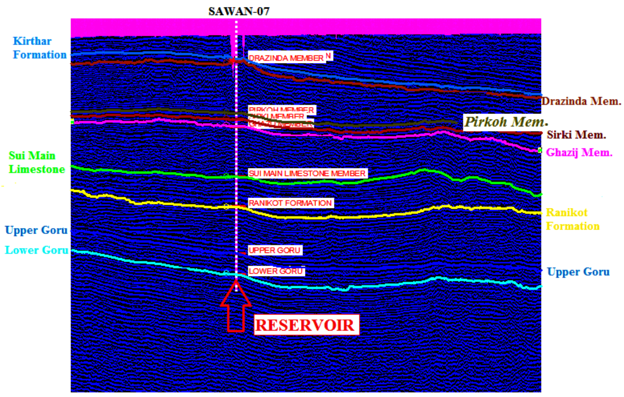

Fig. 4: Interpreted seismic section

3.2 *Interpretations from Depth / Time Contour Maps*

Depth contour map shows joining the points of equal depth in subsurface. This map is used to find the depth variation of the formation. It is very helpful to suggest the new proposed well point in a reservoir. Similarly, time contour map is obtained by joining the points of equal two-way travel time in the subsurface representing the structure. The previous discoveries i.e. Sawan-03 and Sawan-07 (Fig. 5) were made at the depth of 3210m and 3170m respectively. The further discoveries in the area can be made (as shown by the proposed sites on the map) by the names of wells T1 (at new proposed depth of 3230m) and T2 (at new proposed depth of 3300m) respectively. Well T2 is at the gently dipping dome shape structure and at greater depth. So, it is proposed that more hydrocarbons may be entrapped in Well T2 than all other wells.

Map (Fig. 6) is showing the subsurface structure of Lower Goru reflector obtained by joining the points of equal two-way travel time. The discoveries i.e. Sawan-03

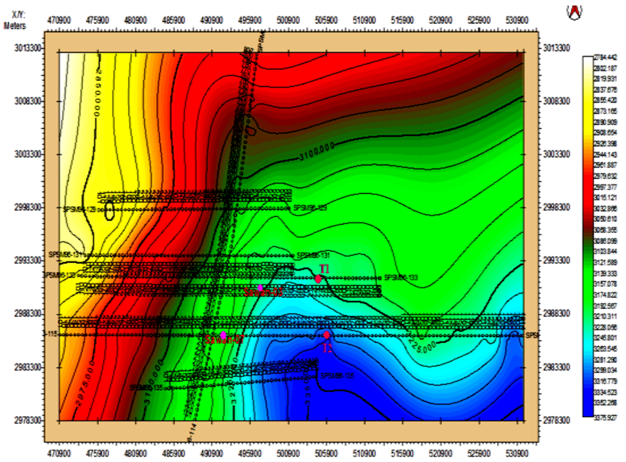

Fig. 5: Depth contour map of lower Goru reflector

and Sawan-07 are showing the value of time of the subsurface 3.347 msec and 3.323 msec (Fig. 6) respectively. New proposed Wells T1 and T2 can be made at their respective time values of 3.372 msec and 3.468 msec respectively. Reason for new proposed Well T2 is that it is at the gently dipping dome shape structure and at greater depth. So, it is proposed that more hydrocarbons may be entrapped in Well T2 than all rest of the wells.

3.3 3-D Modeling

3D subsurface structural models of the study area are shown in Figs. 7(A&B). Subsurface structural patterns of Lower Goru, Upper Goru, Ranikot Formation, Ghazij Formation, Sui Mian Limestone and Kirthar Formation reflectors are shown below. Upper and Lower Goru reflectors are slightly tilted upward on one side while other reflectors are straight with little undulations/folding.

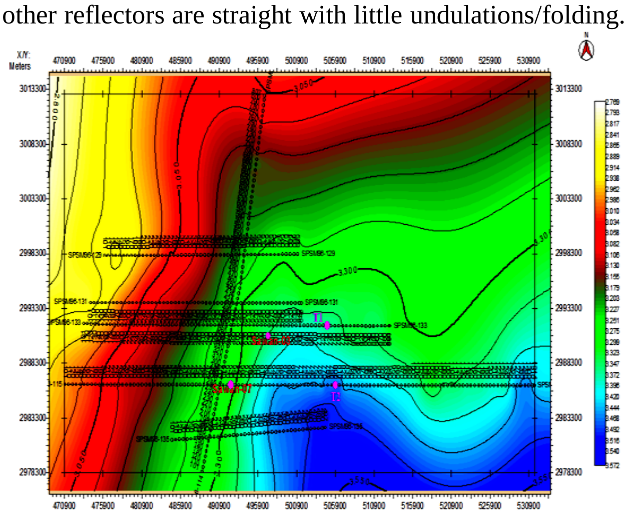

Fig. 6: Time contour map of lower goru reflector

The traps in the area are structure-cum-stratigraphic. The study area lacks structural features like folds and faults as it is far away from the collision zone, hence, it is tectonically least or not disturbed.

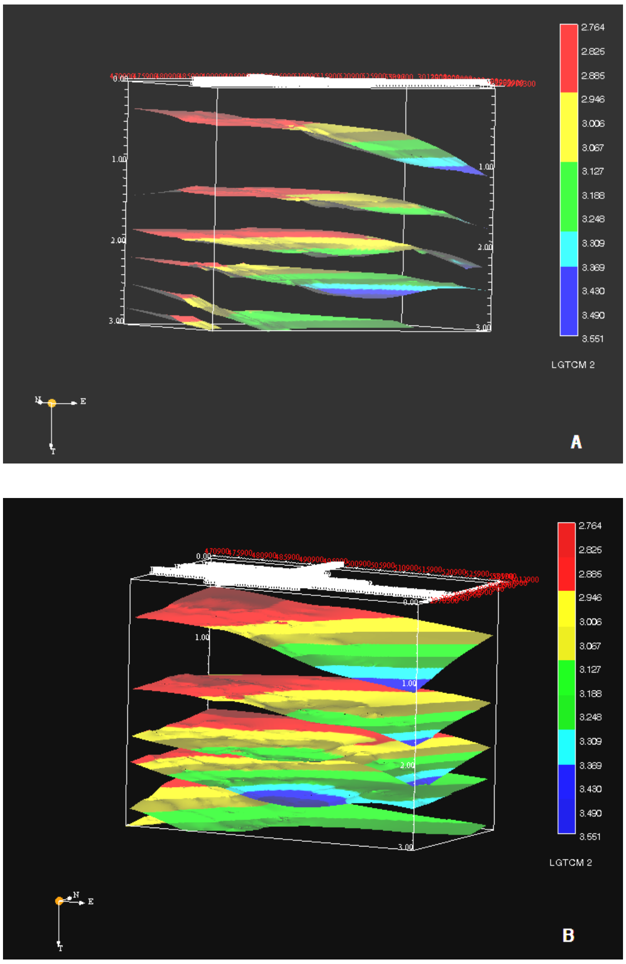

Fig. 7(A, B): .3-D subsurface structural models of the study area

3.4 Petrophysical Interpretation

3.4.1 Introduction

Interpretation is a process which attempts to combine the knowledge of tool response with geology to provide a comprehensive picture of variation of important petrophysical parameters with depth in a well [11]. Continuous recording of a geophysical parameter along a borehole produces a geophysical well log. The value of the measurement is plotted continuously against depth in a well [12]. Wireline logs are run to be able to detect and to quantify the volume of hydrocarbons in a well. The amount of hydrocarbons in a formation is not directly given by any log measurement, so that the petrophysicist must make use of 'best guess' formulae. However, new logging tools are getting much closer to required measurements [13].

3.4.2 Petrophysical Parameters

Following petrophysical parameters are used during petrophysical interpretation.

- Effective porosity
- Shale volume

- Matrix
- Water saturation
- Permeability
- Moved hydrocarbon
- Unmoved hydrocarbon
- Bulk volume water

3.5 Results of Petrophysical Analysis

3.5.1 Sawan-03

In Fig. 8, "Rhosh (density of shale)" curve is giving response with respect to shale volume. Density of shale is higher than that of limestone or sandstone. From depth 3365m to 3410m in Fig. 8. "Rho sh" curve is in the right side of the red line which means density of shale is higher because of larger shale volume. From 3410m to 3550m, "Rho sh" curve is giving lower values because of lower volume of shale, representing sand lithology here. Then again, from 3550m to 3600m, "Rho sh" curve is moving to right side of the red line giving higher values of density of shale representing high volume of shale.

Lithology can be identified using gama ray log. Shale has higher values of density, porosity and gama ray log while lower values of sonic log due to higher porosity. Higher values of gama ray, bulk density and neutron porosity curves are defining the shale lithology from 3365m to 3400m and from 3540m to 3600m. While sandstone has lower values of density, porosity and Gama ray log curves and higher values of sonic log due to lower porosity, opposite to shale. So, from 3400m to 3540m, sandstone lithology is defined by lower values of gama ray, density and porosity curves (Fig. 9).

The unit C-sand (from 3365m to 3600m) of Lower Goru Formation can act as reservoir because of 55% sandstone with 9% effective porosity. Percentage of water saturation in this unit is 25 to 35% which means hydrocarbons are present (Fig. 10). While percentage of water saturation present in the pores is 1% and porosity percentage of invaded zone is 3%. Hence, effective porosity caused unmoved hydrocarbons to move to the reservoir. Percentage of unmoved and moved hydrocarbons present in the unit can be seen from Fig. 10.

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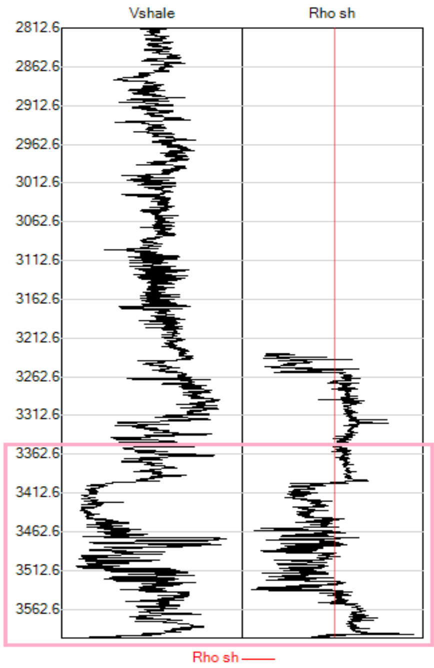

Fig. 8: Variation of density of shale and shale volume with depth in Sawan-03 well

Neutron, Density and Gama Ray Cross plot of the well (Fig. 11) is showing lithologies of shale (grey color) and sand (red color). Red colored zone can act as reservoir as discussed above while interpreting the composite log (Fig. 9).

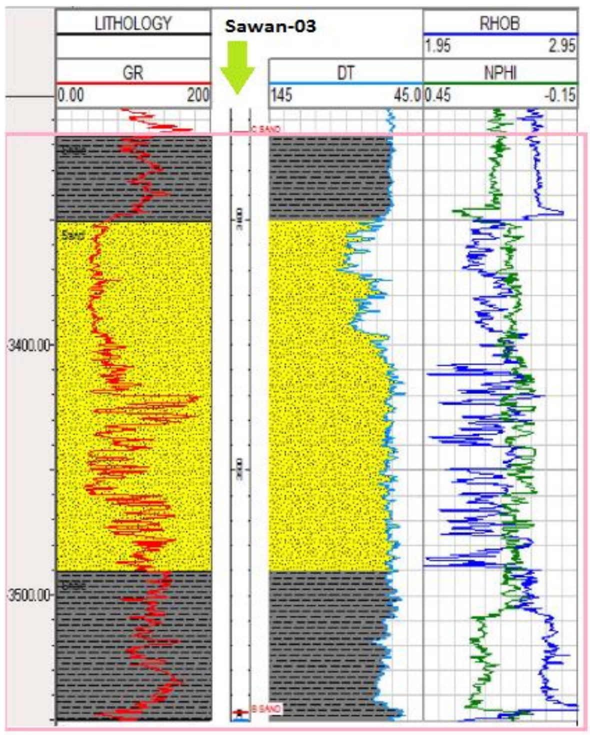

Fig. 9: Composite log showing subsurface lithology of Sawan-03 well using gama ray, density, neutron and sonic logs

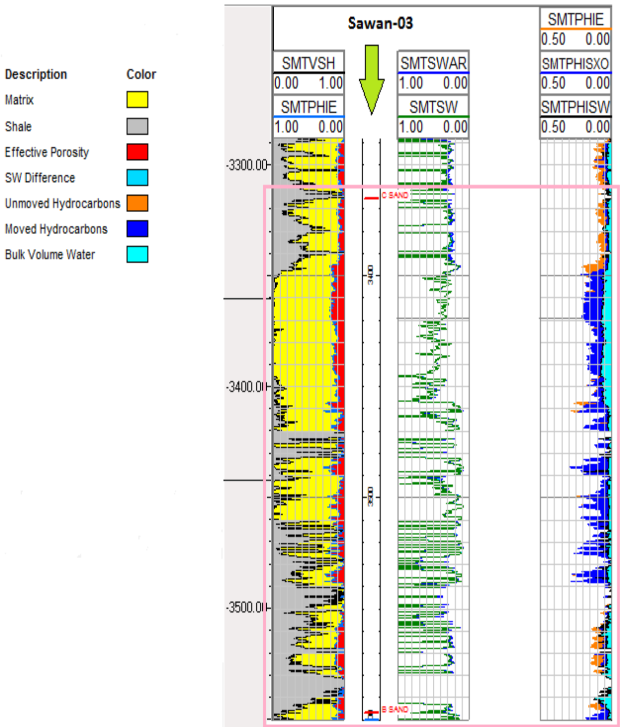

Fig. 10: Percentages of reservoir characteristics like shale, sand, effective porosity, water saturation, moved and unmoved hydrocarbons of Sawan-03 well using well logs

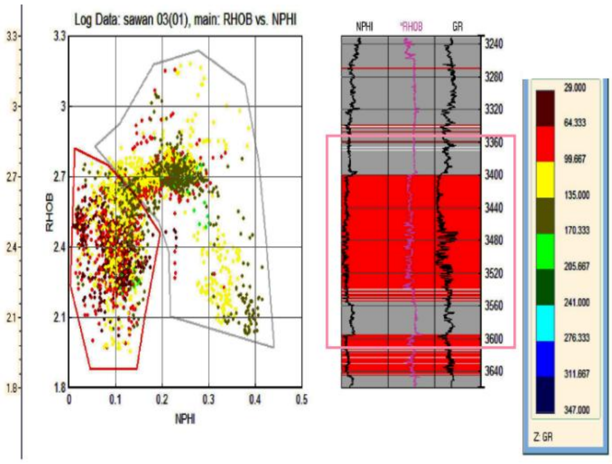

Fig. 11: Neutron, density and gama ray cross plot of Sawan-03 well

3.5.2 *Sawan-07*

In Fig. 12, “Rho sh” curve is in the right side, from 3250m to 3275m, of the red line which means density of shale is high because of higher volume of shale. Then, from 3275m to 3400m, “Rho sh” curve is giving lower values (left side of the red line) because of lower volume of shale, representing sand lithology.

Sandstone has lower values of density, porosity and Gama ray log (Fig. 13). So, higher values of gama ray, bulk density and neutron porosity curves are defining the shale lithology from 3250m to 3265m and from 3360m to 3370m. While, opposite to shale, sandstone lithology is defined by lower values of gama ray, density and porosity curves, from 3265m to 3360m and from 3370m to 3400m (Fig. 13).

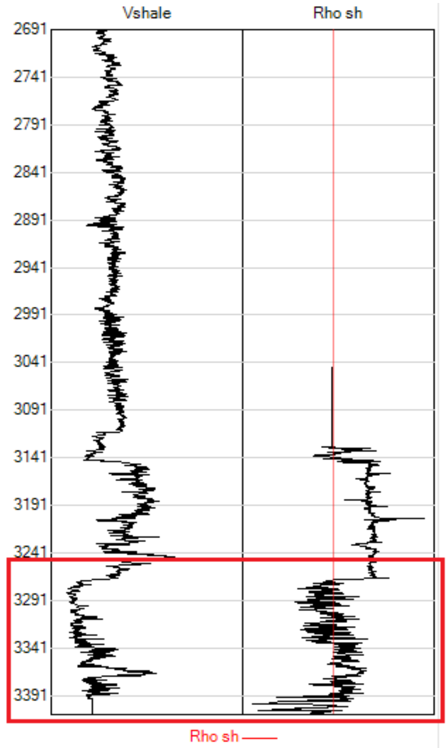

Fig. 12. Variation of density of shale and shale volume with depth in Sawan-07 well

The unit (from 3250m to 3400m) can act as reservoir because of 52% sandstone having 8.4% effective porosity (Fig. 14). Percentage of water saturation in this unit is 35 to 45% representing the presence of hydrocarbons. While percentage of water saturation present in the pores is 1.6% and porosity percentage of invaded zone is 3.3%. So, hydrocarbons moved to the reservoir due to effective porosity. Percentage of unmoved and moved hydrocarbons present in the unit can be seen from Fig. 14.

Neutron, Density and Gama Ray Cross plot of the well (Fig. 15) is showing lithologies of shale (grey color) and sand (red color). Red colored zone can act as reservoir as discussed above in Figs. 9 and 13 while interpreting the composite logs.

4. Conclusions

Based on above information, it is concluded that :

- Lower Indus Basin is tectonically stable area due to the part of Platform region and far away from collision zone. That is why no significant subsurface structures (like folding, faulting etc) are identified in the study area. This is confirmed from the reflectors marked in all seismic sections which are continuous with little undulation.

- Stratigraphic-cum-structural traps are present in the subsurface.
- Since Sawan-03 and Sawan-07 wells were drilled on the eastern side of the reservoir (eastern side of strike line SPSM96-114) and were proven successful. It is therefore suggested that the new points for wells T1 and T2 are identified to drill on the same side of the reservoir at the shot points 730 of line PSM96-133 and 800 of line PSM96-115 respectively. New well points are suggested on greater depth (3300m for T2) of gently dipping dome (Fig. 5) while well T1 is suggested at relatively higher area of same structure to extractremaining hydrocarbons from the reservoir.
- Petrophysical parameters like shale volume, water saturation, porosity and permeability from various logs such as Gama ray, Denisty, Neutron and Sonic logs are used to find reservoir potentials in the wells. Based on these parameters, reservoir potentials for presence of hydrocarbons at different depth in both wells have been found due to low water saturation and good effective porosities of reservoir sandstone.
- Due to the effective porosities, unmoved hydrocarbons present in shale (source rock) migrated to the sandstone (reservoir).

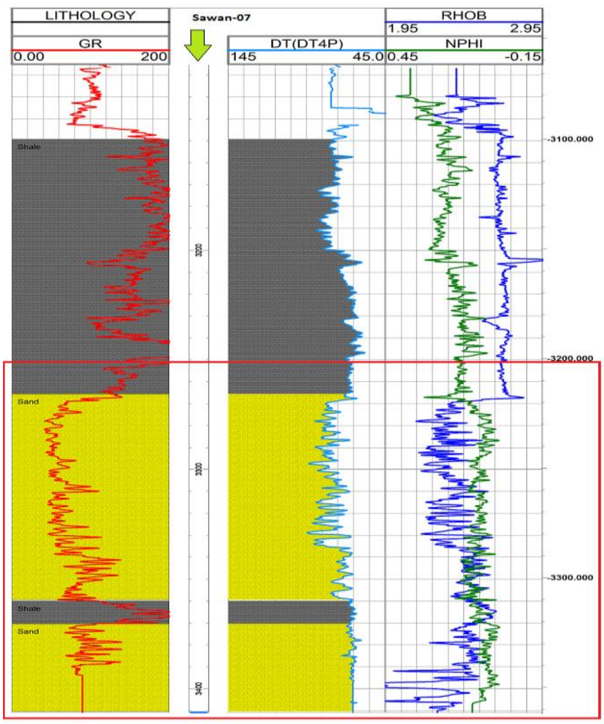

Fig. 13: Composite log showing subsurface lithology of Sawan-07 well using gama ray, density, neutron and sonic logs

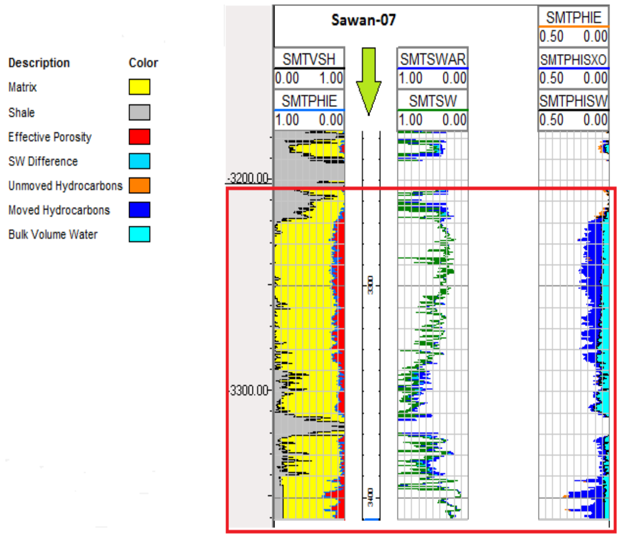

Fig. 14. Percentages of reservoir characteristics like shale, sand, effective porosity, water saturation, moved and unmoved hydrocarbons calculated using well logs, given in given in this log of Sawan-07 well

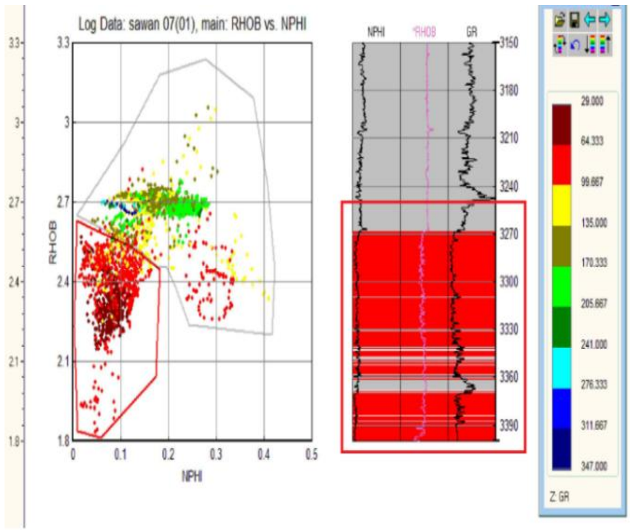

Fig.15. Neutron, density and gama ray cross plot of Sawan-07 well

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References

[1] J. Afzal, T. Kuffner, A. Rahman, and M. Ibrahim,"Seismic and well-log based sequence stratigraphy of the early cretaceous, Lower Goru "C" sand of the Sawan Gas Field, Middle Indus Platform, Pakistan, Annual Technical Conference(ATC), pp. 51, 2009.

[2] M. Ibrahim, "Seismic inversion data, A tool for reservoir characterization / modeling, Sawan Gas Field – A Case Study, Annual Technical Conference (ATC), pp. 1, 2007.

[3] N. Ahsan, M.A.F. Miraj, S. Rehman and A. Ali, "Subsurface structural reconstruction of Joya Mairstructure, Southeast Potwar Sub-Basin, Indus Basin, Pakistan", Int. J. Agric. Appl. Sci., vol. 5, no. 1,pp. 18-24, 2013.

[4] A. Farah and K.A. Dejong, Geodynamics of Pakistan, Geological Survey of Pakistan (GSP),Quetta, Pakistan, pp. 5-24, 1979.

[5] S.A. Mahmud and S. A. Sheikh, "Reservoir potential of lower nari sandstones (early oligocene) in southern indus basin and indus offshore", Annual Technical Conference (ATC), pp. 7-8, 2009.

[6] H.A. Raza, R. Ahmed, S. Alamand S. M. Ali, Petroleum Zones of Pakistan, Pak. J. of Hyd. Research, vol. 2, pp. l-19, 1989.

[7] N. K. Siddiqui, Sui Main Limestone: Regional Geology and the analysis of original pressures of a closed-system Reservoir in Central Pakistan,AAPG Bulletin, vol. 88, no. 7, p. 1017, 2004.

[8] F. G. Khattak, M. Shafeeq, S. M. Ali, "Regional trends in pororsity and permeability of reservoir horizons of lower goru formation, lower indus basin, Pakistan", Pak. J. Hyd. Res;vol. 11, pp.37-50, 1999.

[9] I. B. Kadri, "Petroleum geology of Pakistan", Graphic Publishers, Karachi, Pakistan, pp. 26-37, 1995.

[10] S. M. I Shah, "Stratigraphy of Pakistan, Geological Survey of Pakistan (GSP), Quetta, Pakistan, vol. 22, 2009.

[11] D. V., Ellis, J. M. Singer, Well Logging for Earth Scientists. 2nd Edn. Springer, Publishers, Netherland, pp. 11, 2008.

[12] S. Mustafa, Basic Well Log Interpretation. Focus Energy Ltd., pp. 1-6, 2012.

[13] M. Rider,The Geological Interpretation of Well Logs, 2ndedn. Rider-French Consulting Ltd., pp. 263, 2002.