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Structural Styles and their Suitability for Hydrocarbon in Eastern Sindh Monocline, Lower Indus Basin, Pakistan

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Abstract: The present study is aimed to recognize the structural styles of hydrocarbon exploration and petrophysical properties of the LGF. The 2-D seismic and well log data set is composed of three seismic lines and well log data of Chak 66–1. Five horizons have been marked with the help of well to seismic tie namely tops of Ranikot, Parh, upper Goru, lower Goru, basal and top massive sands, and out of which basal and massive sands are the objective focus of the present study. Based on seismic data, the study area is characterized by normal faults showing NW–SE dipping trend. Horst and graben structural features are prominent on the seismic lines, which indicated the extensional tectonic regime. Time–depth contour maps and 3D surfaces of objective horizons depict their actual spatial distribution in this area. Wireline logging analysis revealed the physical properties of both basal and massive grains of sand, as 17% effective porosity, 25% average volume of shale (Vsh), 40% water and 60% hydrocarbon saturations for basal sands, Whereas, 16% effective porosity, 35% Vsh, 30% water and 70% hydrocarbon saturations are interpreted for massive sands. Cross–plots of Nphi–Dt and Dt–Rhob also identified that both areas of sand are clean, gas–saturated and have the potential to produce hydrocarbons.

Keywords: 2-D seismic and well log data, structural styles, hydrocarbon suitability, lower Indus basin.

Introduction

The lower Indus basin, about 250 km wide is bounded to the east by Indian shield rocks, to the west by Chaman transform zone, middle Indus basin in the north and Indus offshore basin in south (Kazmi and Jan, 1997). The lower Indus basin is situated in an extensional regime (Zaigham and Mallick, 2000). Sinjhoro exploration block is operated by Oil and Gas Development Company Limited. The block covers an area of 180 sq. km, and is located on the eastern flank of Sindh monocline (Fig. 1).

Sinjhoro block is bounded to the east by Indian shield and merges into Kirthar foredeep and Karachi through Mari-Bughti zone in the north, and Indus offshore platform in the south (Eames, 1952). Deep-seated normal faults with NNW–SSE orientations develop horst and graben structures in the study area. These structural features control the hydrocarbon of reservoirs and trapping mechanism in the area. Multiple sand packages in the lower Goru Formation of Cretaceous age are established reservoirs. Whereas, Sembar Formation of Cretaceous age and intra-formational shales of Lower Goru are acting as the source rocks in the study area (Hussain et al., 1991; Zaigham and Mallick, 2000).

Stratigraphy of the lower Indus basin has been established from Triassic to Recent (Fig 2). The present study is based on the lower Goru Formation of Cretaceous age. The formation has been subdivided into various sand packages. The target intervals of the lower Goru Formation for this study are basal and massive sands, and intra-formational shales act as a seal. Whereas, Sembar Formation is the source rock for the target horizons in this area. Eastward tilting strata and structural features like horst and graben provide the structural and stratigraphic trapping mechanism (Ahmad et al., 2012).

Materials and Methods

Seismic lines have been the basis of the structural table utilized in structural interpretation, given as (SNJ-O3, SNJ-04, SNJ-08). Data of the well Chak 66-1 has been used to carry out petrophysical interpretation.

Seismic to well tie was carried out by generating synthetic seismogram using DT and Rhob curves from the well data of Chak 66-1 well (Fig 3). Seismic interpretation includes picking of the following horizons, Top Ranikot, Top upper Goru, Top lower Goru, Top basal sand and Top massive sand by using the earlier generated synthetic seismogram (Fig 4, 5). Deep-seated normal faults with planar geometry were interpreted. These normal faults are dipping in NNW and SSE direction. These normal faults are responsible for the structures delineated in the area (Fig 6b, 7b). Time and depth contour maps depict that the reservoir stratum is uplifted towards the corner of the Sinjhoro block and deepens towards the center. Depth contour maps are computed by the following equation:

S = v*t/2

Whereas

S = depth

V = average velocity

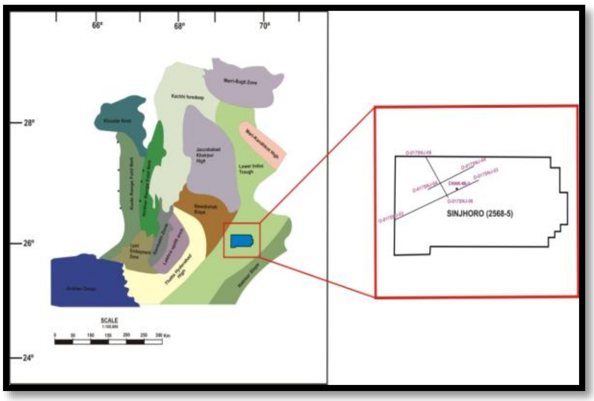


Fig. 1 Location map of the study area (modified after Kazmi and Snee, 1989).

Table 1. Generalized stratigraphic column of lower Indus basin modified after Shabeer et al., 2016.

SYSTEM	SERIES	FORMATION	LITHOLOGY
TERTIARY	HOLOCENE	ALLUVIUM	ALLUVIUM
	OLIGOCENE	GAJ/NARI	SAND/SHALE
	EOCENE	KIRTHAR	LIMESTONE
		LAKI	SHALE
	PALEOCENE	RANIKOT	SANDSTONE
		KHADRO	VOLCANIC/BASALT
CRETACEOUS	UPPER	UPPER GORU	SHALE(SEAL)
	LOWER	LOWER GORU	UPPER SANDS(RESERVOIR)
			UPPER SHALES
			MIDDLEL SANDS(RESERVOIR)
			LOWER SHALES
			BASAL SANDS(RESERVOIR)
		SEMBAR	SHALE & SAND(SOURCE)
JURASSIC	UPPER		
	MIDDLE	CHILTAN	LIMESTONE

Table 2. Nomenclature of Lower Goru established by E&P companies.

	OGDCL			UTP (BP Pakistan)		OMV Pakistan
LOWER GORU	Upper Sand	Layer 1	A Sand	Upper Sand	A Sand	Shale out in North
		Layer 2	Turk Shale		Turk Shale	
		Layer 3	B Sand		B Sand	
		Layer 4	Badin Shale		Badin Shale	
		Layer 5	C Sand		C Sand	
			Jhol Shale		Jhol Shale	
			D Sand		D Sand	
	Upper Shale					No Significant Body
	Middle Sand					D Sand
	Lower Shale					C Sand
	Basal Sand					B Sand
	Talhar Shale					
	Massive Sand					A Sand
Sembar						

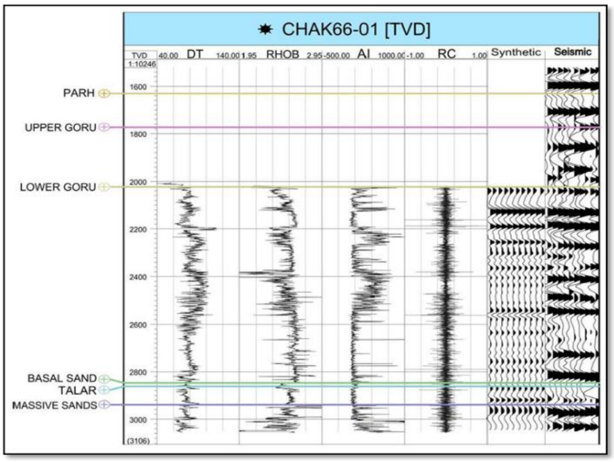


Fig. 2 Synthetic seismogram of well Chak 66-1, for the verification of targeted horizons on seismic line.

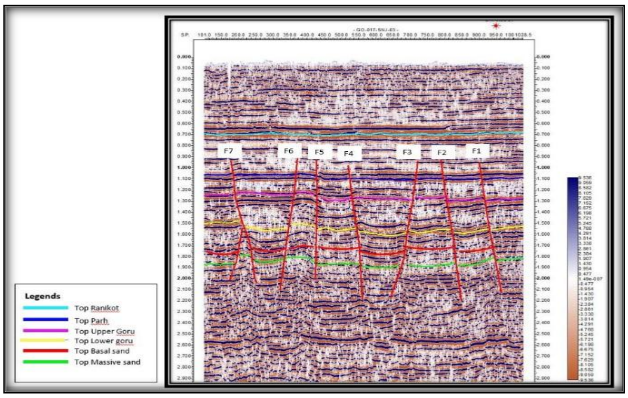
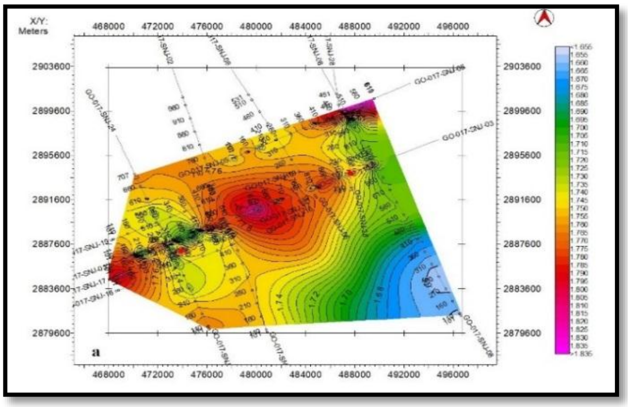


Fig. 3 Interpreted seismic line GO-07-SNJ-03.



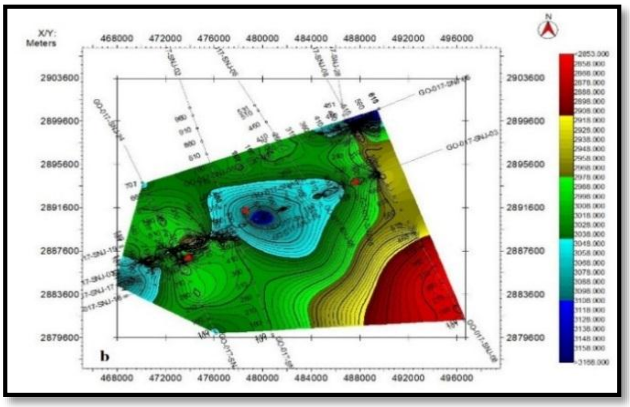


Fig. 4 (a) Time contours (b) Depth contours of basal sands of lower Goru Formation.

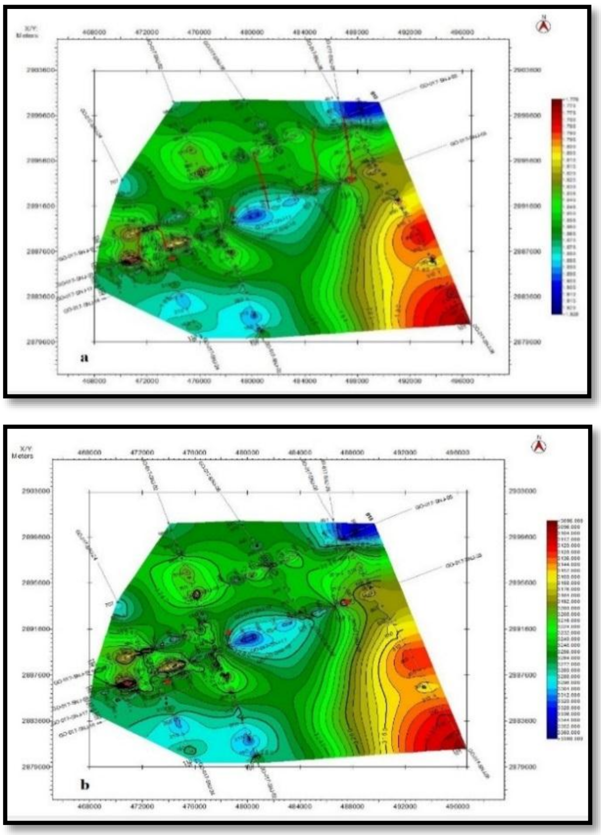


Fig. 5 (a) Time (b) Depth contours of massive sands of lower Goru Formation.

Petrophysical Analysis of Well Logs

Well log data were used for petrophysical interpretation based on parameters of reservior of shale porosity. Natural Gamma-ray and resistivity logs were used to calculate the thickness and lithology of the reservoir (Fig. 9). The volume of shale was obtained by using a natural gamma-ray log by applying the IGR equation.

$$IGR = \frac{(GRlog - GRmin)}{(GRmax - GRmin)}$$

IGR = Gamma-ray Index

GRmin = GR minimum

GRmax = GR maximum

Porosity is an important entity of reservoirs that holds hydrocarbons. As the required effective porosity of reservoir facilitates fluid to migrate, the effective porosity has been calculated as:

$$\text{Effective Porosity} = (1 - \text{Vsh}) * \text{Average Porosity}$$

Whereas Vsh = Volume of shale, Average porosity computed by using neutron and density logs. The 17% average effective porosity is computed for basal sands while the effective porosity average of 16% has been calculated for massive sands.

Water saturation of basal and massive sands have been calculated by using Archie's equation (1942).

$$(\mathrm{Sw})^n = \sqrt{\left(\frac{a}{\Phi^m}\right) \times \left(\frac{\mathrm{R}_w}{\mathrm{R}_t}\right)}$$

Where; a = formation factor coefficient equal to 1; m = cementation exponent equal to 2;

n = saturation exponent; Rw = water resistivity (Ohm-m); Rt = true

Formation resistivity (ohm-m); Ø = porosity (dec)

Hydrocarbon saturation of both reservoir rocks are calculated by $\mathbf{Sh = (1 - Sw)}$.

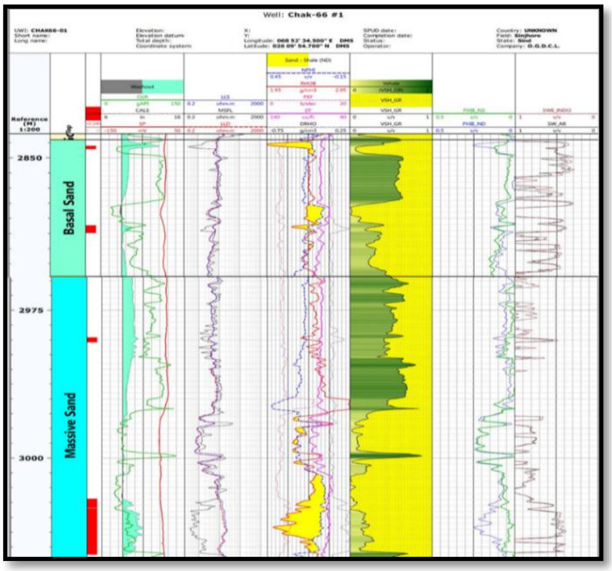


Fig 6. Petrophysical properties of basal and massive sands of Chak66-1.

Results and Discussion

The output of seismic and well data interpretations revealed that both areas of sand (basal and massive) have the potential to produce hydrocarbons (Table 3).

Table 3. Petrophysical parameters of Chak 66-1.

Parameters	Average Values of Basal Sand	Average Values of Massive Sand
Volume of Shale (Vsh)	28 %	16 %
Effective Porosity	17 %	16 %
Water Saturation (Sw)	40 %	30
Hydrocarbon Saturation (Sh)	60 %	70 %

Time and depth contour maps and 3D surfaces have delineated the structural geometry of Sinjhoro block. It is dominated by horst-graben, structures. NNW and SSE dipping normal faults are deep-seated across the whole Mesozoic section. Little displacement has been observed among the faults and most of these faults are vertical and planer in nature.

Petrophysical interpretations of Sinjhoro block recognized the following properties i.e, lithology, porosity, water and hydrocarbon saturations. The results of the analysis for both reservoirs are,

(a) Sonic and density logs also confirmed the gas saturated zones of reservoirs with the anomalous increase in transit time (Fig. 7). This interpretation is also supported by cross-plots of sonic and neutron logs (Fig. 8)

(b) Nphi against Rhob recognized the payable zones for gas of both reservoirs (Fig. 8) with the help cross-over effect.

(c) Both reservoirs are mainly gas saturated with a little-to-moderate amount of water saturation.

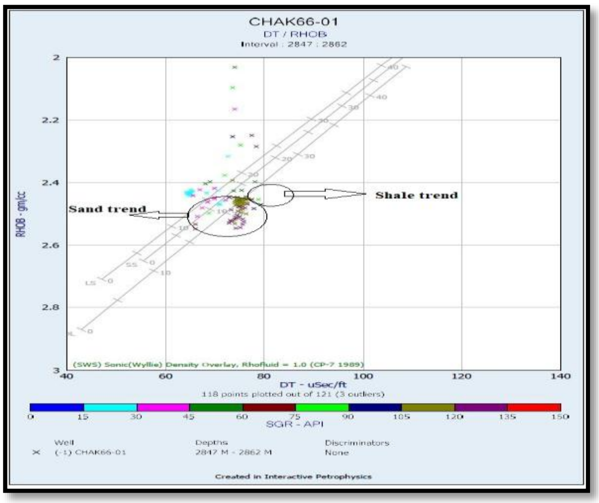


Fig. 7 Cross plot of density and sonic logs.

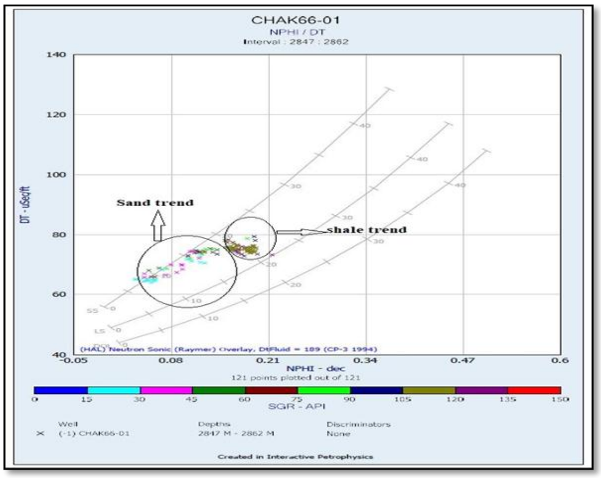


Fig. 8 Cross plot of Nphi and sonic log.

Conclusion

The subsurface structure interpretation using seismic data show that the area is characterized by normal faulting with horst and graben geometry. These faults may contain the areas favourable for the accumulation of hydrocarbons. The well log analysis shows that as the density decreases, neutron porosity also decreases within the depth range of 2830–2860m, and thus, marking a cross-over, which is a probable hydrocarbon-bearing zone. Cross-plots of sonic, density and neutron logs depict that basal and massive sands of the lower Goru Formation have the potential to produce hydrocarbons in sufficient amounts. Furthermore, hydrocarbon profile is also interpreted in resistivity logs (MSFL, LLS, LLD) across both areas of sand intervals, which suggest that both areas of sand are promising to produce hydrocarbons.

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