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Structural and reservoir interpretation of cretaceous lower Goru Formation, Sanghar area, lower Indus Basin, Pakistan

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Abstract

The present study incorporates structural and reservoir interpretation using seismic and well log data. The primary formation of focus is Lower Goru of Cretaceous age in Sanghar Block, Southern Pakistan. The area is characterized by extensional regime and normal faulting is indicated by time contour map which further represent closures towards center portion as we move from East to West (Hydrocarbon leads). Comparison of Geophysical parameters estimated from seismic and well log data indicates that the study area is less complex (as compared to collisional belt resulting in folding and faulting) with horizontal reflectors. Two wells (Fateh-01 and Panairi-01) are studied through well logs for identification of reservoir zone. The reservoir zone identified in both the well ranges from depth of 2700 m to 3100 m. An average value of volume of shale (43% and 28 %), Water saturation (73% and 60%) and hydrocarbon saturation (36% and 33%) were evaluated in Fateh-01 and Panairi-01 wells respectively. The average percentage of water saturation (63.45%) from both wells classifies these wells as water saturated. A strong correlation results in reflection coefficient values between seismic data and Fateh-01 (R=0.62) and Panairi-01 (R=0.43) wells. The absences of useful quantities of hydrocarbons are associated with "Hydrophobic Effect" caused due to excessive water. This effect might have prevented the hydrocarbons to penetrate in the rock at the time of migration and they have probably moved to other distant location which can later on be confirmed by presence of hydrocarbons in adjacent blocks.

Keywords: Synthetic seismogram; Horst and graben; Saturated rocks; Reflection coefficient; Hydrophobic effect.

1. Introduction

Seismic interpretation is the art and science of identifying, correlating, and understanding the geological structure of the subsurface and its layering through geologic time using seismic data (Tnacheri and Bearnth, 2009). It is a technique or tool by which we try to transform the whole seismic information into structural or stratigraphic model of the earth. It is rare that correctness or incorrectness of an interpretation is ascertained, because the actual geology is rarely known in well manner. Therefore, it is important to know all about the area, including gravity and magnetic data, well information, surface geology as well as geologic and physical concept (Kearey, 2002). Interval velocity from the well log data is often different from seismic data depending upon structure of the area. The first use of amplitude information as hydrocarbon indicators was in the early 1970s when it was found that bright-spot amplitude anomalies could be associated with hydrocarbon traps (Hammond, 2011). Detail quantitative work after Ryseth et al. (1998), whose work dealt with acoustic impedance inversions, the use of forward modeling was improved in understanding of shallow marine facies from seismic amplitudes (Zeng, 1996). Reflection Coefficient as a function of acoustic impedance can be served as a strong parameter in determination of lithology and its compactness (Sheriff, 1999).

The study of Petrophysical parameters describes the occurrence and behavior of the rocks, soils and fluids. In order to characterize oil or gas reservoir zone measurements such as resistivity and density are made from which effective porosity, saturations and permeability can be quantified. Therefore, the seismic interpretation in addition with petrophysical interpretation can serve as strong tool in delineating hydrocarbons.

2. Geology of the area

According to Kazmi (1979) Pakistan is located along the Tertiary convergence zone, and this zone marks the interaction of three lithospheric plates

(Indo-Pakistan, Arabian, and Eurasian plates). The triple junction of these three plates is located to the north west of Karachi, Pakistan (Kazmi and Jan, 1997). The southern Indus basin is identified as an extensional basin characterized by tectonic up warping on the western margin of the Indo-Pakistan subcontinent.

Stratigraphically (Fig. 1) southern based on predominant lithologies the Indus Basin is divided into five sedimentary units of Basal Sand unit, Lower Shale, Middle Sand unit, Upper Shale and Upper Sand (Killings et al., 2002).

The Upper Goru sequence of Middle to Late Cretaceous conformably overlies the Lower Goru Formation which consists of mainly marl and calcareous clay stone occasionally with interbeds of silt and limestone (Killings et al., 2002). The upper contact is transitional with the Goru Formation. It may be correlated with the Lumshiwal Formation of Kohat-Potwar Province. The lower contact with the Sembar Formation is conformable (Williams, 1959).

3. Research methodology

Synthetic seismogram is a direct one-dimensional model of acoustic wave moving through the earth. It is estimated by convolving the reflectivity derived from acoustic and density logs with the wavelet derived from seismic data. By comparing marker beds or other correlation points picked on well logs with major reflections on the seismic section. The synthetic seismograms of Fateh-01 and Panairi-01 wells were generated and correlated with seismic time sections to identify different horizons (Fig. 2 and 3). Faults were marked by observing the lateral discontinuity of the horizons.

The time contour map of Lower Goru Formation was constructed by picking times from seismic horizon (Lower Goru) against each shot point and they were contoured using contouring module in Kingdom software. Seismic attributes such as interval velocity, acoustic impedance, formation density and reflection coefficient were derived from seismic time sections and well logs (Fateh-01 and Panairi-01). The interval velocity from selected seismic time section were used as constraint to find density using relation of Gardner (1974). The product of density and velocity gave Acoustic impedance, and reflection coefficient was calculated by using the relation of Zoeppritic (1919). Similar parameters were also derived from sonic logs of Fateh-01 and Panairi-01 wells. Different well logs (Gama ray, sonic, density and Sp) were interpreted to get reservoir estimates such as porosity, hydrocarbon saturation and water saturation.

4. Results and discussion

One dimensional forward modeling of Fateh-01 and Panairi-01 represents Lower Goru Formation with strong peaks at top and bottom. The synthetic seismograms of Fateh-01 and Panairi-01 wells when correlated with seismic time sections provide the position of Upper Goru, Lower Goru and Basal Sand unit horizons in the wells as shown by figure 2 and 3. One dimensional forward modeling of Fateh-01 and Panairi-01 represents Lower Goru Formation with strong peaks at top and bottom. The synthetic seismograms of Fateh-01 and Panairi-01 wells when correlated with seismic time sections provide the position of Upper Goru, Lower Goru and Basal Sand unit horizons in the wells as shown by figure 2 and 3.

The time contour map represents an increase in values from north towards the center and then decrease in values as we move further south. The moderate values are indicated in center representing a constant behavior (Fig. 4). As we move from east to west a slight decrease in values is observed towards the center. The faults that are penetrating the area are of normal nature thus representing extensional regime.

Another important trend which is observed is number of closures as we move towards West from East the trend is of contour lines is changing and many closures can be observed which could probably be a hydrocarbon lead. A seismic time section is shown in figure 5 shows clear horst and greben feature and normal faulting.

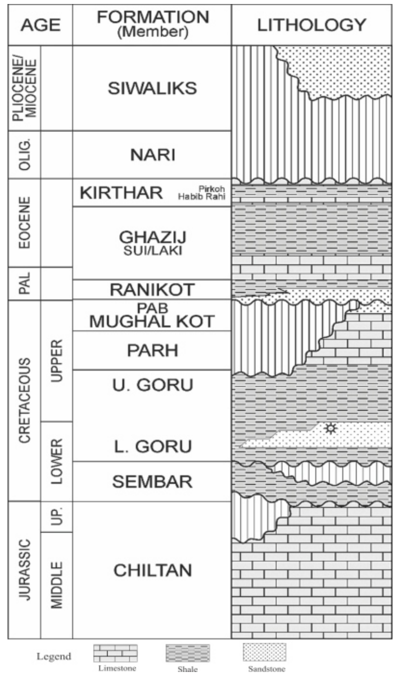

Fig. 1. Generalized Stratigraphy of Study area (Berger, 2009).

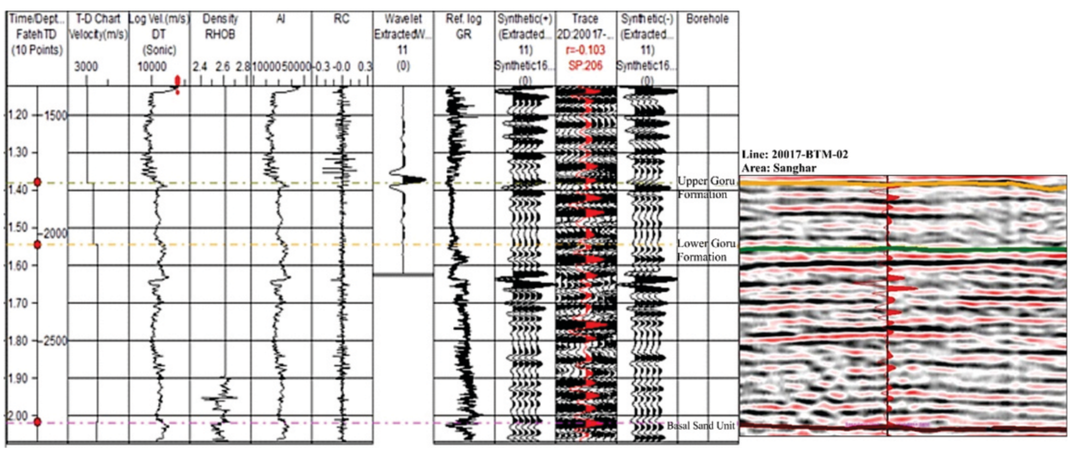

Fig. 2. Horizons and Synthetic seismogram of Fateh-01 Well at 20017- BTM-002. Three horizons Upper Goru, Lower Goru and Basal sand unit are marked using synthetic seismogram (Top, middle and bottom respectively).

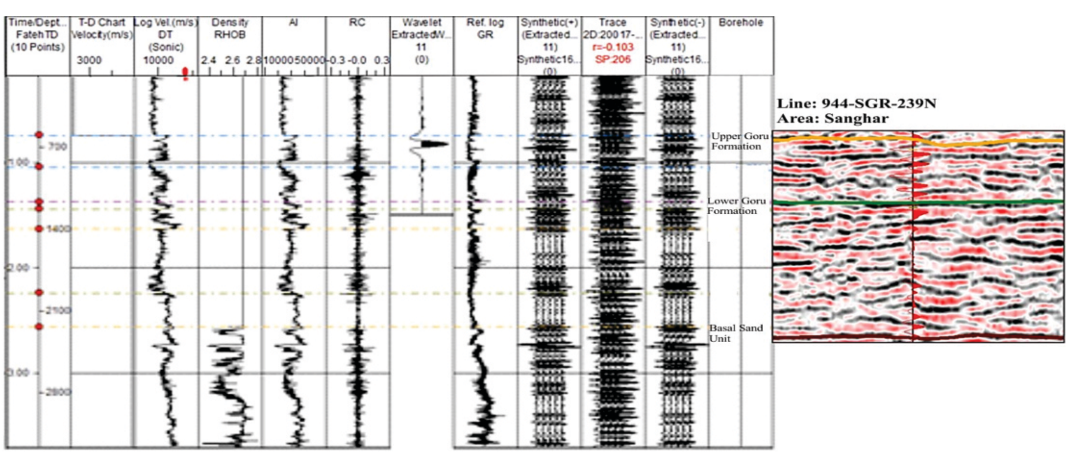

Fig. 3. Horizons and Synthetic Seismogram of Panairi-01 on line 944-SGR-239N. Three horizons Upper Goru, Lower Goru and Basal sand unit are marked using synthetic seismogram (Top, middle and bottom respectively).

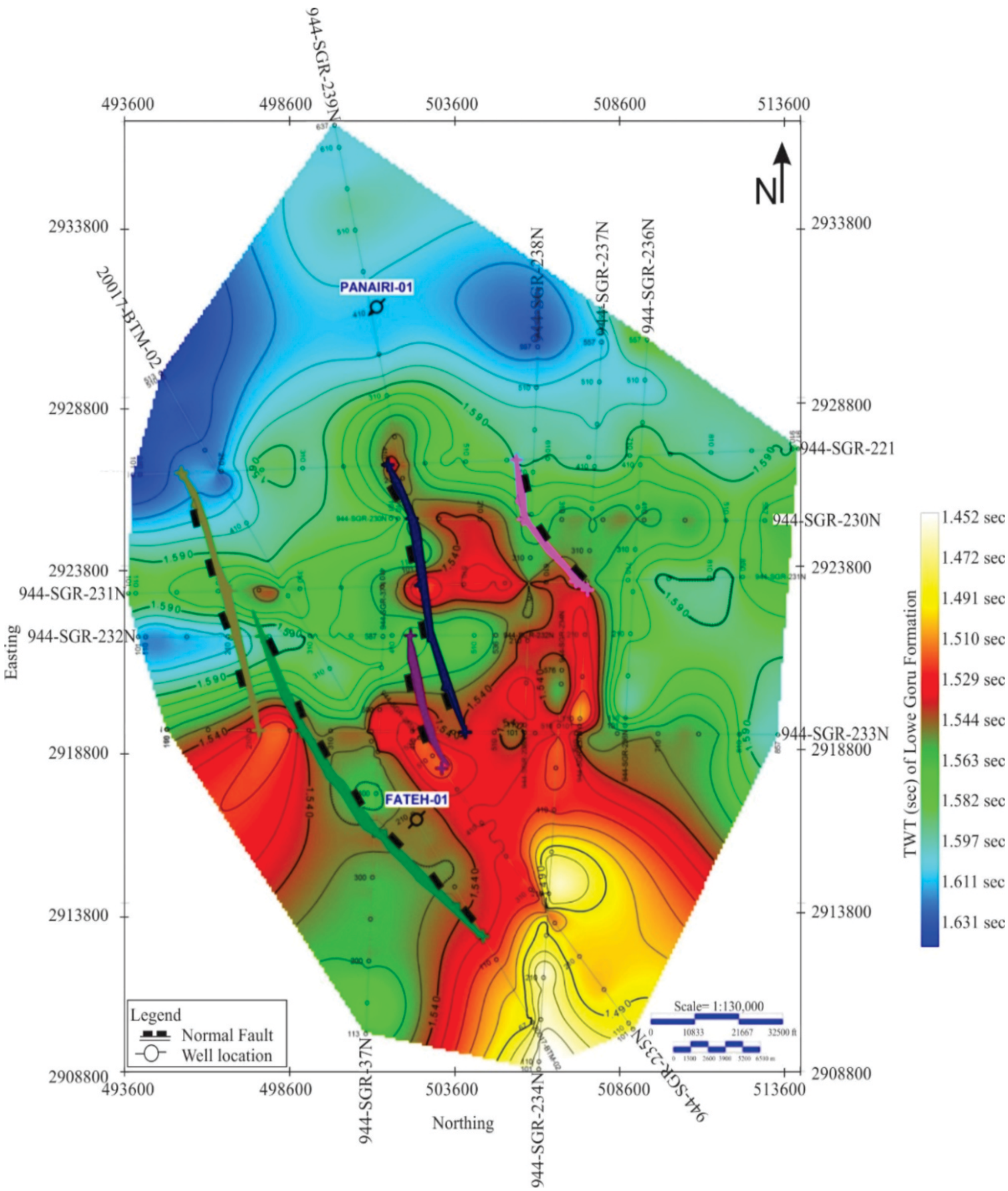

Fig. 4. Time contour map of top of Lower Goru Formation, shows horst and graben structure.

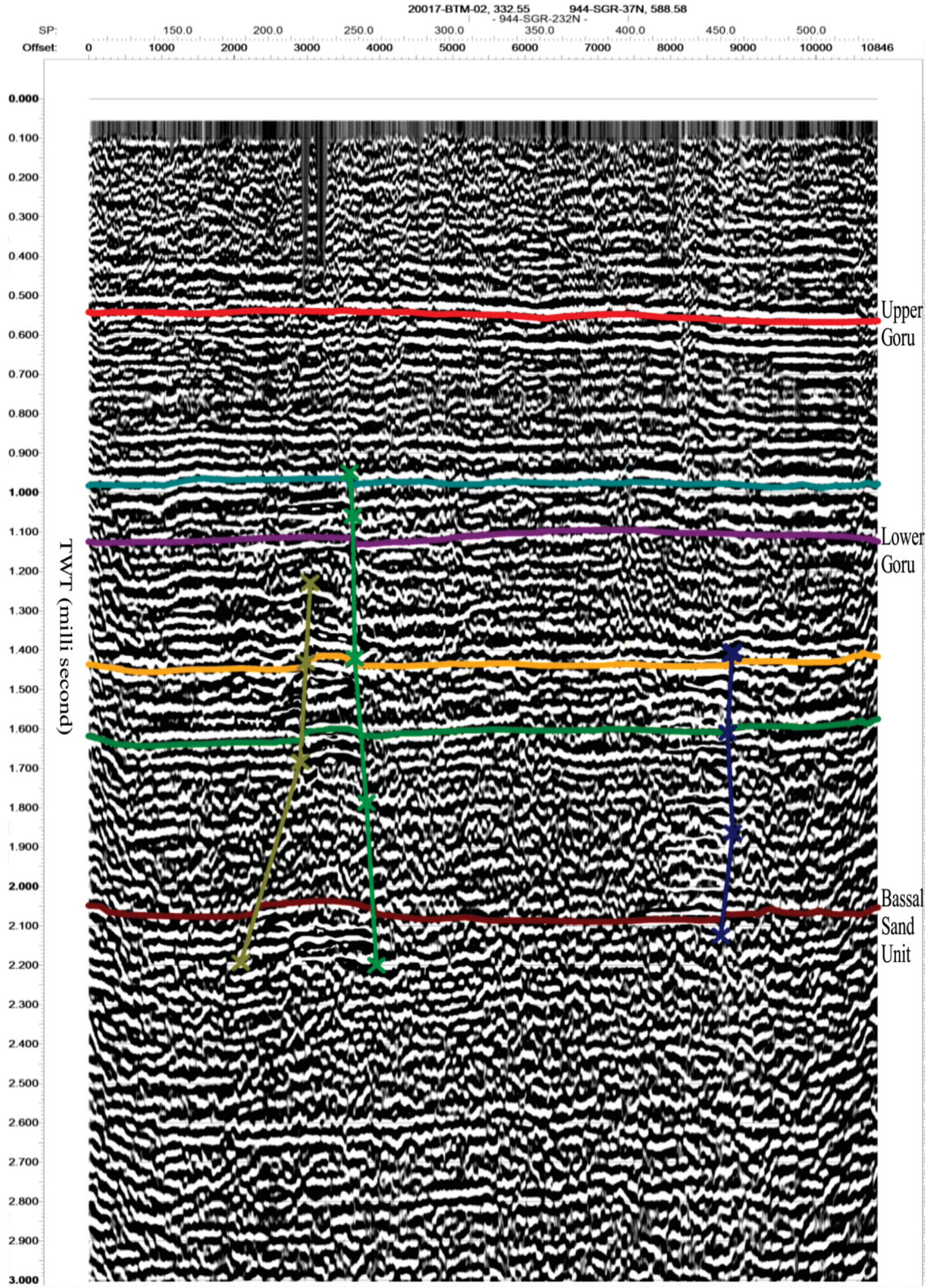

Fig. 5. Seismic time section of seismic line 944-SGR-232 showing time of marked horizons and fault.

5. Comparison of parameters estimated from seismic and well log Data

Table 1 shows the comparison between interval velocity, density, Acoustic impedance and Reflection Coefficient (RC) derived from seismic and well log data. We can clearly see that the variations between all these parameters are very small furthermore relationships are drawn between the seismic line Fateh-01 and Panairi-01 well and also between the wells (Fig. 6).

The results show a strong correlation with R2= 0.62 exist between RC from seismic lines and RC from Fateh-01 well. A moderate correlation of R2=0.43 exist between RC form seismic lines and RC from Panairi-01 well. The reason is the variation in thickness and compaction of Lower Goru Formation. In Fateh-01 the thickness of Lower Goru Formation found to be more compared with Panairi-01 well.

Three relationships (1, 2 and 3) were developed between reflection coefficients values from seismic data and well data. These relations might be helpful in calculation of reflection coefficients form well data to seismic and vice versa.

RC (from seismic line) = 0.6593*RC (Panairi-01 well)-0.0443 ……………………… (1)

with R2 = 0.43 (Panairi-01 to seismic line)

RC (from seismic line) = 0.7872*RC (Fateh-01 well)-0.0276 ……………………….. (2)

with R2 = 0.62 (Fateh-01 to seismic line)

RC (Fateh-01 well) = 0.6068* RC (Panairi-01 well)-0.0507…………………………. (3)

with R2 = 0.37 (Well to Well correlation)

The results indicate that the study area is less complex because more the complex area more will be deviation between the well and seismic results.

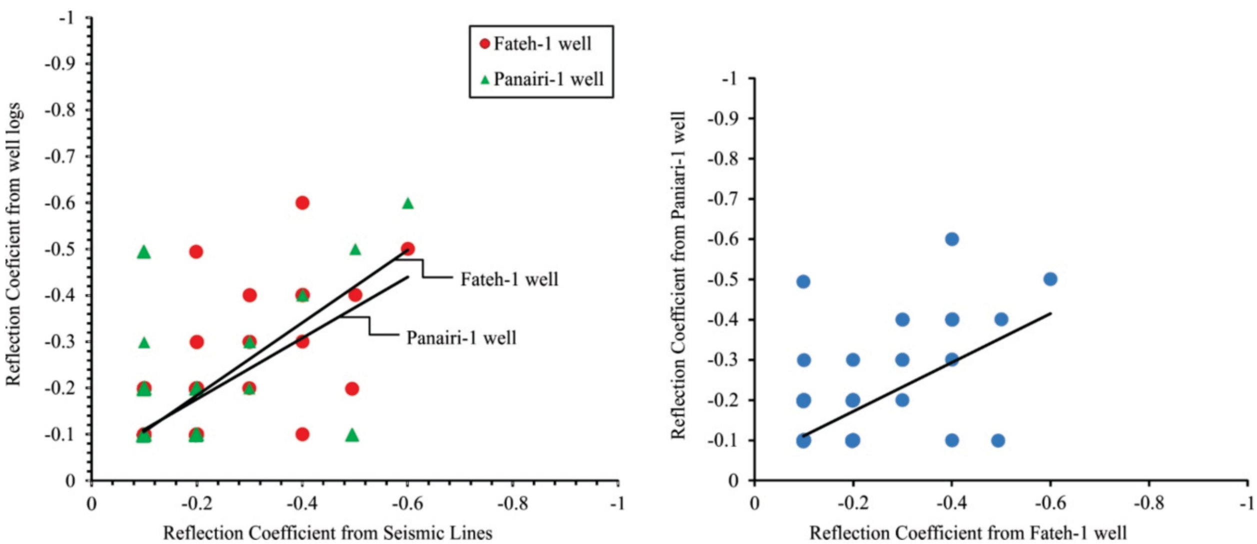

Fig. 6. Correlation of Reflection coeficient from seismic line and well data of Fateh-01 and Panairi-01. A strong correlation of 0.62 results in case of Fateh-01 well, whule moderatecorrelation of 0.43 results in case of Panairi-01 well.

Table 1. Seismic and Well log parameters for Cretaceous Lower Goru Formation.

Data source	Interval velocity (m/sec)	Average Density (kg/cc)	Average Acoustic impedance $(Kg/m^2/sec)$	Average Reflection Coefficient
Seismic Lines	3180.23	2.33	7403.51	0.14806
Fateh-01 Well	3356.43	2.34	7423.72	0.14839
Panairi-01 Well	3346.13	2.33	7439.44	0.14798

The results for Fateh-01 indicate the rocks are mostly saturated with water rather than hydrocarbon (Fig. 7 and 8). In Paniari-01 the average values of volume of shale was 28.24% water saturation was 60.45% while hydrocarbon saturation was 39.55%, for reservoir zone water saturation and hydrocarbon saturation resulted as 33.04%, 56.71% and 43.29% respectively (table 2). The values from Panairi-01 are suitable for hydrocarbon accumulation but still the high water saturation declines this favor.

The well correlation of Fateh-01 and Panairi-01 is shown in the figure 9. The figure represents that Lower Goru Formation is thickening towards the eastern direction indicating mouth of depositional river in eastern direction.

Table 2. Petrophysical analysis of reservoir zone and all three formations (Upper Goru, Lower Goru and Basal sand unit) in Fateh-01 and Panairi-01 well.

Zone	Attributes	Fateh-01 Well	Panairi-01 Well
All three formation	Volume of Shale	47.89%	28.24%
	Water Saturation	73.85%	60.45%
	Hydrocarbon Saturation	26.15%	39.55%
Reservoir zone	Volume of Shale	43%	33.04%
	Water Saturation	74.15%	56.71%
	Hydrocarbon Saturation	36.85%	43.29%

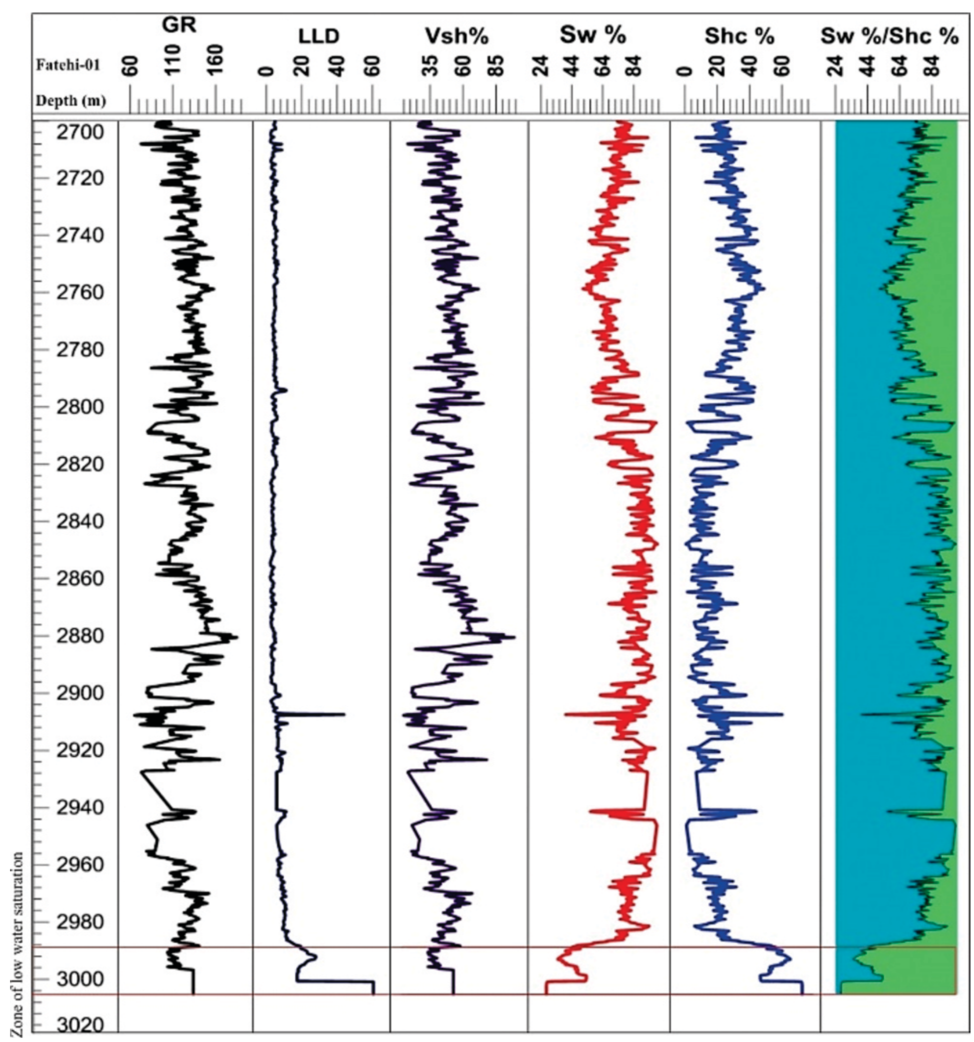

Fig. 7. Petrophysical analysis of Fateh-01 Well, shows variation of different curves with depth and lithology. The zone of low water saturation exist between 2985 to 3005 m.

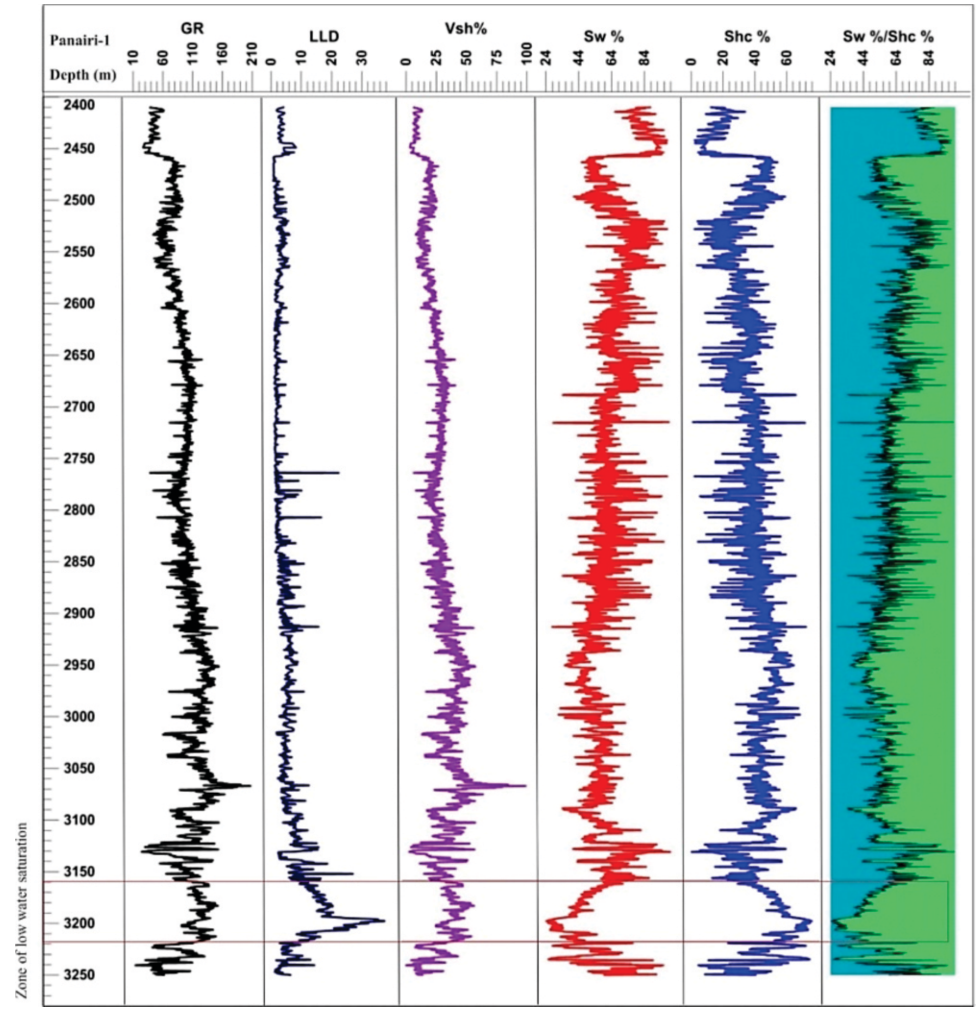

Fig. 8. Petrophysical analysis of Panairi-01 Well, shows variation of different curves with depth and lithology. The zone of low water saturation exist between 3152 to 3210 m.

6. Conclusion

Interpretation of faults indicates normal faulting (Horst and Graben structures) in the study area (Fig. 5); these are formed due to rifting of Indian Plate from African plate during Jurassic and early cretaceous in the north east direction and collision with the Eurasian plate in Paleocene. Contour maps of Lower Goru Formation show many closures towards center portion as we move from East to West. A closure of 39 m slightly towards west from center of map is identified which can probably be a hydrocarbon lead. Comparison of velocity, density, Acoustic Impedance and Reflection Coefficient estimated from seismic and well log data shows that area is less complex (as compared to collisional belt resulting in folding and faulting) with horizontal reflectors furthermore density and velocity values of Lower Goru Formation indicate saturated rocks. The reservoir zone is identified ranging from depth from 2700 m to 3100 m in both the wells is mostly water bounded zone rather than a hydrocarbon bounded zone. As the average percentage of water saturation from both wells is 63.45%. This may be due to “Hydrophobic Effect” caused due to excessive water. This effect might have prevented the hydrocarbons to penetrate in the rock and move to some other distant location this can be confirmed on the basis of surrounding blocks which are rich in hydrocarbons. Further well data can be of great help in understanding this problem.

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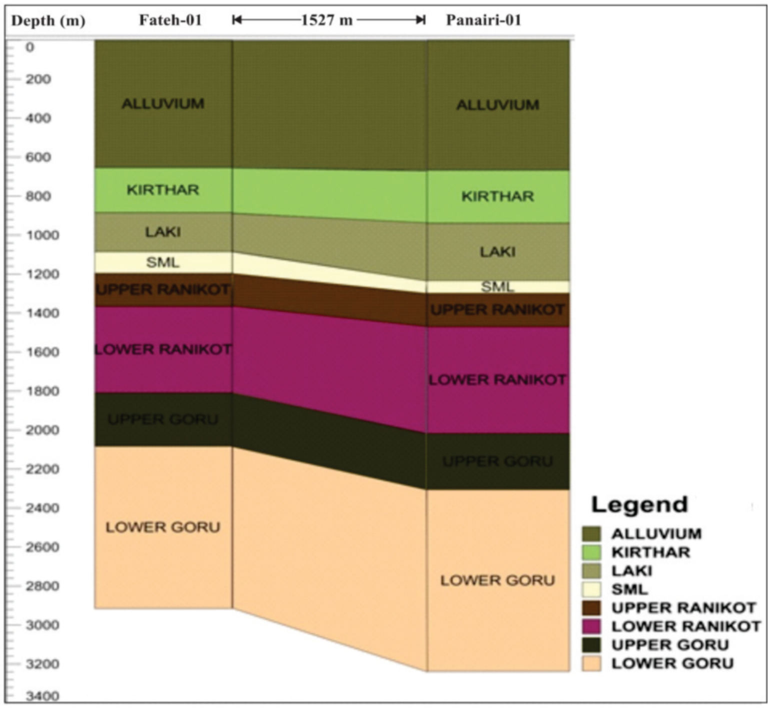

Fig. 9. Geological cross section through Fateh-01 and Panairi-01. Lower Goru Formation has more thickness then other formations in both wells.

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