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Seismic Interpretation and Petrophysical Analysis of a Cretaceous Reservoir in Lower Indus Basin, Pakistan

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Abstract

Seismic interpretation delineates the subsurface features (structural and stratigraphic) that are favorable for hydrocarbons' accumulation and Petrophysical analysis evaluates the reservoir characterization in detail. In this paper, 2D seismic data of the Hala area is used to study the structural traps that may be favorable for hydrocarbons. AdamX-01well in the study area is producing. Petrophysical and facies analysis give information about the reservoir parameters. Interpretation incorporates well data. Sands of Lower Goru Formation (Cretaceous) act as a reservoir. Horst and Graben subsurface geological structures are delineated at reservoir levels by using TWT and depth structures maps. Chiltan Limestone Formation (Jurassic) is also marked and contoured in time and depth domains. The petrophysical analysis gives two potential zones with high hydrocarbon saturations. Facies modeling confirms reservoir sands. Integrating the geophysical techniques, possible hydrocarbons, and new potential zones are identified.

Keywords*: Seismic interpretation; Petrophysics; Seismic attribute; Reservoir; Unconventional; Indus Basin.*

1. Introduction

Seismic interpretation is the art and science of finding, identifying, correlating, and understanding the geological structure of the subsurface and its layering through geologic time using seismic data. Human seismic interpretation is not a linear process where a discrete search, identification, correlation, and understanding are sequentially performed, but rather, it is a global iterative process that combines these steps in a non-deterministic manner using information concealed in the seismic data [1]. For this purpose, well data is also incorporated, where the real geology is known. Therefore it is vitally essential to be in affinity with other information about the area, consisting of gravity, magnetic data, well data, and surface geology [2]. The seismic data uses bright spot amplitude anomaly as a hydrocarbons indicator. The reflection coefficient is a characteristic of acoustic impedance that exists due to strong lithological change [3]. Petro-physical interpretation is the well log evaluation of the estimation at the ratio of gas, oil, and water in the reservoir. Density can be an important parameter to differentiate lithologies and estimate other petrophysical properties, such as porosity or fluid content [4]. It is used to check the presence of hydrocarbons and other fluids. The hydrocarbon amount in the reservoir is the function of porosity and hydrocarbon Saturation of the reservoir. The efficiency of a reservoir depends upon permeability. On the groundwork concerning these strategies, hydrocarbon leads can be identified.

1.1. Geology of the study area

The southern Indus Basin is characterized as an extensional basin by the tectonic uplifting of the western margin concerning the Indo-Pak plate. Structural fashion reflects gradual development over the sedimentary basin regarding Pakistan. Pakistan encompasses a couple of sedimentary-basins, (1) Indus-basin and (2) Baluchistan-Basin, which flourished within different geological periods through the Cretaceous /Paleocene along the strike-slip fault named as Ornach-Nal/Chaman fault. Indus-Basin is further divided among (a) Upper Indus Basin (b) Lower Indus Basin which is further divided into Central Indus Basin and Southern Indus Basin, based on the structural administration and petroleum potentialities [5].

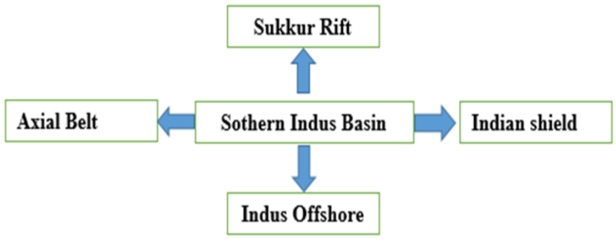

Figure 1. Boundaries of the Southern Indus Basin

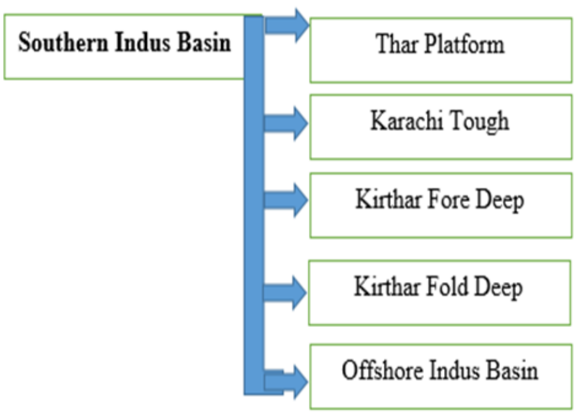

Figure 2. Classification of Southern Indus Basin

Lower-Indus basin includes the greatest gas producing fields of Indus Basin and covers the southern section of Pakistan. The study area is located in DADHAR District Sindh and is called HALA Block with the location of Latitude-25º48'43''N and Longitude-68º25'45'' E and elevation of 27.84 m above mean sea level.

Southern Indus Basin is limited in North by the Middle Indus Basin, in East with the Indian shield, the Axial Belt in the west and Offshore Area in the south [5] (Figures 1 and 2). Sukkur Rift divides Lower Indus basin into Central Indus basins and Southern Indus basin. By Zaigham and Mallick [6] Southern basin lies in extensional regimes, horst and graben structures are formed throughout the basin which affects the hydrocarbons generation, migration, and trapping mechanism. The sands of Lower Goru Formation of Cretaceous age act as a reservoir in Lower Indus Basin (Figure 3). Southern Indus basin has been divided into five units (Figure 3).

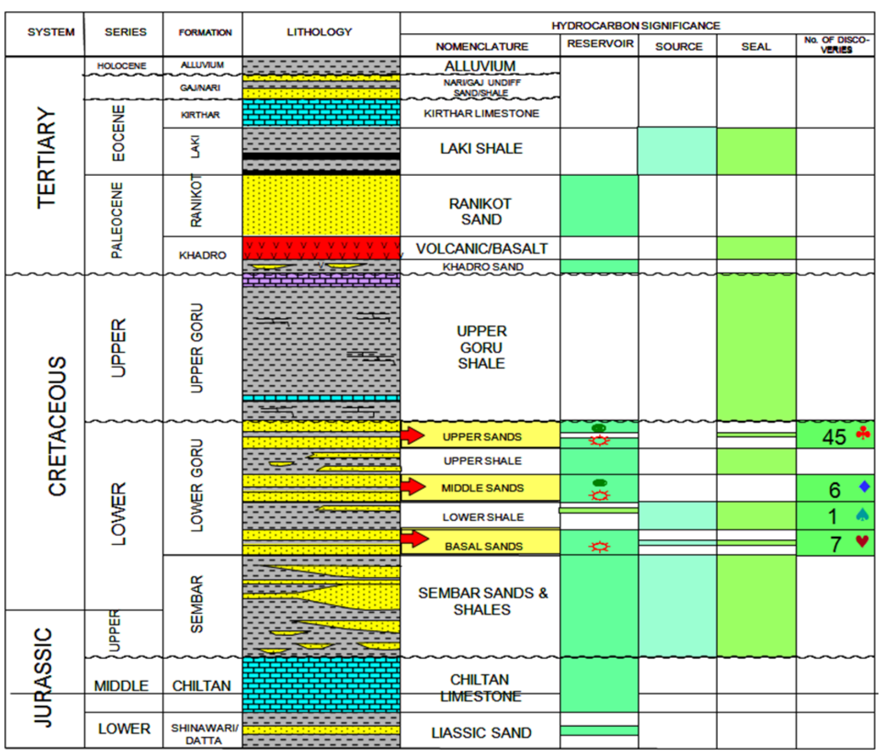

Figure 3. Generalized stratigraphy of Lower Indus basin [7]

2. Database and methodology

2.1. Data used in research work

2D Seismic and well data of the HALA area is obtained from LMKR on the special approval from DGPC and Dept. of Earth Sciences, QAU. The 2D seismic lines and well data concerning the HALA area are shown in Tables 1, 2, and 3.

Table 1. Total number of dip & strike lines and wells data in 2D survey

Line Name	Line Type	Line Name	Line Type
GPPL04-HAL_04	Dip Line	GPPL04-HAL_16	Dip Line
GPPL04-HAL_06	Dip Line	GPPL04-HAL_01	Strike Line
GPPL04-HAL_08	Dip Line	GPPL04-HAL_05	Strike Line
GPPL04-HAL_10	Dip Line	GPPL04-HAL_07	Strike Line
GPPL04-HAL_12	Dip Line	GPPL04-HAL_09	Strike Line

Table 2. Well in the study area

Well Names	Latitude (Degree)	Longitude (Degree)	Start depth (m)(KB)	End depth (m)	Status
AdamX-01	25 0 49' 1''	68036'37''	31	3566	GAS/CON

Table 3. Well Logs Detail of Adamx-01

Logs	AdamX-01	Logs	AdamX-01
GR	Present	DT	Present
SP	Present	MSFL	Present
CALI	Present	LLS	Present
NPHI	Present	LLD	Present
RHOB	Present		

2.2. Base map

The base map shows seismic lines with shot points' annotations, well location AdamX-01, and grid information. Geophysicist generally utilizes maps which exhibit the orientation regarding seismic lines or specific points at which seismic records (data) had been acquired (Figure 4).

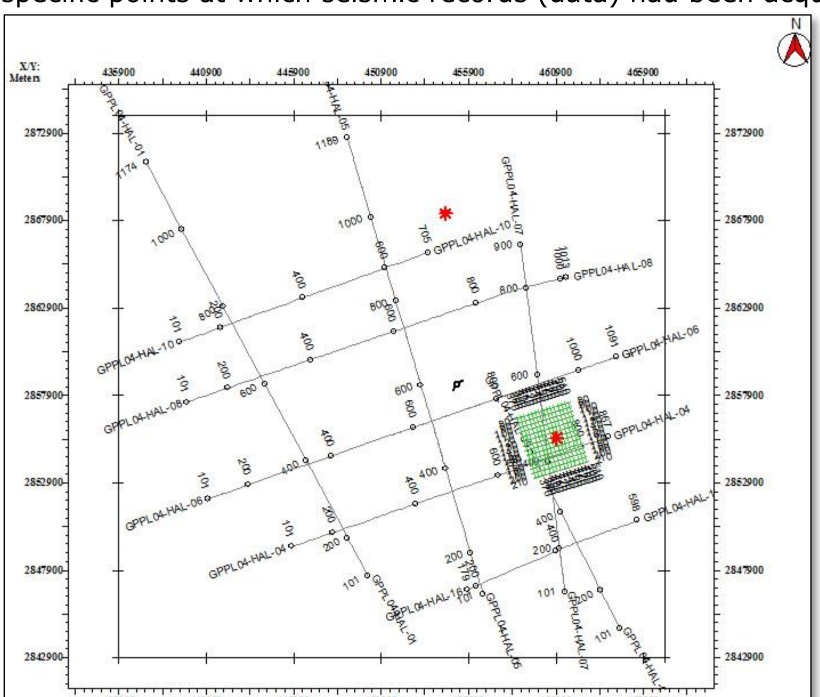

Figure 4. Base map of the area showing location and orientation of seismic lines

2.3. Methodology

The synthetic seismogram is a 1D forward model regarding the acoustic model of the earth. It is estimated by convolution over the reflection coefficient computed from sonic and density logs along the wavelet extracted out of seismic data [7-9]. The Synthetic seismogram over AdamX-01 well, generated and the correlated to different horizons on seismic. Different faults have been marked with the aid of viewing lateral discontinuity of the horizons. The time contour map at Lower Goru Formation (Middle sand, Upper Basal sand, Lower Basal sand) and Chiltan Limestone are constructed by selecting the time of seismic horizons against every shot point. The velocity from TD chart is calculated and the depth contour maps are generated.

For petrophysical analysis, different logs are used such as 1st lithologic track (GR, SP, and HCALI log), 2nd Resistivity track (RLA5 (LLD), RLA3 (LLS), RXO (MSFL) logs) and 3rd porosity track (DT, RhoB, TNHI logs). The petrophysical analysis is done in order to find different reservoir properties. First of all volume of shale is calculated from GR log after that Sonic porosity, average porosity, and effective porosity is calculated and then the water saturation and hydrocarbons saturation is computed in the reservoir zones. The logs are further analyzed for the identification of different possible resources plays and mature source rock formation using Δ log R technique then the modified Δ log R technique [10].

3. Results and discussions (seismic lines)

Lower Indus Basin holds its significance for gas-bearing reservoirs at various levels. Various studies have been carried out at these reservoirs [11-16].Hala area is relatively less explored and production from AdamX-01 shows potential for further exploration. Subsurface structures favor promising leads for prospect generation and well developments.

3.1. Interpretation of GPPL 04-HAL-04, GPPL04-HAL-06

Horst and graben structures are marked on seismic lines. Four major faults and some minor step faults are present. Three horizons of Lower Goru Formation; Middle Sand, Upper Basal Sand, Lower Basal Sand, and one horizon of Chiltan limestone Formation, are marked on the seismic line GPPL 04-HAL-04 at TWT 1.835Sec, 2.072Sec, 2.135Sec and 3.26Sec respectively. The time over the Horizons increases west to east which indicates that the direction of sedimentation is east to west. The two horst and two graben structures are formed and well was drilled on the horst structure. While on the line GPPL04-HAL-06 three horst and two graben structures are formed. The horizons are marked at the time at 1.89Sec, 2.16Sec, 2.25Sec, and 3.25Sec respectively. The seismic lines GPPL04-HAL-04 and GPPL04-HAL-06 are dip lines and all horizons and faults marked are shown in Figure 5 and 6.

3.2. Interpretation of GPPL04-HAL-08, GPPL04-HAL-10

The same horizons are marked on GPPL04-HAL-08 and GPPL04-HAL-10. These are east-west oriented dip lines in the Northern part of the study area. The seismic two way travel time for the horizons on GPPL04-HAL-08 is 1.76Sec, 2.009Sec, 2.10Sec, and 3.13Sec respectively. The horizons on the line GPPL04-HAL-10 are at the TWT of 1.84Sec, 2.139Sec, 2.25Sec, and 3.38Sec respectively. Similar series of Normal faults are marked as in previous seismic lines. The interpreted seismic lines are shown in Figures 7 and 8.

3.3. Interpretation of GPPL04-HAL-16

GPPL04-HAL-16 is an east-west oriented dip line in the Southern part of the Hala area. Horizons marked on the line have TWT of 2.11Sec, 2.31Sec, 2.42Sec, and 3.31Sec respectively. Similar series of faults are marked as in previous lines forming horst and graben structures. The interpreted seismic line is shown in Figure 9.

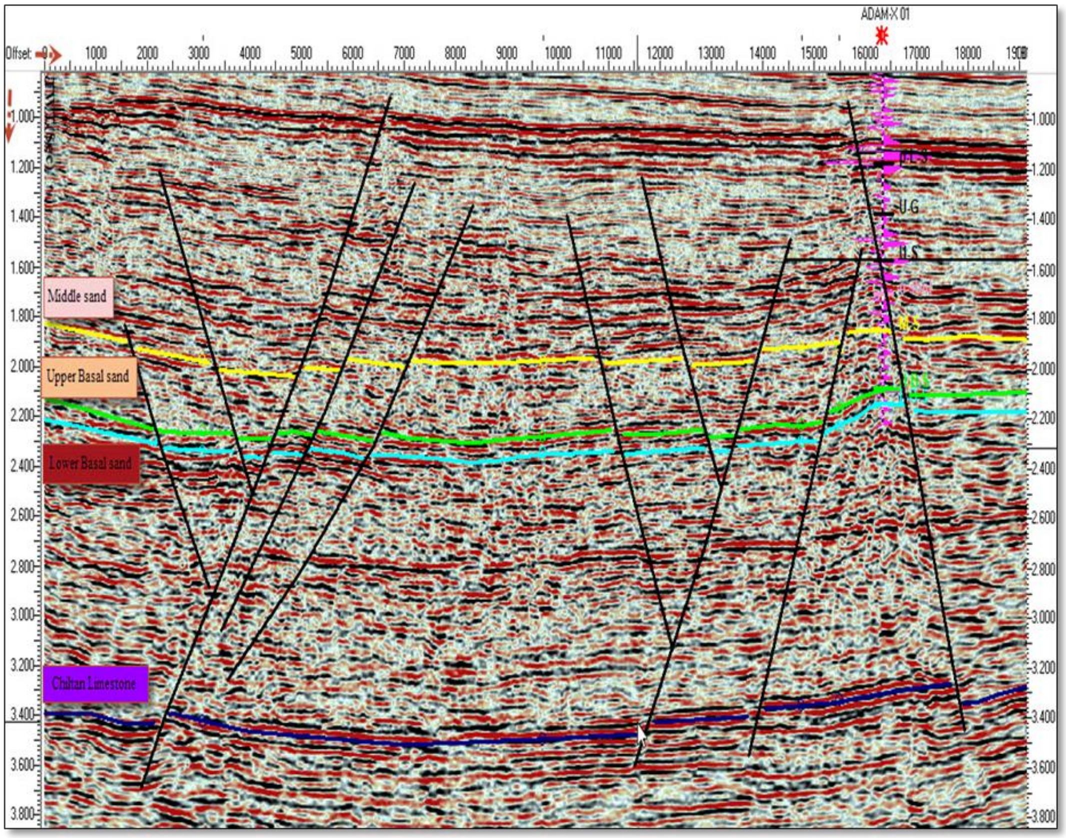

Figure 5. Marked seismic line GPPL04-HAL-04

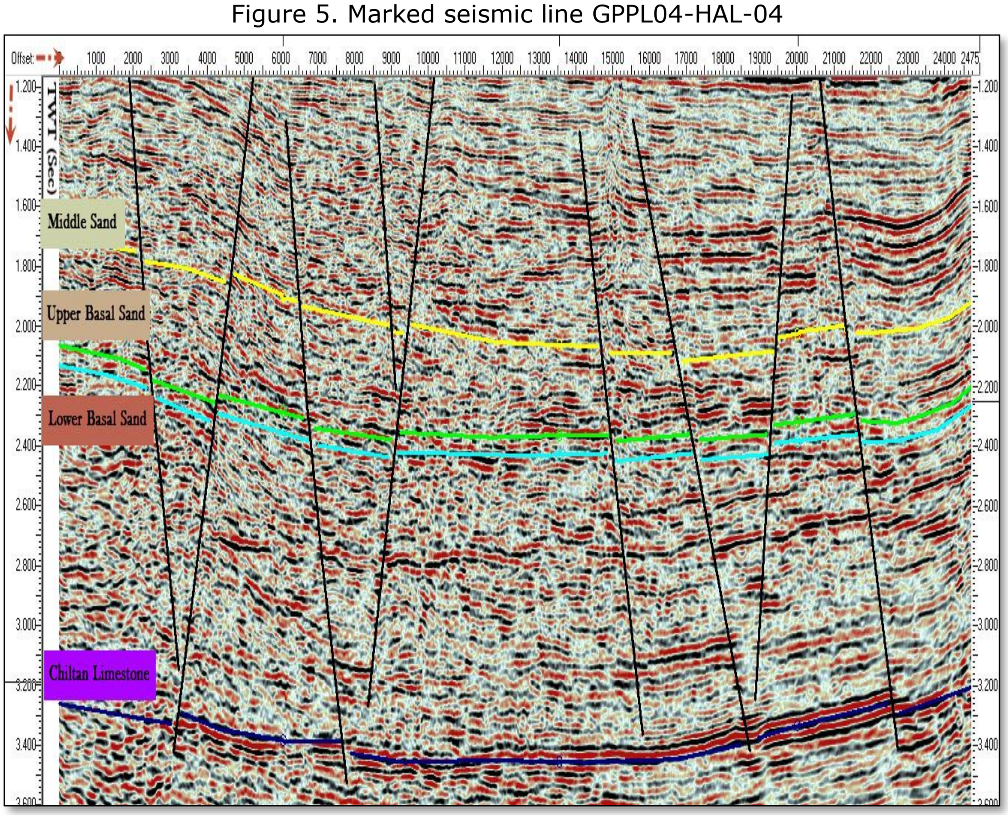

Figure 6. Interpreted seismic line GPPL04-HAL-06

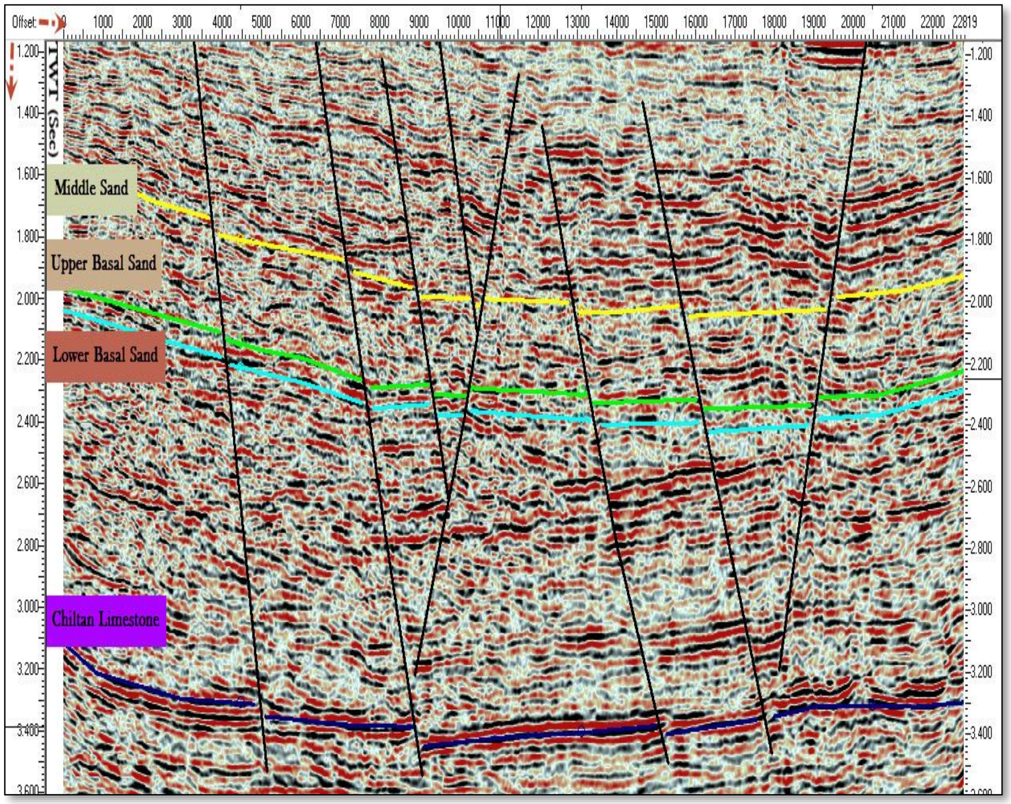

Figure 7. Interpreted seismic line GPPL04-HAL-08

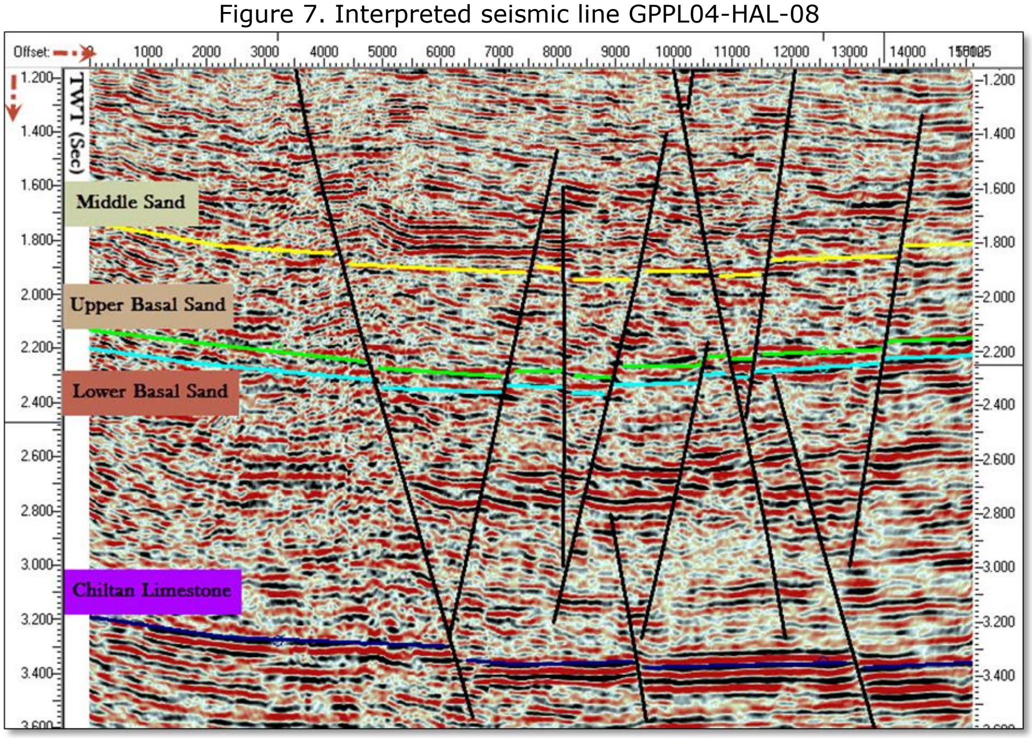

Figure 8. Interpreted seismic line GPPL04-HAL-10

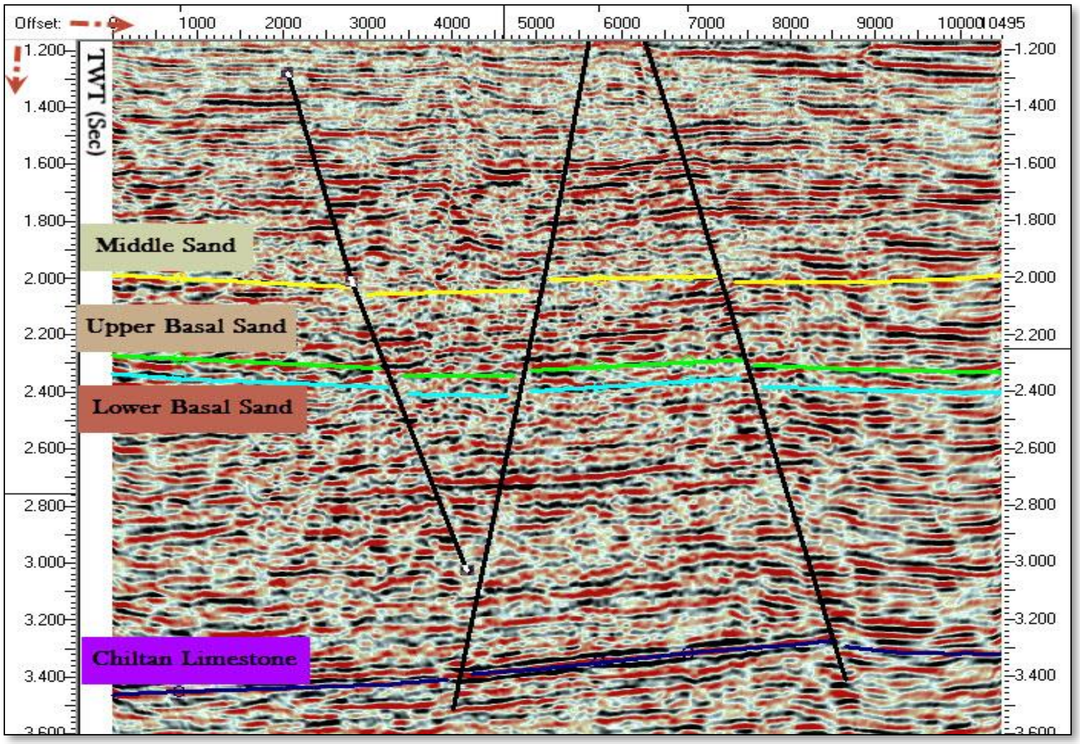

Figure 9. Marked seismic section of line GPPL04-HAL-16

3.4. Fault correlation

In this study, seven major faults are correlated on the base map for horizons of Upper Basal Sand and Lower Basal Sand of Lower Goru Formation. These faults are forming horst and graben structures and a well is drilled at horst structure. The faults polygon maps are constructed for F1, F2, F3, F4, F5, F6, and F7 at different horizons (Figures 10 and 11).

3.5. Time contours maps

The contour maps summarize the interpretation work. These maps are called contour maps as like the imaginary lines which join points of equal time or depth or any other variables [16]. Contours are the 3D representation of the 2D surface. The close contour values indicate steep gradients, increased values show depression, and vice versa. Hence these contours essentially show the slope/dip or structural relief of that formation. Time contour maps are generated for four horizons (Figures 12 to 15).

3.6. Time map of middle sand

The time contour map of middle sand is shown in Figure 12. The contour shows the deepest section on the Horizon within the time 1.977-2.116 seconds is at graben and the shallowest section is toward the western side of the formation up in accordance with 1.596-1.699 seconds. A three-way closure is formed between purple (F4) and green (F5) fault and that can be a potential structural trap for hydrocarbon.

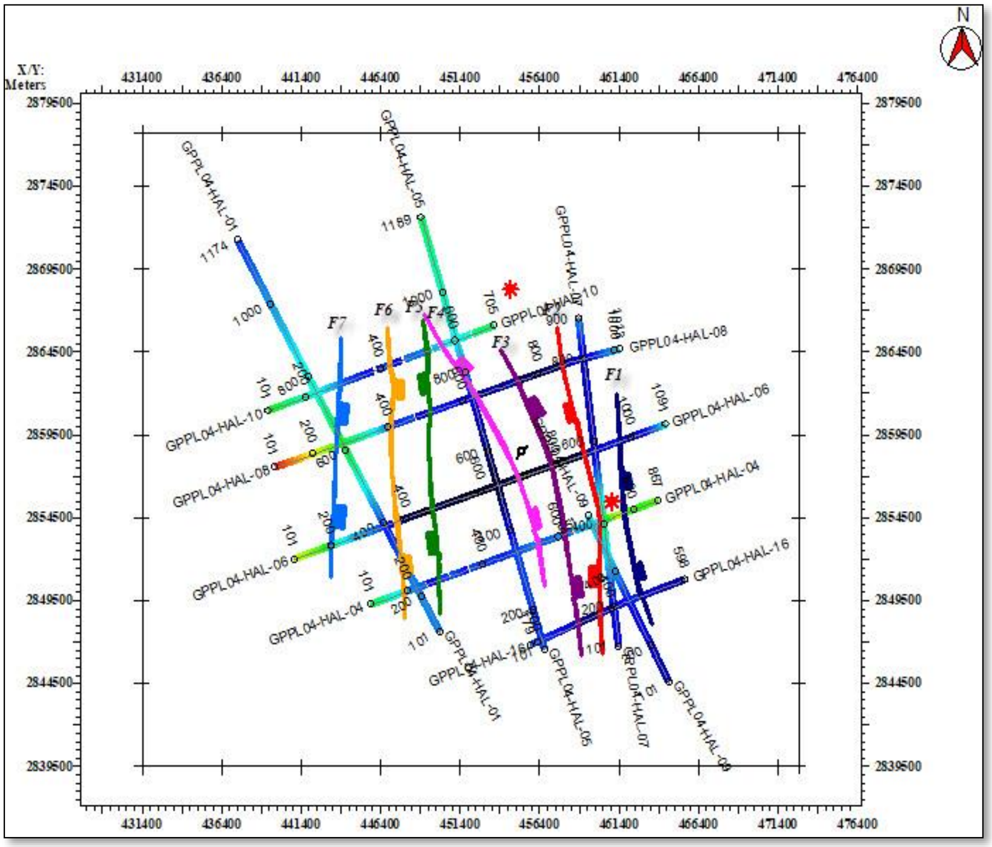

Figure 10. Faults polygon on base map F1, F2, F3, F4, F5, F6, F7 of Upper Basal Sand

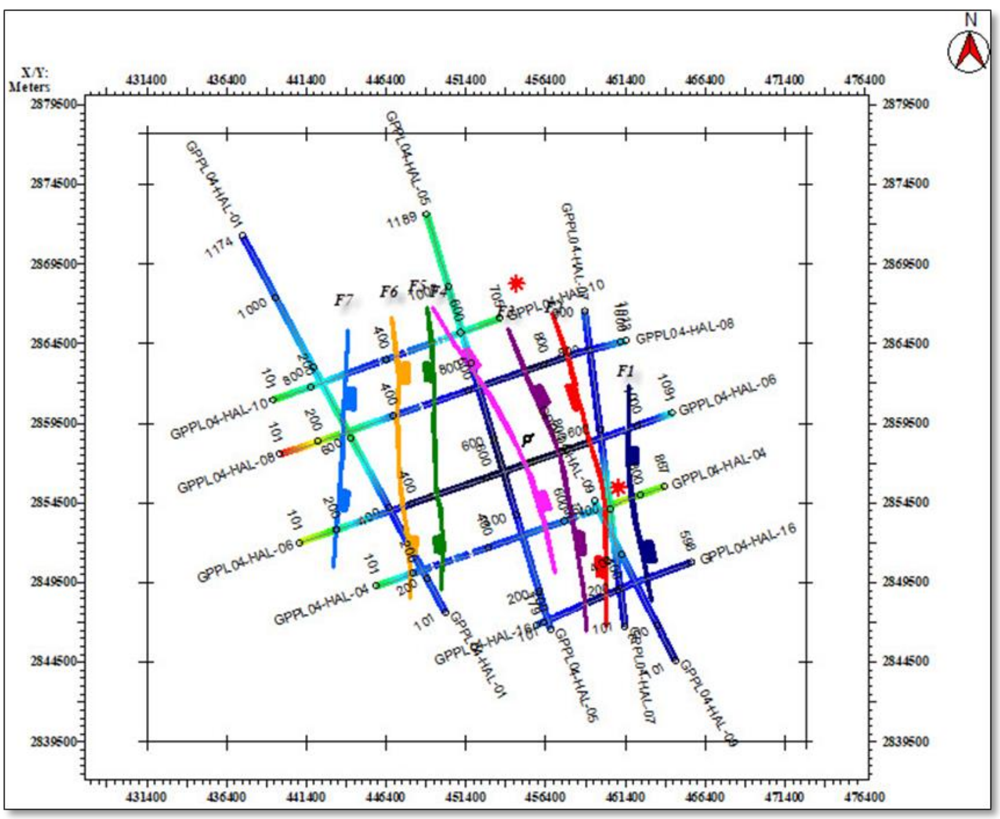

Figure 11. Faults polygons F1, F2, F3, F4, F5, F6, and F7 (right to left) of Lower Basal Sand

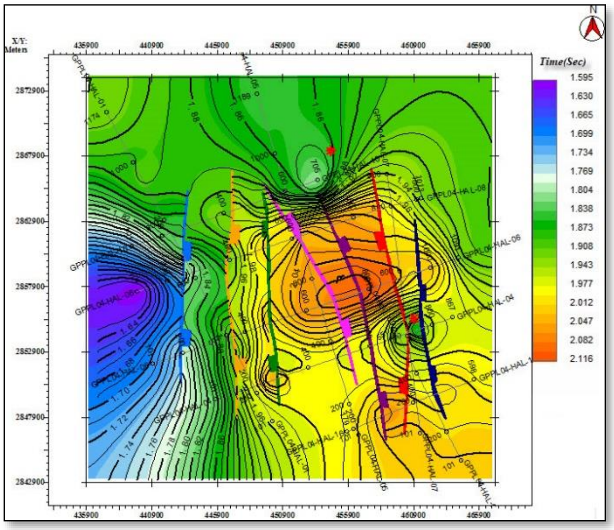

Figure 12. Time contour map of middle sand

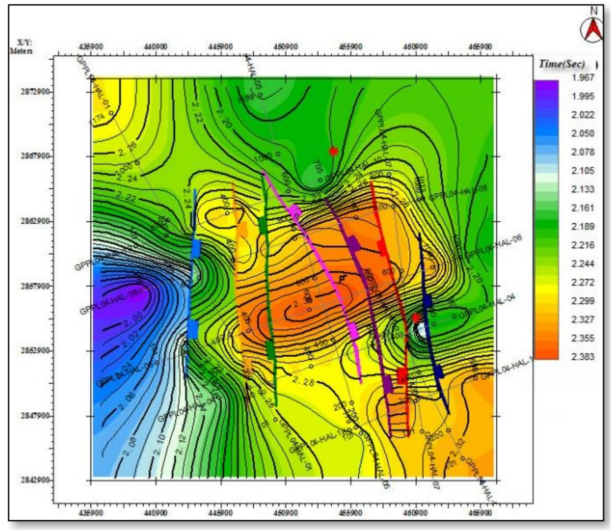

Figure 13. Time Contour Map of Upper Basal Sand

3.7. Time map of Upper Basal Sand

The time contour map of upper basal sand is prepared at 0.010 seconds (10 milliseconds) contour intervals. The time contour shows the highest time 2.272-2.283 seconds at graben on the east side the shallow part is toward the west at time 1.967-2.078 second. Seven faults have been correlated. A well is drilled at three-way closure beside F1 and a lead can be marked close to F4 at a similar closure (Figure 13).

3.8. Time map of Lower Basal Sand

The time contour chart on the main reservoir lower basal sand is organized by means of SMT Kingdom software. The time contour shows the deep part of the horizon with time above in accordance with 2.341-2.451 seconds is at widespread graben between the east side aspects while the shallow part is toward the west with time 2.038-2.148 second. Similar faults are correlated at the top of Lower Basal Sand (Figure 14). A well is present at the horst structure bounded by F1 and F2. A potential horst structure is bounded by F4 and F5.

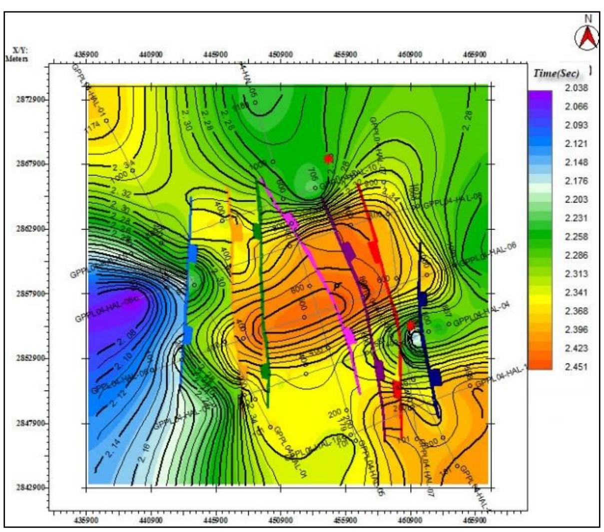

Figure 14. Time Contour Map of Lower Basal Sand

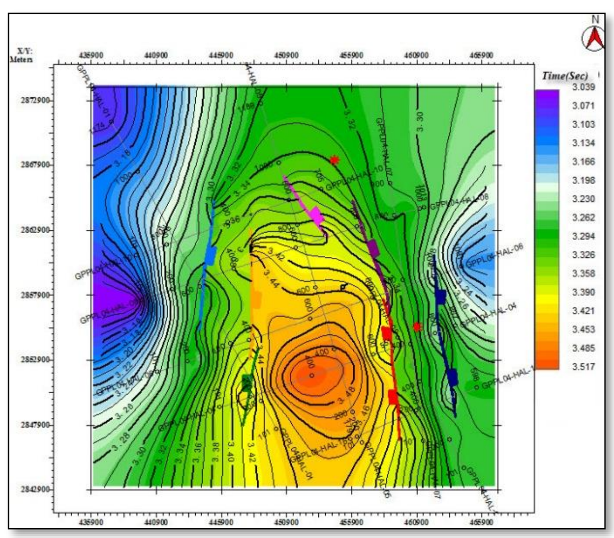

Figure 15. Time Contour Map of Chiltan Limestone

3.9. Time Contour Map of Chiltan Limestone

The contour map generated for Chiltan limestone shows a graben structure in the center of the area (Figures 15). Chiltan is an outstanding reflector that acts as good reservoir at several locations with shales providing a seal at the top and a presence of source at a deeper level where it attains good maturity [12-14].

3.10. Depth Contour Maps

Figures 16 to 19 show the depth contour maps of middle sand, upper basal sand, and lower basal sand and Chiltan Formation. Depths are calculated using the time values and velocities calculated from DT-log at four horizons by simple relation S=V*TWT/2. The main reservoir in the Hala area is Lower basal sand and Talhar shale act as a seal.

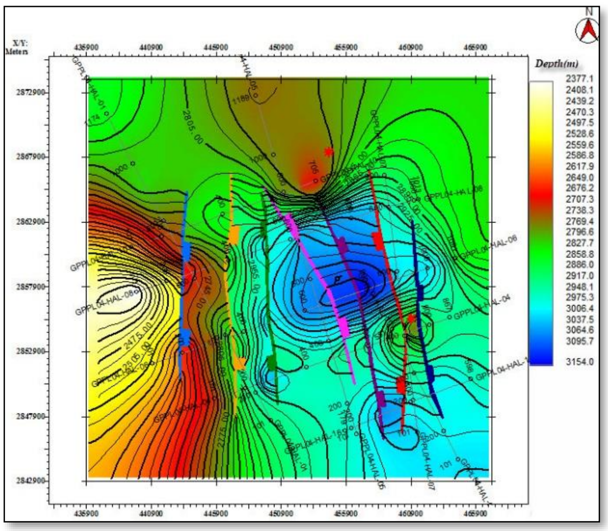

Figure 16. Depth Contour Map of Middle Sand

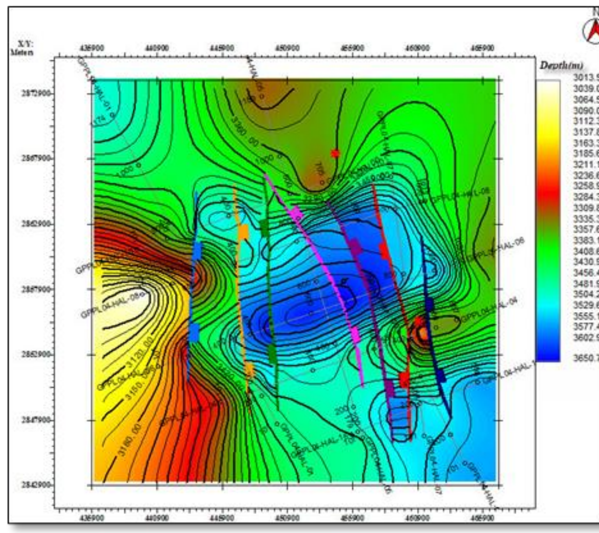

Figure 17. Depth Contour Map of Upper Basal sand

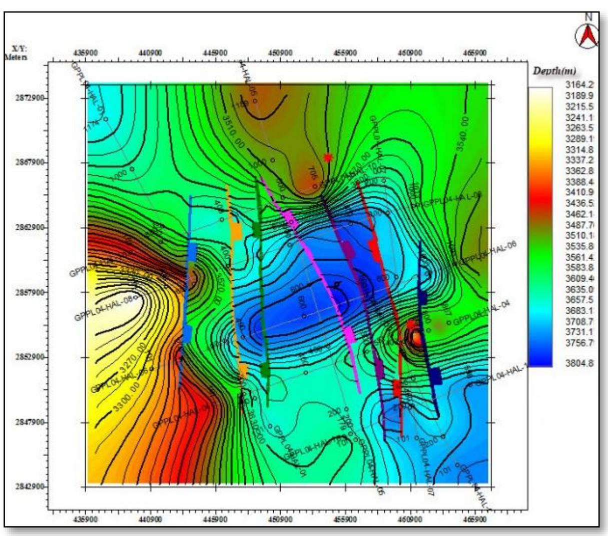

Figure 18. Depth Contour Map of Lower Basal Sand

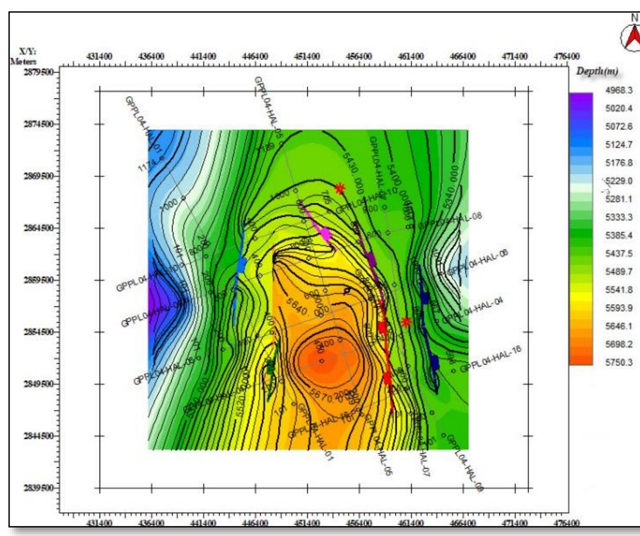

Figure 19. Depth contour map of Chiltan Limestone

Chiltan Formation is the most outstanding and prominent formation in the Lower Indus Basin. The depth structural map with seven faults has been plotted. The depth contour maps concerning middle sand, upper basal sand, and lower basal sand ranges from 2377-3154m, 3014-3651m, and 3165-3804m respectively and over Chiltan Formation the depths range

4100-4800m. The 2D & 3D Depth contour maps of the above-mentioned horizons are shown in Figures 16, 17, 18, and 19 respectively.

4. Petrophysical analysis

The petrophysical studies are related to the physical characteristics of rocks along with the fluid behavior relationship in the rock body, such as permeability, porosity, and density. These properties directly affect the fluid movement within the rock body. These properties are also directly linked with the zone of interest called reservoir rock, which is the basic objective of this chapter for detailed analysis. These analyses are done through well log data. The results of this limited area are implemented in the whole reservoir.

These petrophysical properties are used to detect and quantify the volume of hydrocarbons in the wells and implemented in the whole area of interest. The quantity of hydrocarbons in a reservoir, the amount required, is no longer through log directly, as instead are the best guess by relation.

4.1. Data Set

The dataset includes different log curves that are mostly presented in different tracks for analysis. In the First track, Gama Ray log, SP log, and caliper log, whereas Resistivity logs (LLD, LLS, and MSFL) are used in the second track. Sonic log (DT), Density log, and Neutron log are placed in the third track. The first track is called lithology track, the second track is called resistivity track and the third track is called porosity track.

Parameters determined are as follows;

- The volume of shale.
- Porosity.
- The resistivity of water in the reservoir.
- Water saturation.
- Hydrocarbons saturation.
- The probable hydrocarbon zone from where these Hydrocarbons can be extracted.

4.2. Results and discussion (Adamx-01 Well)

All the available log data is used to interpret the well (Adamx-01). Different petrophysical properties as the volume of shale, porosities (density derived porosity, sonic derived porosity, average porosities, and effective porosity), water saturation, a bulk volume of water, and finally the hydrocarbon saturation are computed. These parameters are explained in Figure 20. Three zones are selected after the detailed analysis of all logs in Lower Basal Sands of Lower Goru Formation and their derived results are given in Table 4.

Table 4. Petrophysical properties of Zones in Study area

Petrophysical properties of Zone 1		Petrophysical Properties of Zone 2	
Depth Range	3389m-3402m	Depth Range	3440m-3452m
Thickness	13m	Thickness	12m
Sonic Porosity	14%	Sonic Porosity	14%
Average porosity	21%	Average Porosity	21%,
Effective Porosity	13%	Effective Porosity	14%
Water Saturation	47%	Water Saturation	15%,
Hydrocarbon Saturation	53%	Hydrocarbon Saturation	85%,
Petrophysical Properties of Zone 3			
Depth Range	3510m-3522m		
Thickness	12m		
Sonic Porosity	13%,		
Average Porosity	16%,		
Effective Porosity	9%		
Water Saturation	13%,		
Hydrocarbon Saturation	87%,		

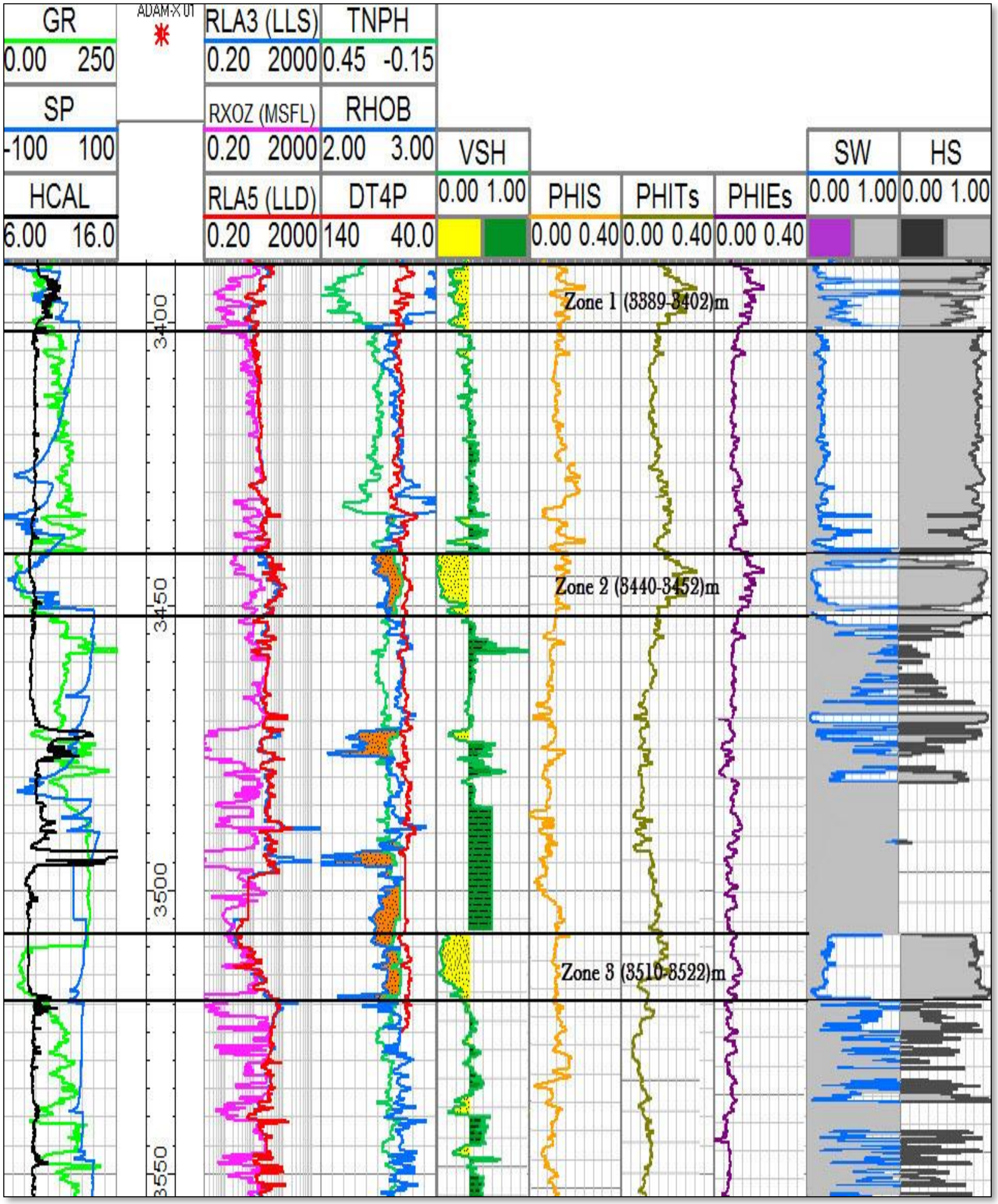

Figure 20. Petrophysical Analysis of Lower Basal Sand

Zone-1 has low water saturation and high hydrocarbon saturation but GR values show some shale is present in the sand which affects the quality of reservoir in this specific zone.

Similarly, the zone-2 has more clean sands as shown by GR and volume of shale curves. The porosity logs show greater porosity values in this zone of interest. The possibility of fluid presence is given by the crossover values between density and neutron density logs.

In 3rd zone of interest, GR and volume of shale show a high percentage of sand. The water saturation and hydrocarbon saturation are 13% and 87% respectively. The porosities are good. The crossover of values between the density log and neutron density log show light hydrocarbon is present in the zone of interest. The zone-2 and zone-3 are more suitable as compared to zone-01.

4.3. Facies modeling

Facies are mostly considered as bodies of rocks that show some specific characters but ideally, these are rock units that form under a certain condition of sedimentation, displaying a particular process or environment of deposition. Various kinds of facies are identified based on structure, composition, and sedimentary texture. Different types of sedimentary environments are known such as, a continental includes glacial, alluvial fan, river channel, floodplain, aeolian, and lacustrine environments. Transitional (shoreline) environment includes delta, beach, Barrier Island, lagoon, and tidal flats. The marine environment includes coral reefs and submarine facies. Each unit (facies) possesses a distinctive set of characteristics reflecting the condition in a particular environment. The facies reflect a high energetic and low energetic hydrodynamic condition that is either related to gradually increasing water depths or are produced by superimposed high energy events, for instance, during storms.

Facies model provides additional aid to the understanding of the sedimentary environment. Different models can be made to explain a given set of data, depending on which aspect of the facies should be highlighted most to get much information about it.

4.4. Facies Analysis of Adamx-01 well

The facies modeling of Lower Goru formation in Adamx-01 well shows interbedded shale and sandstone. A depth range of Lower Basal Sand from 3400 to 3460m is selected for facies analysis that acts as a reservoir in the project area. Three log curves are used for the facies modeling that is RHOB (unit: gram per centimeter cube and value range from 2.3-3) on x-axis, LLD (unit: ohm-m and value range from 0-200) on y-axis and GR (measured as count per second and its range is 30 to 250 in API) is coded on z-axis (Figure 21). The interbedded sands are clearly defined with low values of GR, high values of LLD matching with the Zone-2 of petrophysical analysis.

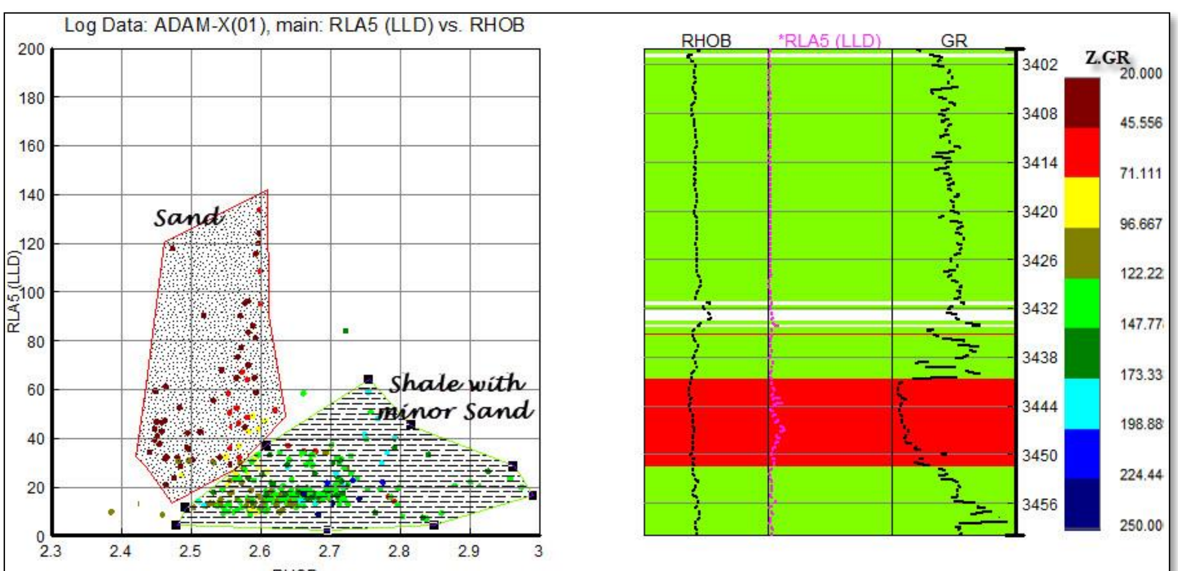

Figure 21. Cross Plots of RHOB, GR, LLD Logs at Reservoir Level (Adamx-01 Well)

4.5. Cross-Plot of Neutron and Density log

In the petrophysical interpretation, neutron and density plots are widely used for lithology discrimination. The cross plots are generated for the reservoir zone i.e. Lower Basal Sand (3400 m to 3460 m) in Adamx-01. Cross plot for the productive zones of the well is displayed in Figures 22. The values for the sands and shale are clearly separated from each other.

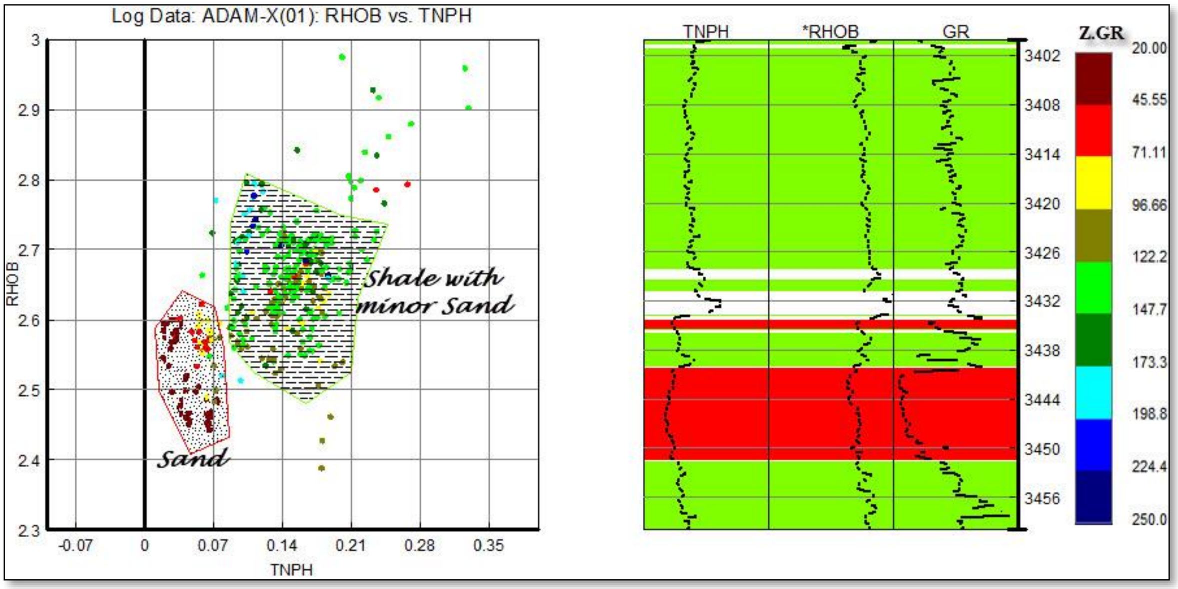

Figure 22. Cross Plot of TNPHI, GR, RHOB at Reservoir Level (Adamx-01 Well)

5. Conclusions

The principal purpose of this research was to interpret structures, identify lithology, and delineate recent prospect zones within the study area for optimum field development. Structural interpretation indicates normal faulting in the Hala area. It is confirmed that North-South trending horst and graben structures are present, indicating extensional regime due to rifting of Indian plate from African plate during Jurassic and early Cretaceous.

Contour maps of Lower Goru formation exhibit closures at the center portion. Petro-physical analysis of AdamX-01confirms the significant porosity and amount of hydrocarbons that is economically favorable for exploration in Basal Sands of Lower Goru Formation.

Acknowledgment

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