The Nucleus 56, No. 2 (2019) 55-62

www.thenucleuspak.org.pk

The Nucleus
ISSN 0029-5698 (Print)
ISSN 2306-6539 (Online)

# Structural Delineation and Hydrocarbon Potential Evaluation of Lockhart Limestone in Basal Area, Upper Indus Basin, Pakistan

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ARTICLE INFO

*Article history*:
*Received:* *07 March, 2019*
*Accepted:* *30 August, 2019*
*Published:* *04 September, 2019*

*Keywords*:
*Compressional regime,*
*Fault propagated anticline,*
*Petrophysical analysis,*
*Upper Indus basin*

ABSTRACT

*The Basal area is situated in Upper Indus Basin of Pakistan dominated by intense thrust faulting along with the involvement of salt tectonics, which are responsible for the formation of structural traps in study area. Oil reserves in sedimentary rocks are the source of hydrocarbons for the energy and these reserves are trapped in a structure provided by tectonics. Integration of geological and geophysical tools provide an insight to explore these reserves in the sub surface. Main focus of this research paper is to delineate a suitable structure favorable for hydrocarbon entrapment in the Basal area by integrating seismic and well log data near Fateh Jhang, Attock district, Upper Indus basin, Pakistan. The Upper Indus basin lies in compressional tectonic regime exhibiting thrust faulting with inference of overprints of transpressional strike-slip deformation. Basal oil field lies 77 km south-west of Islamabad with Main Boundary Thrust (MBT) in north, Khairi Murat thrust in south, Jhelum/Soan river in east and Indus river in west. Seismic data interpretation has been performed on given seismic lines by marking faults and reservoir horizons of Chorgali and Lockhart formations using formation tops and making T-D charts via analysis of multiple velocity functions (MVF) of all seismic lines. Mapping of the reservoir formations have confirmed the presence of fault-propagated anticlinal structure in study area. One main fault (throw ~ 100-200 ms) and two back thrust faults EW-oriented with moderate dipping angles have been marked with dips towards North and South respectively. Petrophysical analysis is done on the well Garhi X-01, Gamma Ray, Resistivity and Porosity tracks have confirmed the presence of hydrocarbon in Lockhart Formation of Paleocene age. Three zones have been identified, out of which zone 2 is considered most favorable one due to less shale volume (Vsh), sufficient effective porosity and high hydrocarbon saturation values.*

## 1. Introduction

Reflection seismic imaging is a fundamental tool for understanding the structure of the Earth's crust. The seismic data interpretation is an important step as it is used to correlate the surface geology with subsurface structures [1]. The interpretation of seismic reflection data is the fundamental method for determining the geometry and displacement of faults in the subsurface at lithospheric to reservoir scales [2]. Interpretation of seismic image data involves a certain degree of knowledge in structural geology, stratigraphy and tectonic settings, as well as an understanding of the physics behind the creation of a seismic image. Interpreters must use knowledge to produce a consistent solution that satisfies not only all available data, but also confirms the expectations [3, 4]. Knowledge is acquired from new information by developing new or modifying existing schemes (models). This study is performed to delineate the sub surface structural style and to evaluate the hydrocarbon potential in Chorgali and Lokhart formations of the Basal anticline.

Basal oil field is an exclusive Development and Production Lease of Oil and Gas Development Company Limited (OGDCL) discovered in 1999, when 2-D seismic survey was done in the area. Garhi-X-01 well was drilled by OGDCL in 2002. This well was giving production in past, but now it is abandoned. It is situated about 77 km southwest of Islamabad and lies in Attock district and specifically close to Fateh Jhang. This field is located on a positive structure resulted as a byproduct of complex Himalayan orogeny and characterized by the thick repeated succession of late Eocene and Miocene [2, 3]. The main productive reservoirs are of the Paleocene and Miocene age.

Previous studies by Jaswal et al. [2] confirmed that the area lies in North Potwar Deformed Zone (NPDZ) and has imbricate, ramp-flat duplex structures, triangle zones, and shortening of 55 km (55%). According to Jaswal [3] and Baker et al. [4] the area between Khairi Murat Thrust and passive back thrust (Dhurnal fault) forms a triangle zone. The triangle zone arrangement of faults is a common feature of the foreland basins throughout the world with associated tectonic wedges, sole thrusts and roof thrusts. This deeper level shortening has been accommodated by the development of a passive roof back thrust emanating from the tip of the southernmost ramp in the subsurface [4].

### 1.1. *Geology of the Area*

Basal lies in the north western part of Potwar basin. Geographically, the Indus River and the Jhelum/Soan rivers are passing on its western and eastern sides respectively. Main Boundary Thrust (MBT) and Khairi Murat Faults are running in the North while Salt Range Thrust (SRT) lies in the south [5]. The thrust faults, propagation folds, triangle zones and pop-up structures are believed to be formed by the salt

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movement along the decollement surface. It has plenty of tectonic structures and hosts continental margins, thick marine sedimentary sequence of source, reservoir and cap rocks [6]. Potwar basin is bounded to the south by the Salt Range escarpment, where rocks of Precambrian to Tertiary are exposed. Infra-Cambrian evaporites of unknown true thickness were deposited in Potwar in restricted and hypersaline environments. It is caused by carbonate banks developed over the east bank of the Jhelum re-entrant, north of present Kala Chitta and Margala ranges along Precambrian basement lineaments, which isolated the Potwar basin from Kashmir and Hazara, where open marine conditions prevailed [6]. A number of active structural features dominate this part of Potwar basin as shown in Fig. 1a [7].

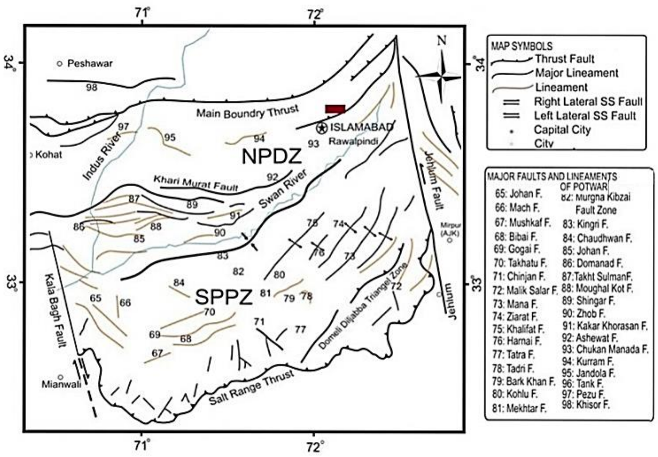


Fig. 1a: Tectonic map showing major tectonic subdivisions of Potwar region with red highlighted study area [7].

Northern Potwar represents Passive Roof Duplex geometry, where thrusted anticlines are the potential targets. Further north in the North Potwar Deformed Zone (NPDZ) imbricated antiformal stacks are the main targets. The Kohat area has experienced very complex deformation style due to the development of multiple detachment levels and compressions as well as strike slip motion. The area is represented by antiformal stack and possibly flower structures, thrusted anticlines, pop-up and fault propagating folds [6].

Geologically, basal anticline is developed due to Khairi Murat thrust and is a part of NPDZ. MBT juxtaposed the Miocene Murree Formation against the Eocene limestone. The surface exposure of this fault is more prominent due to thrusting of the Eocene Chorgali strata over the Murree Formation. In the regions, with intense tectonic deformation, some surface features mismatch subsurface structures due to decollements at different levels. In such circumstances, it is necessary to integrate seismic data with surface geological information for precise delineation of sub-surface configuration of various structures [8].

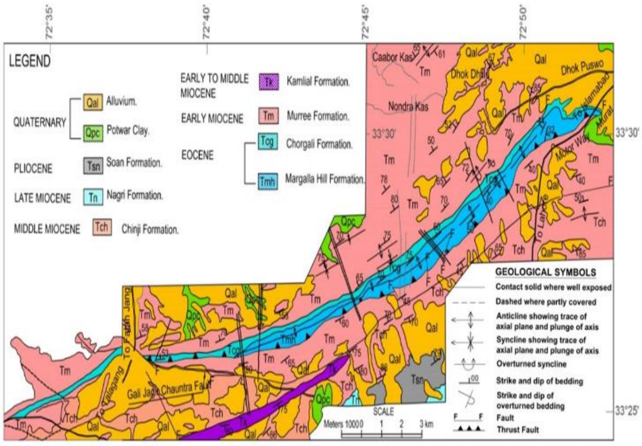


Fig. 1b: Geological map of the study area indicating different local faults [9].

The localized geological map of the area has been shown in the Fig. 1b [9]. The oldest formation present in this area is Salt Range Formation of Precambrian age, which is dominantly composed of Halite with subordinate marl, dolomite and shales, and is best developed and exposed in the Eastern Salt Range. The salt lies unconformably on the Precambrian basement rocks. The overlying platform sequence consists of Cambrian to Eocene shallow water sediments with major unconformities at the base of Permian and Paleocene [10].

The Potwar basin was raised during Ordovician to Carboniferous; therefore, no sediments of this time interval were deposited in the basin. The second sudden alteration to the sedimentary system is represented by the complete lack of the Mesozoic sedimentary sequence, including late Permian to Cretaceous, throughout the eastern Potwar basin. In Mesozoic time, the depocenter was in central Potwar basin, where a thick Mesozoic sedimentary section is present as shown in Fig. 2 [11].

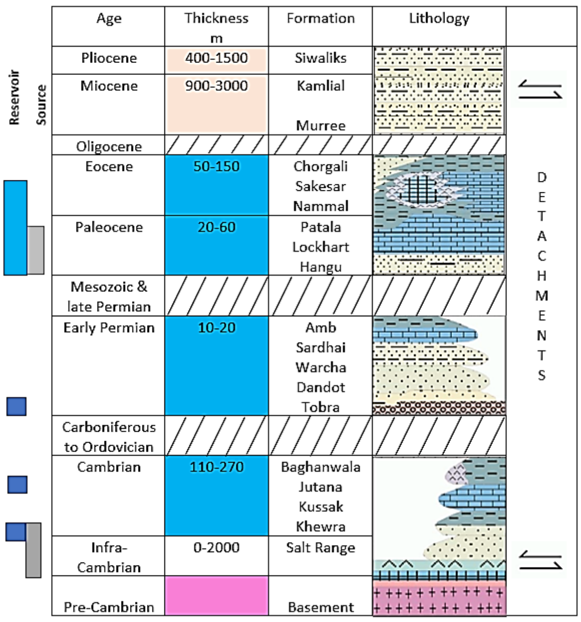


Fig. 2: Stratigraphy of Potwar basin, Pakistan [11].

The geological history of this basin begins from Precambrian age. East of Potwar basin is salt-cored and the cores of these salt anticlines are thrusted and originated due to the compression of Himalayan orogeny in Miocene-Pliocene age. The oil and gas in the area has been produced from the fractured carbonates of Paleocene and Eocene age but Mesozoic sandstones and Paleozoic carbonates and sandstones has produced additional oil in the area [11]. The carbonates and evaporitic sequence are mostly in the sub surface in the northern Potwar as compared to the eastern western and southern Potwar. So, there is maximum chance that hydrocarbons being charged and trapped in the subsurface [12]. The borehole stratigraphy of Garhi-X-01 well is given in Table 1.

Table 1: Borehole stratigraphic succession of Garhi-X-01 well.

| *Formation Top* | *Formation Top age* | *Formation Top (m)* | *Thickness (m)* |
|---|---|---|---|
| Murree | Miocene | 0.00 | 4014.00 |
| Kohat | Eocene | 4014.00 | 48.00 |
| Murree | Miocene | 4062.00 | 66.00 |
| Kohat | Eocene | 4128.00 | 48.00 |
| Murree | Miocene | 4176.00 | 268.00 |
| Kohat | Eocene | 4444.00 | 113.00 |
| Kuldana | Eocene | 4557.00 | 198.00 |
| Chorgali | Eocene | 4755.00 | 31.00 |
| Sakesar | Eocene | 4786.00 | 100.00 |
| Nammal | Eocene | 4886.00 | 49.00 |
| Patala | Paleocene | 4935.00 | 52.00 |
| Lockhart | Paleocene | 4987.00 | 313.00 |

The Patala Formation containing oil shales with 35-45% Total Organic Content (TOC) acts the proven source rock in the Potwar basin and also in this area [12-14]. The thin-skinned tectonics have developed the traps creating the faulted anticlines, pop-up and positive flower structures above Pre-Cambrian salt. Here in the study area, two main reservoirs have been identified and targeted, based on the available literature and kerogen history. The lower one is Lockhart Formation which is being charged by the shales of Hangu Formation lying at the bottom. The second (upper) reservoir is Chorgali and Sakesar formations, which is being fed by Patala shales. The lateral and vertical seals to the reservoirs are provided by the Kuldana clays and Patala shales respectively [15, 16].

## 2. Available Data

Data used for structural interpretation consist of 5 seismic lines with one well of Garhi-X-01. Base map typically shows the orientation of seismic lines, shot points and well location with a geographic reference such as latitude and longitude. The base map is shown in Fig. 3. Well logs including gamma ray, caliper, self-potential, resistivity, neutron, density and sonic were available for petrophysical analysis. Well data for Eocene formations was not available, so reservoir properties were evaluated only for Lockhart Formation of Paleocene age.

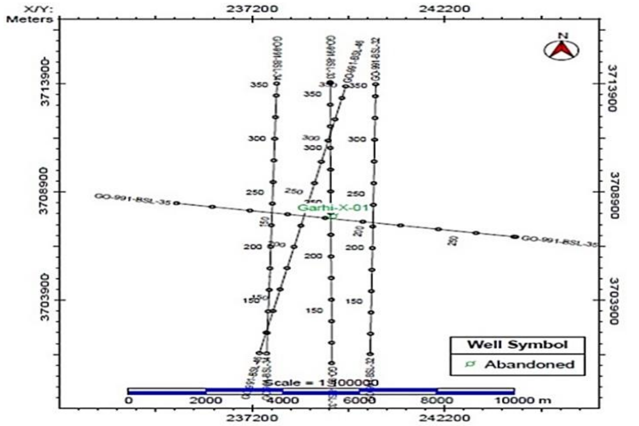


Fig. 3: Base map representing dip and strike lines along with well Garhi-X-01.

## 3. Methodology

Seismic interpretation is an art of identifying, correlating and understanding the geological structure of the subsurface through geologic time using seismic data [17]. 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 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 data, well information, surface geology as well as geologic and physical concept [18]. Interval and average velocity from the well log data are often different from seismic data depending upon structure of the area.

The 2D seismic interpretation is achieved in a parallel manner with the geological interpretation. In order to mark the formations of different ages well data of Garhi-X-01 was utilized. Well is located on the seismic dip line 33 so TD chart is prepared by using the RMS velocities given on it. Formations are then named by correlating the information plotted on time depth chart. Two formations of different ages Lockhart Paleocene and Chorgali Eocene were considered favorable for hydrocarbon presence based on geological history. Using the velocity information, available borehole and geological well data, the picked seismic horizons have been calibrated on all the seismic lines. The time data was then utilized for constructing the structural map of the concerned formations in order to validate the structure interpreted on seismic data. Time and depth chart is shown below in Fig. 4. For making the time contour maps, times are read directly from the sections and so are immediately available for mapping. TWT contours represent contour lines having the same time values. These are plotted on base map where latitude/longitude values of each shot point are given. For mapping, the area of interest is digitized in such a way that ends of seismic lines are cut off in order to reduce the chances of errors. A time grid for each horizon is generated, and represented by different colors showing the marked horizon time. The contour map is generated using Kingdom Software (used for Geological and Geophysical Data Interpretation).

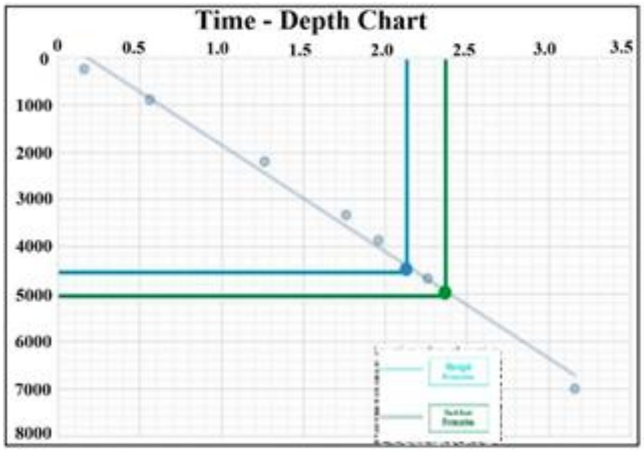


Fig. 4: Time-depth chart showing depth and corresponding time of Chorgali Formation (sky blue color) and Lockhart Limestone (green color).

## 4. Results of Seismic Data Interpretation

Based on continuity of the amplitude of the waves and best coherency, horizons are marked and this happens when the acoustic impedance changes in the sub surface. After the confirmation of horizons, Chorgali and Lockhart formations were picked on control line. During demarcation of horizons it was made sure that every fault is justified with horizons. In case of compressional regime, if there is a hanging wall then the horizon should be relatively uplifted with respect to the corresponding foot wall and if there is foot wall then the horizon should be relatively downthrown with respect to corresponding hanging wall. Chorgali (R1) got confirmed at control line 991-BSL-33 with sky blue reflector lying exactly beneath the well shot point no. SP – 235 at 2.25 seconds time while Lockhart (R2) with green color at 2.38 seconds time. F1 is the main thrust fault while F2 and F3 are the back thrusts dipping in north and south directions, respectively. Interpreted seismic sections of lines 991-BSL-33 and 991-BSL-32 are shown in Figs. 5 and 6, respectively. Salt range thrust is also marked at the base while Murree thrust is delineated in the Siwaliks on the top. As the area lies in compressional tectonics which there is high chance of repetition of strata due to thrust impact. This repetition can clearly be observed on the seismic data.

The overall structure in the study area is being controlled by three detachments. Salt Range Thrust provides the basal detachments due to the evaporites of Salt Range Formation while middle and upper detachments are marked by Middle and Murree thrusts, respectively, in gypsiferous marls of Kuldana Formation and clays of Murree Formation, causing this sequence to repeat. These three detachments resulted in the stacking of the sequence forming a duplex geometry where middle thrust acting as roof thrust for Cambrian to Eocene sequence which is further bisected by back thrusts, i.e., F1 and F2 and floor trust for Miocene sequence. Since all the thrusts in this stacked sequence dip towards north resulting into an active roof duplex.

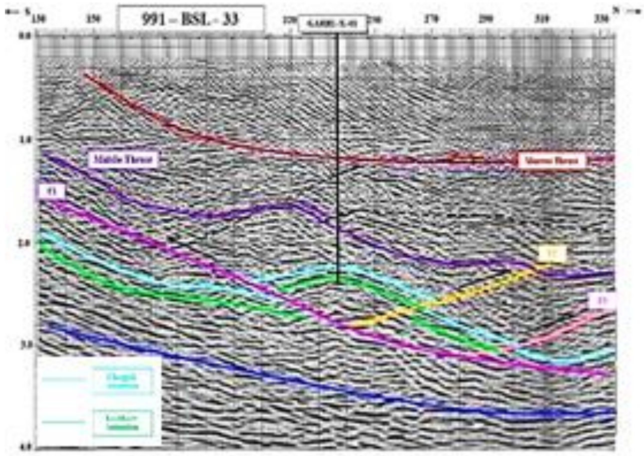


Fig. 5: Interpreted seismic section of line 991-BSL-33.

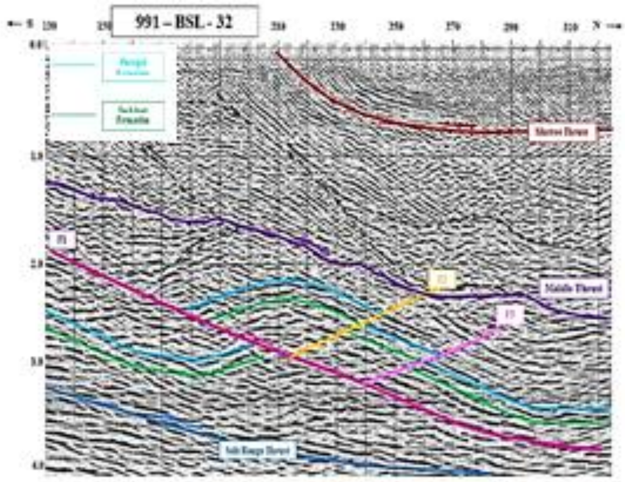


Fig. 6: Interpreted seismic section of line 991-BSL-32.

### 4.1 *Mapping*

The contour interval of Chorgali contour map is 0.18 sec while 1.1 sec for Lockhart formation. The central portion is red to orange in color for Chorgali and yellow to green for Lockhart which according to the scale shows the smallest values of time ranging between 2.1 to 2.3 sec and 2.7 to 2.9 sec corresponding to the topographic high. This central portion is bounded by thrust fault representing the pop-up anticlinal structure. While moving away from the crestal part time values increase progressively and so does the corresponding values of depth. Time contour maps of Chorgali and Lockhart formations are shown in Figs. 7 and 8, respectively.

Depth contour map represents the horizon in units of depth, i.e., meters. This gives more accurate position of the horizon in the subsurface. The interpretation of depth contour map is like that done for time contour map except that in case of depth contour map, the units are in meters instead of milliseconds and now depth is displayed instead of time. The map of seismic time is projected to display the structure of horizons in the subsurface. To make a map that is more truly related to the subsurface shapes, depths must be calculated

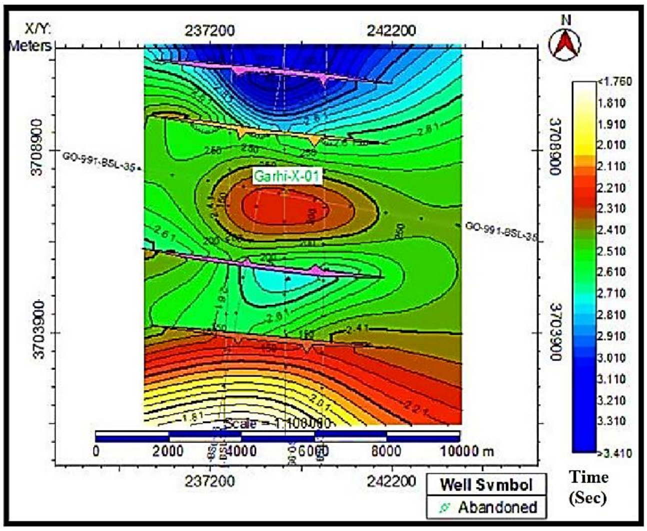


Fig. 7: Time contour map of Chorgali Formation.

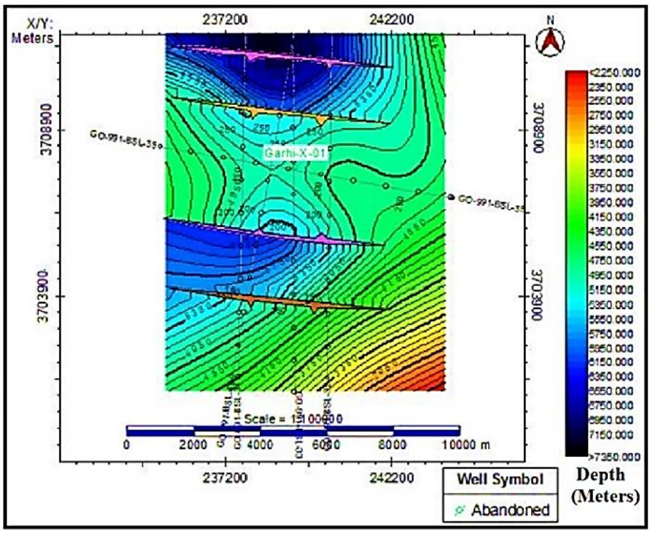


Fig. 9: Depth contour map of Chorgali Formation.

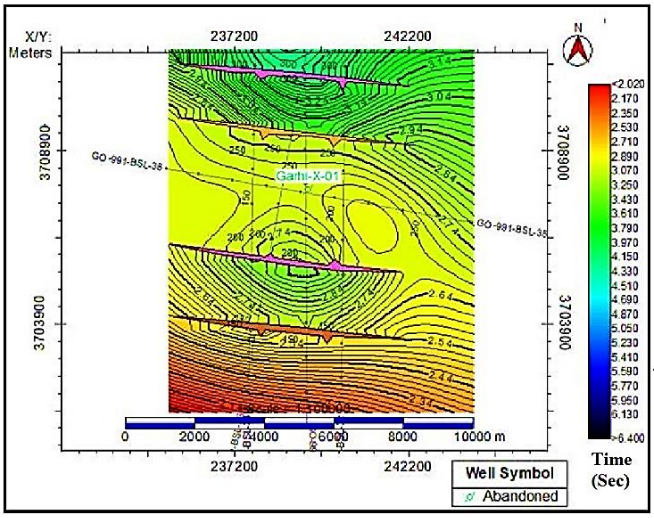


Fig. 8: Time contour map of Lockhart Limestone.

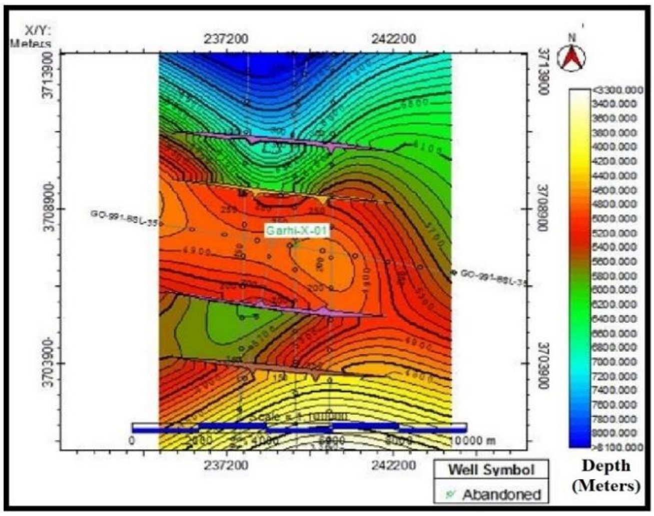


Fig. 10: Depth contour map of Lockhart Limestone.

from the times. The idea of converting the times to depths is very reasonable in case of showing the subsurface structures. RMS velocities taken from the velocity functions are used for depth calculations.

The depth contour maps are generated by using the contour interval of 200 m and the variations in the color represent changes in the depth. The scale shows the values of depth ranging between 3300-8000 m and 2250-7150 m for Chorgali and Lockhart formations, respectively. The central portion is shallowest according to the depth value scale and is bounded on the both sides by thrust faults making it a pop-up geometry and the structure developed is known as 2-way fault bounded anticline. As moving from the crestal portion the values are increasing across the faults. The central portion has widely spaced values showing the gentleness of the strata while narrow contours respond to the relatively steeper portion. The crestal point lies at approximately 4800 m and 5020 m; the depth contour maps are shown in Figs. 9 and 10, for Chorgali and Lockhart formations, respectively. Depths calibrated with the well and contour data validates the seismic structural analysis. The seismic structural interpretation and contour trend confirms that the well Grahi-X-01 is drilled on structural high. The closure is two-way fault bounded.

Mapping done at the reservoir level very closely matched with the structure interpreted on the seismic sections where duplex geometry is visible with repeated Miocene and recent strata and splays of SRT and Murre thrust.

### *4.2 Petrophysical Analysis*

#### *4.2.1 Neutron-density lithological crossplot*

In order to determine the lithological variations in the Lockhart Formation, Neutron-Density (N-D) Lithological crossplot has been prepared. The standard lithological crossplot depicting the three major lithologies, i.e., sandstone, limestone and dolomite has been used in the Prizm module of Discovery software suite for the identification of lithology. Neutron-Density lithological crossplot is shown in Fig. 11.

The log data of Bulk Density (RHOB) and Neutron Porosity (NPHI) recorded against the Lockhart Formation (4987-5229 m) in the Garhi-X-01 well has been plotted on the N-D Lithological crossplot. Two major lithological zones have been marked according to the data distribution on the lithological crossplot, i.e., dolomite and limestone. The blue polygon marked on the crossplot represents the data cluster covering the Dolomite lithological curve, whereas the red polygon represents the Limestone lithology. The top 40 m (4987-5027 m) interval of the Lockhart Formation shows Dolomite, whereas the rest of the 202 m interval (5027-5229 m) has been identified as the Limestone lithology. The porosity range within the Limestone interval is less than 5% whereas in the Dolomite, the average porosity is around 10%. Facies column representing the Dolomite and Limestone intervals and their respective N-D log curves are also shown along with the cross plot.

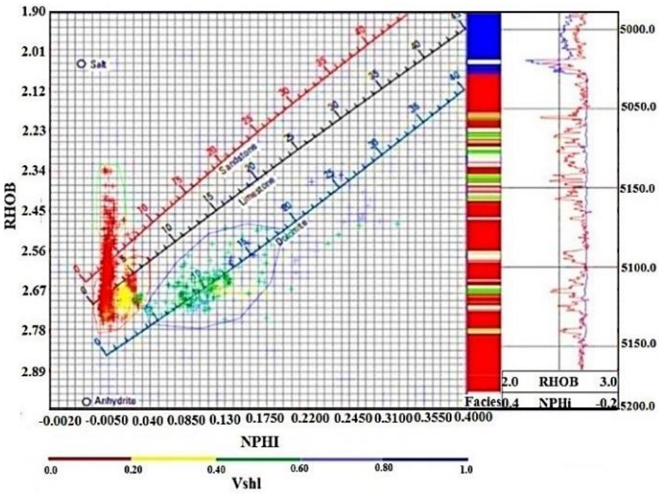


Fig. 11: Lithological cross plot b/w Nphi/Rho B vs Vsh.

Throughout the log interval, neutron log shows very less variation within the Limestone interval whereas the neutron curve within the Dolomite interval shows relatively more variations. Apart from the neutron curve, the variations displayed in the density curve specifically the low values of RHOB might be due to the presence of fractures which could be filled with hydrocarbons resulting in the decrease of density values. If the fractures are filled with the gas, the values of neutron log should also be deflecting towards the lower side. In this case only the density log curve shows more variations, but the neutron log values are very much stable except for some minor fluctuations of around 3-6 % porosity values on the neutron scale. This might be due to the presence of oil in the fractures within the Lockhart Limestone. The green polygon is marked for the data cluster showing low values of density depicting the hydrocarbon effect.

Neutron Porosity (NPHI) values have been plotted on the x-axis whereas the Bulk Density (RHOB) values are on the y-axis. The changes in the lithology in terms of shale content (Vshl) are shown by the color variations along the z-axis. The red (sandstone), black (limestone) and blue (dolomite) colored curves depict the major lithological changes, whereas each lithological curve has been marked with the porosity values through which the porosity ranges within the formations can also be determined.

### *4.2.2 Well log interpretation*

Lockhart Limestone of Paleocene age has been interpreted in terms of its Petrophysical properties for the identification of good reservoir zones. The basic three log types including the lithological logs, porosity logs and fluid indicator logs have been used for the interpretation. Gamma ray log, SP log and caliper log have been plotted in the track 1, resistivity logs in track 2 and porosity logs in track 3. As per the lithological divisions identified using N-D cross plot, the overall log trend of gamma ray indicates very low values with a constant trend in the limestone interval showing clean lithology. However, the top 40 m dolomite interval shows relatively greater values of gamma ray. The resistivity logs show significant separation within the limestone unit where the deep resistivity values are more than 1000 ohm-m in most of the strata. This separation between the Micro Spherically Focused Log (MSFL) and Latero Log Deep (LLD) curve depicts prominent invasion profile having high resistive fluid in the un-invaded zone (probably oil-bearing zone), whereas relatively less resistive drilling fluid within the invaded zone. The same effect can be identified based on the neutron density cross-over. Although there is less variation in the neutron curve which suggests the presence of oil instead of gas but density values show relatively greater deflections towards the lower side.

Three reservoir zones (Table 2) have been marked within the Lockhart Limestone on the basis of log curve trends which provide the indications for the presence of hydrocarbon. The low values of gamma ray log, separation between the MSFL and LLD resistivity curves and N-D crossover have been identified on different intervals which shows the probable hydrocarbon bearing zones. All three zones have been highlighted in Fig. 12. These zones are named as Zone 1, Zone 2 and Zone 3 and their thicknesses are 59.3 m, 7.9 m and 20.6 m, respectively. The basic Petrophysical properties which have been determined within the Lockhart Limestone includes the volume of shale, volume of clean (Dolomite/Limestone), average porosity, effective porosity, water saturation and hydrocarbon saturation.

Table 2: Results of the physical properties calculated for the three zones of Lockhart Formation. (MD: Measured Depth, m: meters, Vshl: Volume of Shale, PHIE: Effective Porosity, Sw: Saturation of water, Sh: Saturation of hydrocarbons).

| Zone | Zone 1 | Zone 2 | Zone 3 |
|---|---|---|---|
| Top MD (m) | 5050 | 5139 | 5157 |
| Base MD (m) | 5109 | 5147 | 5177 |
| Thickness (m) | 59 | 8 | 20 |
| Average Vshl (%) | 6.1 | 2.9 | 3.8 |
| Average PHIE (%) | 2.8 | 3.1 | 2.9 |
| Average Sw (%) | 29 | 28 | 43 |
| Average Sh (%) | 71 | 72 | 57 |

In Fig. 12, Track 4 presents the calculated volume of shale, average and effective porosities are given in track 5, whereas track 6 gives the calculated results of fluid saturation within the Lockhart Limestone. In the top 40 m Dolomite interval, the average volume of shale is 47%, whereas this interval shows relatively good porosity values, but the strata is fully saturated with water which is also confirmed by the low resistivity values. The Limestone interval of the Lockhart formation shows relatively good results in terms of hydrocarbon saturation. Three zones have been identified within this limestone interval. Zone 1 is marked from 5050 m to 5109 m having thickness of 59 m. This 59 m zone does not show continues trend with high hydrocarbon saturation, rather has some small alternate intervals of water saturated zones. However, the average volume of shale in this zone is 6.1% with 2.8% effective porosity and 71.4% hydrocarbon saturation.

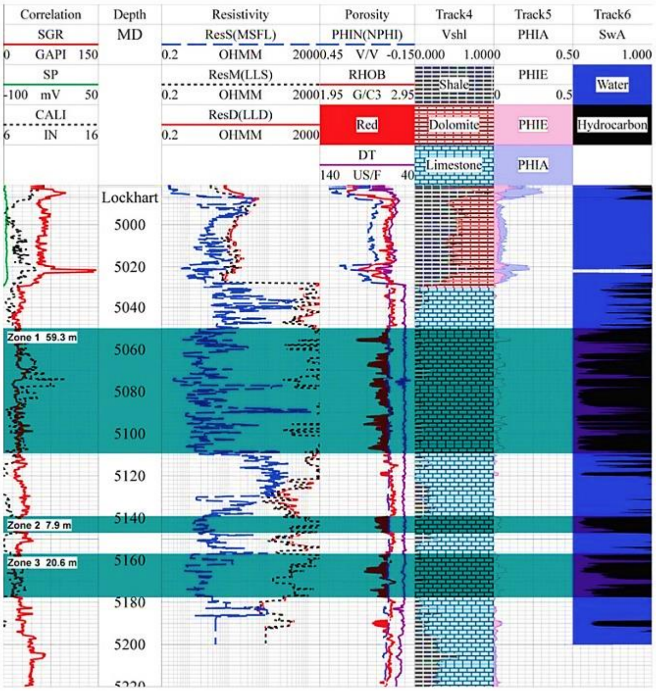


Fig. 12: Well log interpretation of Well Garhi X-01 with highlighted zones of interest in Lockhart Limestone.

Zone 2 is marked from 5139 m to 5147 m with the total thickness of around 8 m. This zone shows very low volume of shale value of 2.9% with effective porosity 3.1% and 72% hydrocarbon saturation. The third zone is marked from the depth of 5157 m to 5177 m having overall thickness of 20 m. This zone shows relatively higher water saturation of about 43% making 57% of hydrocarbon saturation. The values of effective porosity in this interval is 2.9% and having very less shale volume of only 3%.

## 5. Results and Discussion

The Himalayan foreland in North Pakistan is an active system. To evaluate its geometry, it is essential to map detachment/decollement surfaces because they control the trapping mechanism of the overlying sedimentary sequence. The presence of Basal decollement and transition of folds into faults and faults into decollement are regular features of the thin-skinned deformation [19]. The hydrocarbons are commonly produced from stacked Cambrian to Eocene clastic and carbonate reservoirs which have an average thickness of 1 km. These strata are overlain by at least 5 km of Miocene and younger continental molasse sedimentation in the deepest part of the foreland basin [20]. The current study is done for the structural analysis and hydrocarbon potential of the Basal anticline, which is a part of Himalayan orogeny in north Potwar basin. Structurally the area lies in compressional regime characterized by dominant thrust faulting, fault propagated anticlines and pop up structures. Seismic data including five dip and strike lines have been utilized. Contour maps confirm the presence of pop up anticlinal structure in the study area. Contour maps generated at the level of Paleocene and Eocene also confirm the faulted anticline and pop-up geometry present in the subsurface which has been delineated on the seismic sections. Depth structural maps also confirmed the placement of well point at the crestal high. In Basal potential reservoirs were Lockhart and Chorgali of late Paleocene and Eocene respectively which were probably charged by the Patala Formation of early Paleocene. The presence of 2-way fault bounded structure is confirmed through seismic interpretation, while the seal to that is provided by the Murree Formation of Miocene age. Trapping mechanism in the Basal oil field were revealed to be fault associated two-way dip closure and possibly served as the trapping mechanism for the reservoirs [21, 22]. As the log data of Chorgali Formation was not available; therefore, petrophysical analysis has been done only on Lockhart Formation of well Garhi X-01. Three hydrocarbon bearing zones were identified based on the zones of interest criteria showing fair potential thicknesses. Although, the thickness of Zone 1 and 3 was more than the zone 2, but zone 2 out of three was considered best having 2.9% Vsh, 3.1% Effective porosity and 72% Sh, respectively.

## 6. Conclusions

The area under study, lies in North Potwar Deformed Zone (NPDZ) and has imbricate, ramp-flat duplex structures. The area is highly folded, faulted and fractured. Because of the nearness of Basal area to the Khairi Murat Range, the Basal area shows overturning behavior with mesoscale sub-vertical folding due to associated transpressional tectonics. The axis of the fold follows the general trend of the fault, i.e., NE-SW direction. The Lockhart Limestone is considered as main reservoir as it shows enough percentage of hydrocarbon saturation with good fractured effective porosity.

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