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Subsurface structural investigation based on seismic data of the north-eastern Potwar basin, Pakistan

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The north-eastern Potwar is present in the foothills of Himalayas on the northern boundary of the Indian Plate and is filled by the Infra-Cambrian to Pliocene sedimentation. The area is affected by the regional structures of the Potwar and the Salt-Range Structures, such as the North Potwar Deformed Zone (NPDZ), the Soan Syncline, the Main Boundary Thrust (MBT) and the Jhelum Fault. Due to complex tectonic-structural framework, it is extremely significant to understand the subsurface structural mechanisms for further hydrocarbons exploration. The 2D seismic data was acquired in the NE-Potwar in the Rawat area is used for this purpose. The current study helps to present rigorous and mechanically feasible structure understanding of the Rawat and associated local structures of the area in the context of the Sub-Himalayas. The study area mainly comprises on the eastern Potwar with tight anticlines and wide synclines with associated thrusts showing collisional regime of the Himalayan Fold and the thrust belt. The structural interpretation and restoration of paleo-section provide a mechanically feasible model for the Rawat area. The interpretation of seismic data shows that this area is associated with conjugate faults and a triangle zone. The results of this study help us to develop understanding in geological history, structural overprint and future leads for hydrocarbons in this geological province.

[**Keywords**: Compressional Regime, Complex Structures, Seismic Interpretation, Structural Traps, Sub-Himalayas]

Introduction

The Potwar Province is one of the earliest hydrocarbon provinces in the world[1,2]. It is in the western foothill region of the Himalaya Mountains in the northern Pakistan[3-5]. The Potwar sub-basin holds several structural leads. Oil and gas have been reported from different reservoirs in the stratigraphic successions[5]. The Eocene to the Cambrian succession is almost 400 meters in thickness[6]. The Eocene, the Permian and the Cambrian are the main reservoirs in this area[4,5] and almost 50 wells are present in the eastern part of the basin. The discoveries in the south of the Soan Syncline are mostly EW oriented anticlines which often are faulted[6].

Himalayan orogenic episodes from Pliocene to Middle Pleistocene have affected the Potwar Sub-basin with severe deformation stages[7]. The severity of these tectonic episodes has been reflected in the form of several regional unconformities in the stratigraphic order[5]. Surface anticlines are major exploration targets in the area[7]. From the development of new seismic technologies which led to new understandings about the subsurface structure and stratigraphy[6,8]. In the Potwar Sub-basin sporadically, the surface geology mismatches the subsurface geometry[5]. The seismic interpretation has revealed two decollement levels, the lower one is in the Pre-Cambrian Salt Range Formation, while the upper is on the interface of the Eocene to Neogene sediments[1,5]. The structural style of the Potwar sub-basin has been strongly altered by these decollement levels, as they offset structures above and below. The lower decollement along the Salt Range Formation is a low angle thrust fault that transports the entire sedimentary succession to the south. It is widely accepted that the structures have been formed and modified due to southward propagations related to salt movement activated by southward thrusting of sedimentary package[5].

The Potwar Basin is located in the Himalayan Foredeep. In the East, the area is bounded by the Jhelum Fault, west is marked by the Kalabagh Fault, north by the MBT and South is covered by the Salt

Range Thrust (Fig. 1)[8-11]. Topographically, the area is marked by East-West running ridges and valleys[13]. In terms of tectonics, the area is a part of foreland zone of the Himalayas[12]. The area is famous for complex structures resultant of intense deformation[5,13]. The most deformed part of the Potwar called NPDZ lies between the MBT and the Soan Syncline[14] (Fig. 1). The area is more deformed than the rest of Southern Potwar[9,10,15].

Kallar X-1 is located on the Kallar anticline. Kallar anticline is located east to southeast of the Batala Syncline and Rawat Fault, respectively. The area under study lies in the Rawat, Potwar Plateau (Fig. 1). The main trend for the folding and faulting is East West in this Potwar zone[7] described it as the stack of subsurface blind thrust faults and surface imbricate faults[12]. The general trend of these structures changes from EW and NE in the eastern part of the Potwar[7,16]. The southern Potwar is mainly covered by the gentler Soan Syncline[13]. The southern Potwar was formed 1.9-3.4 Ma, before the NDPZ, the southern limb was formed as a result of thrusting along the Rawat Thrust[10]. The depth of basement according to is 6 km, however, near the MBT it increases up to 8 km[11-14]. The hydrocarbon potential of the Potwar Plateau[9] is also discussed in this study and special emphasis is made on one of a case studies in the Rawat Area, Pakistan.

The core objective of the research work is to make a realistic structural model of the below ground of the Rawat area is to develop deep understanding beneath the surface structures and improve our practical knowledge on various seismic interpretation methods that is a part of seismic data interpretation[15-17]; and to present a workflow for: picking of reflectors on the seismic sections, identification of structure using 2D seismic data, generation of time and depth contour plots of reflectors, preparation of depth sections of seismic lines and paleoseismic section.

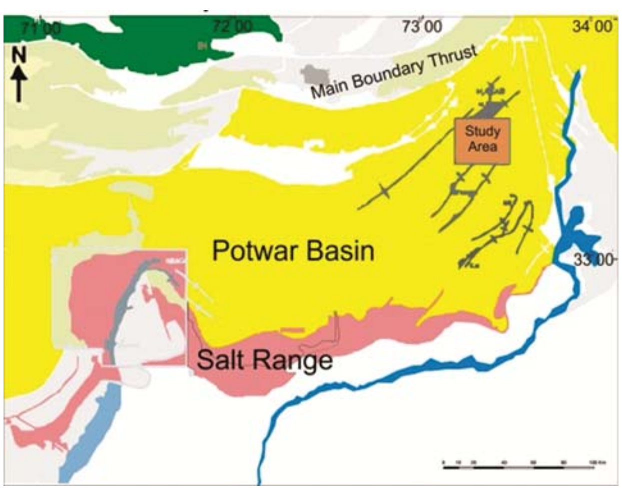

Fig. 1 — The location of the study area is marked on the map of the Potwar basin, Pakistan

Structural style

The collision between the Indian and the Eurasian plates resulted in crustal deformation, along an arc-shaped confluence zone: the Himalayan-Tibetan orogenic belt[16,17]. At present, the Indian plate is descending northward into the Eurasia at an approximate rate of 5 mm/year, and this induces to a tectonically active area, which has several destructive earthquakes[18]. Moreover, the juncture generated a southward advancement of large north-dipping thrusts to contain crustal shortening/thickening, from north to south from Main Mantle Thrust (MMT), Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT)[19]. The Potwar Province is located between the Main Boundary Thrust (MBT) and Main Frontal Thrust (MFT) folds and thrust belts[18]. The continual collision between the Eurasia and the Indian plates provided compressional stresses that contributed to this deformation[20]. The deformations episodes in the study area are characterized by both folding and faulting originated due to tectonic and uplift of the Precambrian Salt Range Formation evaporites[21]. The Salt Range (SR) is separated by the Potwar Province (PP), a slightly elevated (~270 m), 150 km region with very low topographic relief[22] (Fig. 1).

The Western Potwar went through transpressional deformation due to relative Kalabagh dextral fault (active, with an average slip rate of around 5.3 mm/year) and the Main Frontal Thrust (MFT) with compressional force direction from NNW to SSE[23,24]. Furthermore, the GPS studies indicates that the Potwar Province is moving southward at a rate of 5 mm/year[24]. This study covers the Eastern Potwar area is bounded on east by the Jhelum sinistral fault[25]. These tectonic structures resulted from regional compression, have significantly affected the petroleum creation and storage in the basin. The orientation of these structures in mainly oriented NE-SW, describing the local stress direction[26].

Stratigraphic framework

There are three sequences present in the area bounded by unconformities as seen in Figure 2. These unconformities are challenging to decipher on the 2D seismic data due to complex thrusting. The basement

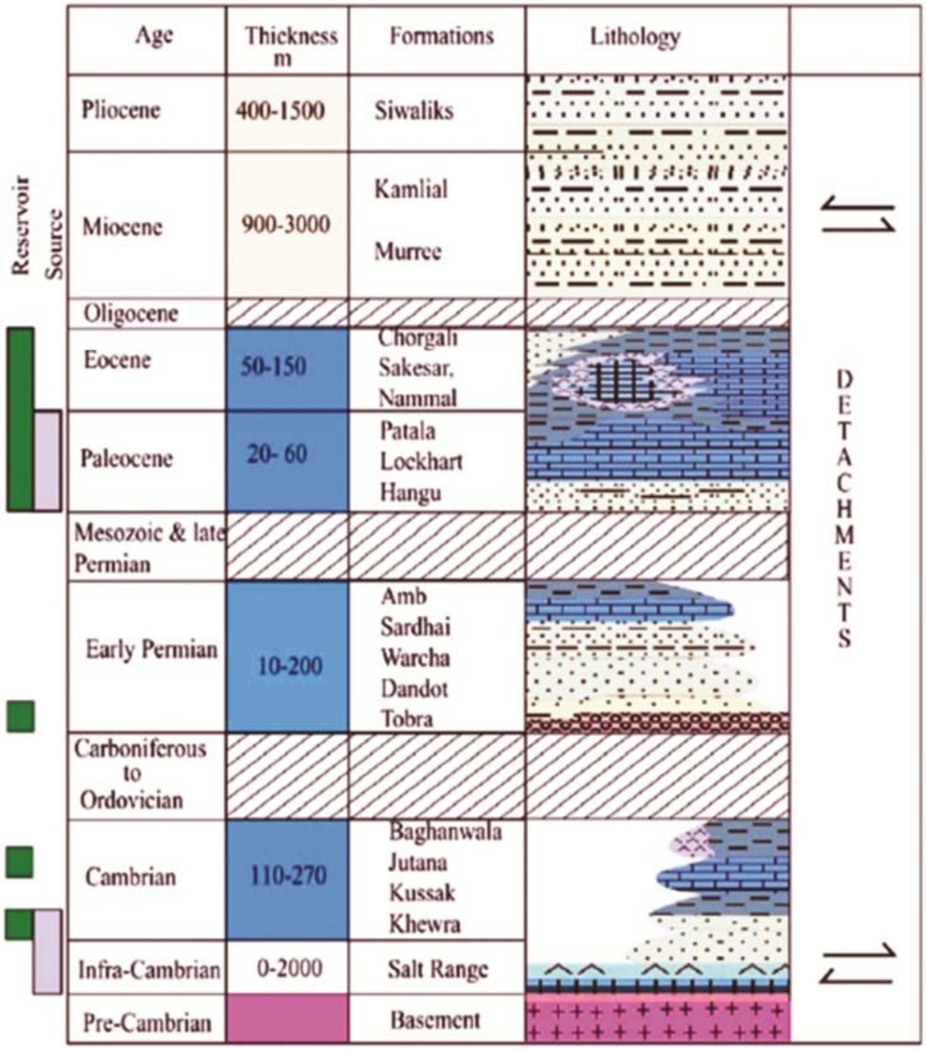

Fig. 2 — The stratigraphic column describing the age, thicknesses, lithologies present in the eastern Potwar Basin [1]. The source and reservoir rocks present in the project area are also marked on the figure

is covered by the Salt Range Formation of the Precambrian age. The Cambrian to the Eocene sedimentary cover is present on this basement[27]. The oldest unit unconformably overlying the igneous metamorphic basement is the Salt Range Formation. The Salt Range Formation is comprised of rock salt, marl, dolomite, gypsum and shale are present in it and is well developed in the Eastern Salt Range[28-30].

Molasse deposits of the Miocene to the Pliocene in turn overlie the Eocene-Cambrian succession. The base of the Permian and the Paleocene are marked by unconformities. During the Ordovician to the Carboniferous time the basin was uplifted and there was no deposition. The Mesozoic is not present in the Eastern Potwar Basin. The Lower Cambrian to the Eocene sequence is separated by an unconformity. The Oligocene deposition is missing here and the stratigraphic column of the Rawat area (Fig. 2). The formations encountered in the well Kallar-X-1 are the Nagri (thickness 1273 m), the Chinji (thickness 1823 m), the Kamlial (thickness 390 m), the Murree (thickness 2604 m), the Kuldana and the Chorgali Formations. The formation tops of the Nagri, the Chinji, the Kamlial, the Murree, the Kuldana with respect to the Kelly Bushing 0 m, 1273 m, 3096 m, 3486 m and 6090 m respectively.

Petroleum system

Petroleum history of the Potwar basin is one of the oldest provinces in the world that dates to 1914[(ref. 31)]. More than 150 oil and gas boreholes have been bored in the basin so far, many of them abandoned and could not drilled up to the target depths because of high pressure. These conditions and drilling problems could be the result of poor understanding of structural framework of the area[32].

The prospective reservoir rocks in the Kohat and the Potwar foredeep are the Eocene Carbonates and Cambrian, Permian Clastics[13]. In the Rawat area, the most significant reservoir rocks in the foredeep are of the Eocene carbonates (that include the Chorgali Formation and the Sakesar Limestones) with average primary porosities ranging from 2 to 4 %, which developed secondary porosities of 15 to 25 % because of dolomitization and fracturing. In the eastern part of Potwar area, the Patala Formation (mainly shale) and the Lockhart Limestone (carbonates but not common in the area) are considered as mature source rocks that produce high quality oil[33]. In the eastern Potwar, the shale of the Kuldana Formation acts as seal rock that stops the further movement of oil and gas for the reservoirs of the Chorgali Formation and the Sakesar Limestone[33]. In southern Potwar area, the Lower Eocene claystone (the Kuldana Formation) forms excellent sealing cap rock. The main sealing cover above the Eocene reservoir rocks is provided by claystone developed in the Miocene molasses sediments such as Siwalik Group.

The Potwar Sub-basin is separated from the Indus Foreland due to ENE trending structures in the Salt Range[33]. The structural printing is mainly compressional and responsible for providing structural traps for hydrocarbon accumulations[33-35].

Methodology and data used

The eight seismic lines comprise of six dip and two strike lines have been used for this study (Fig. 3).

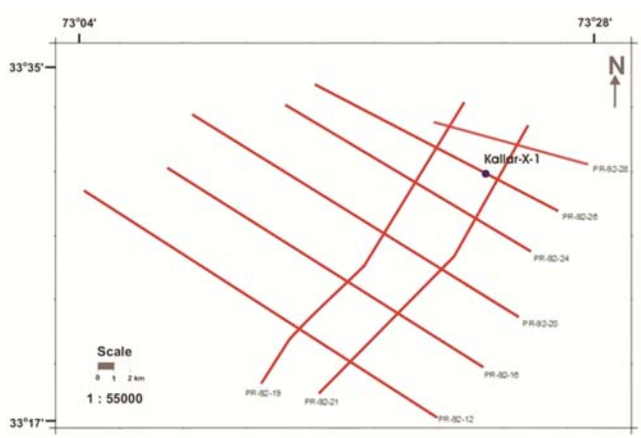

Fig. 3 — Base map of the study area showing the locations of the dip and strike lines used to interpret the subsurface structures in the Rawat Area. The location of the Kallar X 1 well is given on the base map

Firstly, time of the Chorgali Formation, reflector 1 and basement was calculated from the seismic sections in milliseconds and it is transformed into depth sections using the succeeding formula:

$$D = V\left(\frac{T}{2}\right)\times 1000 \qquad \ldots (1)$$

Here, D, V and T are depth in meters, average velocity of seismic waves and two-way transit time of P wave (TWT) in milliseconds respectively.

The SRD (Seismic Reference Datum) is 400 meters above the mean sea level. Therefore, 400 meters is subtracted from the depth value in order to gain the depths with respect to mean sea level. The depth of reflectors is plotted against shot points and formation thicknesses from the well are plotted above and below the reflectors.

Reflection data on maps

The seismic data (2D seismic section having recording time in vertical axis) is transferred from 2D sections to a map (showing the subsurface structures in time or depth domains)[31]. The data that is being displayed on the plotting maps is in the form of contours demonstrating the real reflection times or depths. These time or depth plots are generated on the base map. This base map has the localities of the dip and strike lines along with drilled wells of oil and gas.

Seismic data is in time domain while the well data is in depth domain and we need seismic velocities for time-depth tie. Sometimes due to inappropriate seismic velocities both well and seismic data do not tie exactly. One millisecond of error can mean from 5 to 10 feet, and it is impossible to pick precisely to the millisecond. This amount of certainty has been called seismic wobble. Two types of contour maps are made such as time contour plot (map) and depth contour map.

Time and depth contour maps

Times or depths values are ordinary plotted on the base map at suitable interval along the direction of shot points of seismic shooting line. After time to depth conversion by using suitable seismic velocities, such as V = 4150 m/sec and 3200 m/sec for the Chorgali Formation reflector and reflector 1 respectively, the reflection contour plot should perfectly be a structure contour map for the selected geological interface from the study area.

For preparing time and depth contour map, four seismic lines i.e. PR-92-19, PR-92-20, PR-92-24, and

PR-92-26 are used. Two time and depth contour (subsurface structural) maps have been constructed for both horizons (i.e. Reflector 1 which is a phantom and Reflector 2 which is the Chorgali Formation). Reflection times for both reflectors below the datum plane are obtained from the sections. The reflection time for that horizon is read from the timing lines on the section. This reflection time is plotted at that shot point's location on the base map. Time may be first converted to depth, and the depth plotted. Faults which have been identified on the record sections are drawn on the map as shown in our contour maps. The plotted times or depths are contoured. The anticline trap (oil may possibly) is collected at local high points in the subsurface, as shown by the mapping. That is, where the high contours are closed, going completely around some area on the map, the high area they enclose may be a good location for a well.

Fixed pole method

The fixed pole method is used for palinspastic reconstruction and restoration. Paleosections can be made by shifting the time traces to flatten some distinctive horizon which can be assumed to have been deposited horizontally. The objective is to show the relationship as they were present at the moment of deposition of the particular horizon.

Seismic interpretation

The process of deciphering the subsurface using seismic waves is called seismic interpretation. An interpreter concentrates on certain lineups of wiggles[31]. This is a very important condition for the estimation of the depth and geometry of bedrock or target horizons.

Five seismic lines i.e. PR-92-19, PR-92-20, PR-92-24, PR-92-26 and PR-92-28 have been used for interpretation of the study area. PR-92-19 is strike line trending NE-SW and remaining four dip lines trending NW-SE (Fig. 3). Un-migrated or dip move-out stacking are not interpreted properly which are PR-92-12, PR-92-16 and PR-92-21. The interpreted seismic lines (showing the reflectors of basement, the Chorgali Formation, reflector 1 and faults) have been shown in the results and discussion section.

Structural interpretation

Structural interpretation is based on reflector geometry study based on reflection time. The structural interpretation helps in the identification of future leads for hydrocarbon exploration. Some seismic sections contain images that can be interpreted without difficulty. Two-way travel time is used for structural interpretation. Depth and time structural contour maps help to present the geometry of chosen reflection events. Time structure contour maps look very similar to structural contour maps, but they have distortions associated with vertical shifts in velocity due to strata overlying the reflector[1].

Stratigraphic interpretation

Genetically related sedimentary sequences are a group of seismic reflections that can be used to divide a seismic section into a number of sequences. Stratigraphical interpretation involves the subdivision of seismic section into sequences of reflections that are interpreted as the seismic expression of genetically related sedimentary sequences[1]. Basic principle in the seismic stratigraphical interpretation is that the reflections are taken to define chronostratigraphic units because interfaces that produce them are the stratal surfaces. Seismic stratigraphy is used to find out depositional processes and environmental settings, because a genetically related sedimentary sequence normally consists of concordant strata that show disconcordance with sequences lying above and below. It also helps to identify the geological formations, stratigraphic traps as unconformity, reefs etc.

Picking horizons

Once a horizon has been selected for picking, whether identified or not, there must be some means of picking the same horizon throughout the area, or at least over some part of the area[35]. A colored pencil mark can be drawn on the reflection from one end of the section to the others. Occasionally an area will be encountered in which no continuous reflections can be picked at all. This may be because record quality is poor, or because the subsurface itself contains no continuous layers. In either of these cases a line can be drawn on the section paralleling the discontinuous bits of nearby reflections.

Tying 2D seismic lines

The dip and strike always cross each other almost at right angles and therefore tie points of are helpful to shift the reflector and fault position from one line to others. We have interpreted the one dip line and then tie-up it with other strike line to shift the reflectors to the strike lines. The tying of interpreted strike line (PR-92-19) and a dip line (PR-92-26) has been shown in Figure 4. Since the strike line has cross points with other dip lines therefore, these reflectors are extended and mapped on all the dip lines.

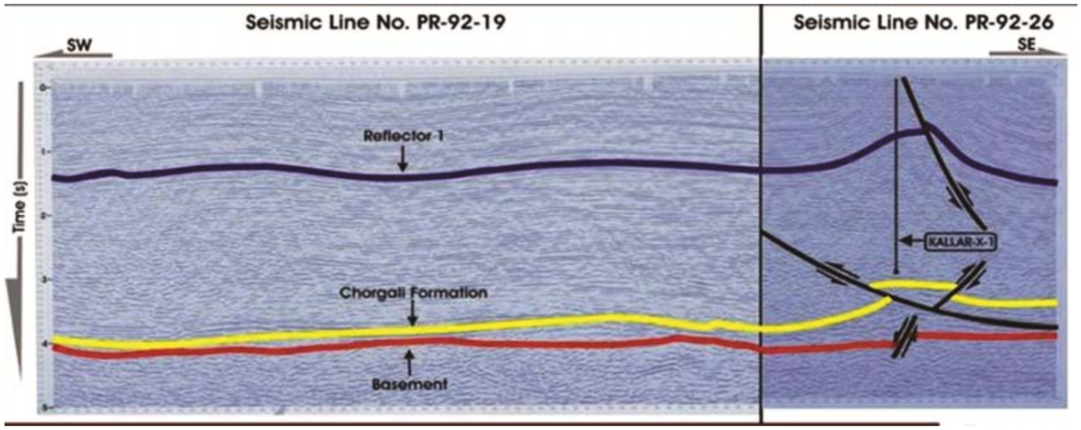

Fig. 4 — Seismic lines (dip and strike lines) are shown and tied by matching the time reflectors. The continuation of reflectors from strike line to dip line can be observed in the figure

Construction of geo-seismic section

Geo-seismic section represents the structure of the seismic lines in true manner because it is adjusted manually with the help of geological drilling order of well Kallar-X-1.

Results and Discussion

Based on the seismic reflection data interpretation, the following subsurface structural features have been identified and are discussed below. We have discussed all the interpreted structures that are present in the area one by one.

Tight anticlines and broad synclines

This project area lies in the highly tectonically deformed zone at the foothills of Himalayas therefore very complex folding and faulting can be observed. Since compressional forces have active in the region therefore tight anticlines and broader synclines can be visualized at the interpreted seismic lines PR-92-20, PR-92-24 and PR-92-26 at the Pre-Cambrian to Recent deposits (Siwalik Group) are marked on those seismic lines as shown in the Figure 5. An uncommon type of anticline (tight anticlines) as portrayed on the migrated seismic section. The tight anticlines and broad synclines have also been marked on the geo-seismic sections as shown in the Figure 5.

Faults

The faults on the seismic lines have also been marked that are thrust faults and back thrust that made pop-up structures as displayed in the interpreted seismic and geo-seismic sections in Figures 5 and 6. The major fault in the study area is the Rawat fault which is a roof thrust of a passive duplex. The recognition and mapping of thrust fault is normally based on divergence between reflections as well as on the replication of recognizable reflections above and below the thrust plane as shown in the seismic lines.

Basement structures

The categorized faulting and structures as either basement involved, or basement detached[36-38] have been shown in the seismic lines and geo-seismic sections in Figure 5.

Time and depth structural contour plots

The time contour plots of the interpreted seismic horizons were created and represented in terms of seismic waves two-way travel time (TWT) in milliseconds[35]. The faults have been exposed by black line on the time (ms) structure contour plots. These time and depth contour plots are represented in Figures 6 and 7. These time and depth structure plots (contour draws) are generated for the Kamlial (Figs. 6a, b) and the Chorgali Formations (Figs. 7a, b), respectively.

The time contour maps were prepared at 1:55,000 scale as it is be proposed to be applicable in the understanding of regional structure styles. The time contour maps were prepared for interpreted horizons based on accessible data acquired by seismic reflection methods. The time contour plot of blue reflector is exhibiting the structure style of the Kamlial Formation as seen in Figures 6(a, b). The faults are interpreted and represented on the maps and the time contour interval between two adjacent contours is 200 milliseconds as seen in Figure 6a. The time contour map of blue reflector showed that two-way travel time (TWT) growing in case of syncline while decreasing for the anticlinal structures. The peak time of the blue horizon ranges around 1100 milliseconds in the NW direction that is expected because of the elevating of the project area in the north direction.

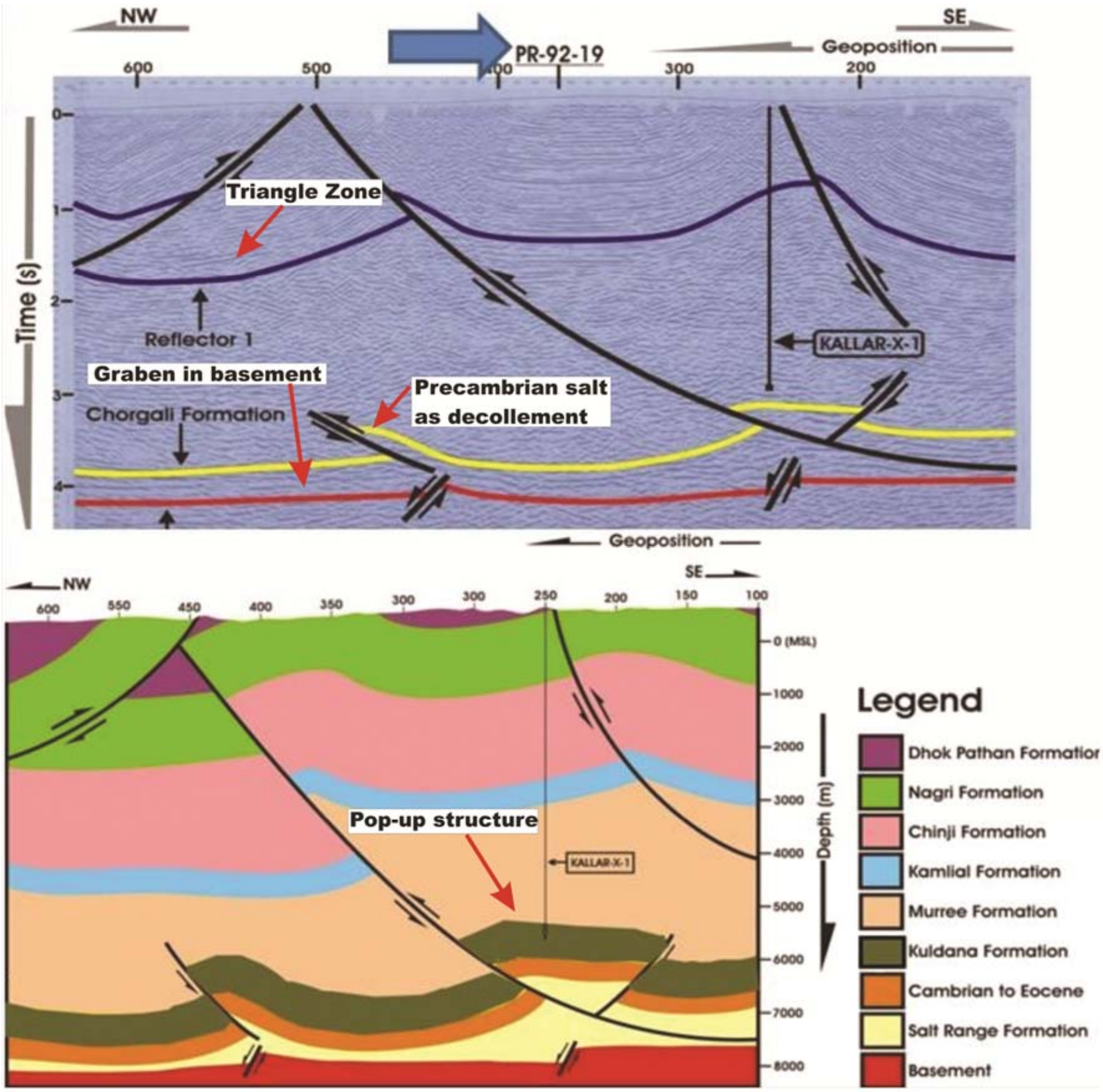

Fig. 5 — Showing the dip line (PR-92-26) and the geoseismic section of the same line, you can see the targeted pop-up structure in the area. The tight anticlines, broad synclines, triangle zone, graben in the basement, the décollement level, pop-up structure and thrust faults can be visualized in the seismic section. The dip line (PR-92-26) and the geoseismic section of the same line also showing the location of the well (Kallar X 1). From the figure, it is clear that the well has not been reached the reservoir top

The time contour map of the Chorgali Formation is shown in Figure 7a. The faults are also interpreted to display the structural style of this formation in better way. The contour interval is observed in the range of 50 milliseconds for this time contour map. The TWT is increasing towards SE and decreasing towards North. However, this fluctuation of two-way travel time is very rigorous due to tectonic activity in the study area. The maximum time is interpreted towards central part of the map ranging from 3800-3900 milliseconds. The difference in TWT values is justified by interpreting three thrust faults in the map that showing opposite trends of the dip.

Structural interpretation

The triangle zones and pop up linked with foreland folding and thrust belts provide a portfolio area for important structures for accumulation of hydrocarbons[2-3]. The Potwar Basin is comprised of such structures and most of the faults are dipping north while conjugate backthrust faults are dipping towards south[33]. In the Potwar basin, the sedimentary rocks are deformed due to décollement in the Precambrian evaporates present in Salt Range Formation[32,36-41]. The triangle zones were developed due to thin skinned deformation in surrounding rocks[4,41-43].

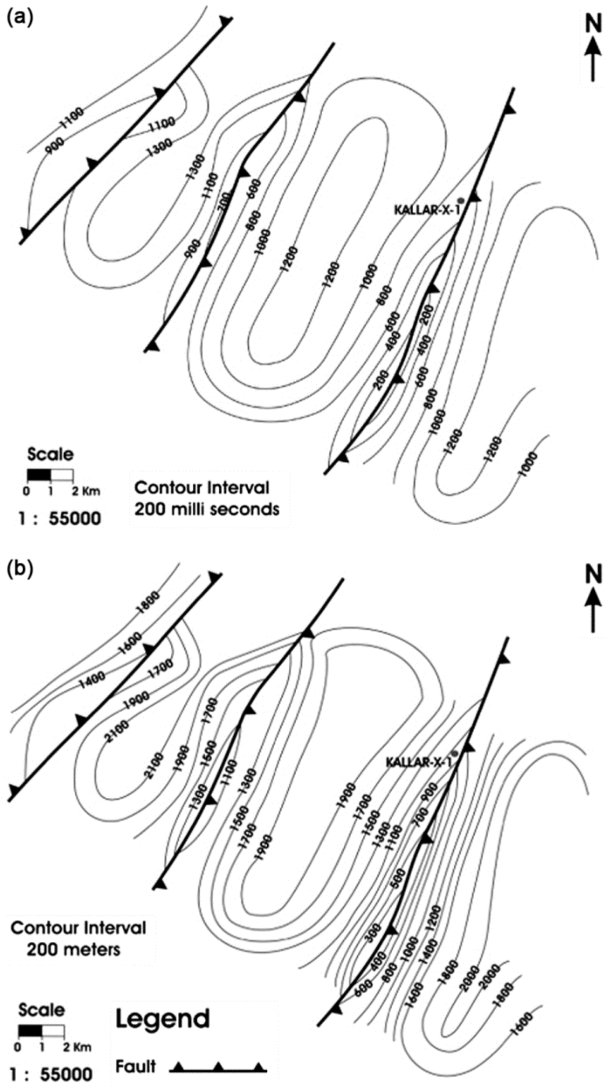

Fig. 6 — (a) Time contour map of blue reflector (phantom/Kamlial Formation) is shown the figure. The time contour map represents the subsurface structures and elevations in time. (b) Depth contour map of the Kamlial Formation is prepared with the contour interval of 200 m and given in the figure. Major thrust faults, relative movement along fault planes; anticline and syncline structures can be visualized

The present study was fulfilled by using seismic line (dip and strike lines) acquired from Potwar Basin. The reflector continuation was observed in all seismic lines and an example from interpreted strike line PR-92-19 is portrayed in the figure (Fig. 4) where dip and strike lines are tied by matching the time reflectors. The extension of reflector 1, the Chorgali formation reflector and basement reflector are interpreted from SW to NE. This continuance is also confirmed by constructing a geoseismic section of the same line in terms of depth. The thickness and extension of different formations are easily understood in geoseismic section, it can be observed that the persistence styles of the Miocene to Precambrian rocks arealmost same.

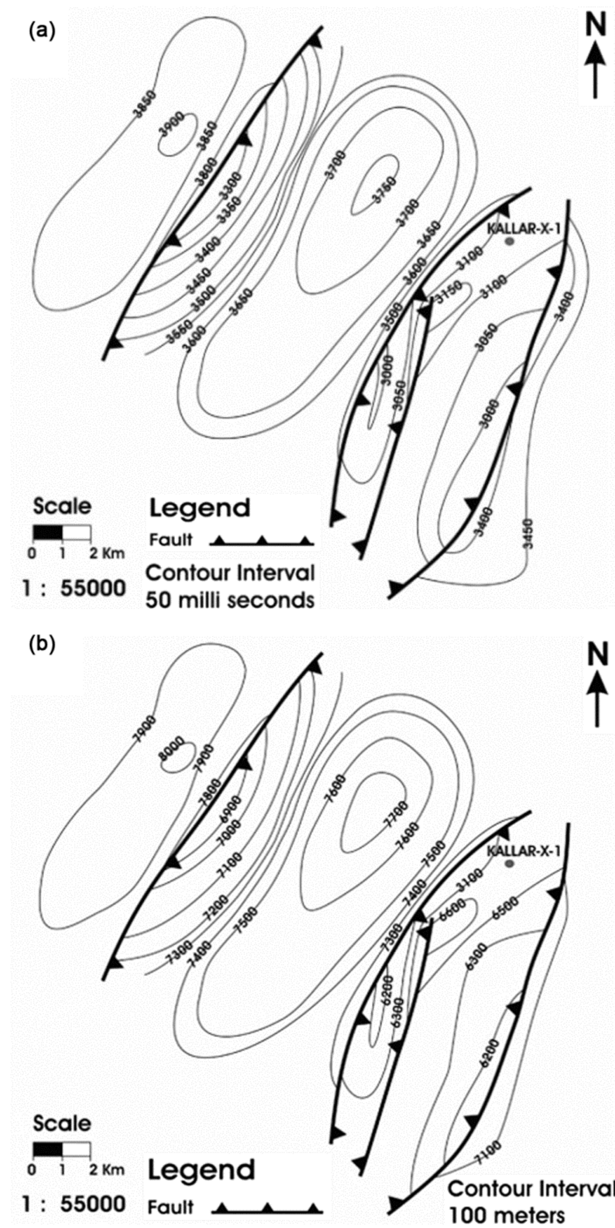

Fig. 7 — (a) Time contour map of the yellow reflector (Chorgali Formation) is portraying the major and minor thrust faults, subsurface structures and reflector positions in time. (b) Depth contour map of the Chorgali Formation of Eocene age is drawn with 100 m interval

Based on the seismic data interpretation, it can be inferred that the Potwar Basin is comprised of pop-up anticlines, triangle zones and salt domes due to compressional regimes[33]. The pop-up structures are interpreted in the studied seismic line (dip line No 92-20) as shown in Figure 5. The targeted pop-up structure is shown in seismic line as well as geoseismic section to understand the behavior of the structure. In the Chorgali Formation, which is considered as best reservoir in the Potwar Basin is consisting of pop-up structure and surrounded by faults, one fault is extending from top reflector to basement reflector that depicts the extensive tectonic activity in the study area. The oil and gas exploration history of Potwar basin belongs to long and seems to have attained maturity; however, it still provides some surprising phenomenon. The petroleum play categories in the Potwar area are faulted anticlinal structures and those are commonly salt centered. Therefore, the existence of hydrocarbons in many portions of the Potwar area is mostly dependent on structural styles. It can be noticed in Figure 6 that the pop-up structures are present in the eastern side of the Potwar Basin and it is confirmed that most of the oil and gas discoveries are reported from this area[33].

Another structural feature was observed in the study area that is salt décollement triangle zone and graben in basement as shown in Figure 5. The triangle zone is observed in reflector 1 and it provides the trapping of hydrocarbons in the Potwar Basin. These types of traps are kept under consideration during seismic interpretation because they are most important for oil and gas industry. In basement, the Salt Range is comprised of décollement structure and graben structures that also considered as key feature of the Potwar Basin. The geoseismic section of the same dip line delivers best opportunity to understand and interpret the structural styles in terms of depth because the seismic section provides the result in the form of time in milliseconds.

Traps and future prospects

Based on detailed seismic interpretation in this study, some well location is also provided and shown that due to structural styles and faults the well location could not reach up to reservoir section as shown in Figure 5. Some faults are covering the area from top to basement and due to that the well location is missed for Chorgali reservoir that is considered as best carbonate reservoir. Due to complex deformation style in the Potwar-sub basin, the seismic interpretation becomes challenging and some new traps are also misinterpreted[1,33]. However, the geoseismic section also confirms the findings based on seismic interpretation for this study and it provides an integrated approach to understand the behavior of different structures and traps.

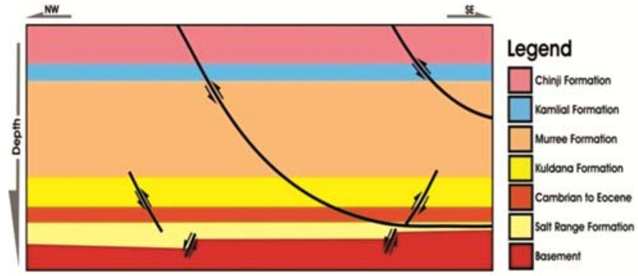

Fig. 8 — Paleosection (flattened seismic cross section) of seismic line PR-92-26 is shown in the figure. The seismic events have been flattened showing the altitude of the deeper events at the time of deposition

It can be noticed that most of the structural traps are observed in the Southeastern flank of the strike line, whereas, the western part is continued. This interpretation gives us the clue of tectonic activity influence was more in the Eastern part of Potwar area. Therefore, the Eastern part is considered as portfolio for this basin. Overall, the best hydrocarbon traps have been identified in the Potwar basin consisting of Pop-up, triangle zones and faults structures. So, these observations provide us best chance to explore the hydrocarbons in the Potwar sub-basin area.

Paleoseismic section

The paleosection also known flattened seismic cross section of seismic line PR-92-26 is prepared and shown in the Figure 8. The paleosection shows the relationship as the seismic horizons were present during the time of deposition. This help to unravel of the geological history of the area. It is important due to the reason of checking the trap has been tilted sufficiently for the accumulation of oil displacement of part of the structure by faulting occurs before and after possible emplacement of oil.

Conclusions

The series of geological and seismic transects provide an understanding for architecture of the Rawat area, Northeastern Potwar, Pakistan. This study forms a basis of demarcation of regional structural domains. Décollement and faults have very critical role in the creation of the eastern Potwar sub-basin. The Eocene to the Cambrian Sequence is mainly subjected to folding and faulting. The presence of the Eocambrian salt provided the perfect detachment for the Eocene-Cambrian Sequence. The structural complexity is the result of subsidiary décollement levels other than the one at the base of Pre-Cambrian Salt Range Formation and the Basement. These subsidiary décollements occur in the shales of various Paleozoic layers. One example occurs in the interface of the Siwaliks with the Chorgali Formation. Seismic interpretation and workflow presented indicate that Rawat area has very distinct structural styles and orientations. The subsurface structures observed in the study include tight anticlines, broad synclines, pop-up structures, graben in the basement rock and thrust faults. The thrust faulting present in the area showing the compressional regimes. However, sub-thrust and stratigraphic plays have key for potential exploration efforts in the area. Moreover, 3D seismic will help in understanding better exploration targets for further exploration.

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Conflict of Interest

The authors declare that there is no competing or conflict of interest.

Author Contributions

NA and SHA have conceptualized the main research idea and wrote the manuscript with support from PK and MSA. ZUD supervised the project and field work and provided help in the interpretation of the seismic data. BA, SF and MA have contributed by interpreting the seismic data and derived the models and analyzed the data.

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