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Seismic Characterization to Identify Geological Structures and Petroleum Play in Lower Indus Basin, Pakistan

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Abstract: The Cretaceous shale intervals of Talhar and Sembar Formations – distributed in the Lower Indus Basin of Pakistan – are organic-rich shales that can act as shale gas plays. Two-dimensional seismic using synthetic modeling has been carried out in Khewari oil field to identify petroleum plays. This work was completed with the help of eight seismic processed and migrated lines. Based on structural interpretation different geological structures were marked. The seismic character, continuity, and coherency in seismic reflection patterns indicate that the area is under an extensional regime with normal faults pattern associated with horst and graben structure. This structure is favorable for the accumulation of hydrocarbon. The shales of Talhar and Sembar formations are overlying Chilton limestone, which is a proven reservoir. The isopach maps show that Talhar Shales and Sembar Formation are dipping towards the northeast. Precisely to characterize the reflector, a synthetic seismogram was employed to tie well tops and seismic profiles.

Keywords: Seismic section, interpretation, synthetic seismogram, hydrocarbon, horst, graben.

Introduction

The integration of geology and geophysics is seismic interpretation, and only those who accept a continuity between the two can see the information about the underlying environment (Chapman, 2004; Faisal et al., 2013). Integrating waveform, amplitude, and polarity defines the reflection's characteristics. It represents the intervention between reflections of seismic energy from narrowly distributed reflecting layers as well as the physical attributes above and below the reflector (Bacon et al., 2003). Seismic data acquisition and interpretation result in seismic images of an acoustic impedance interface. Seismic data is related to subsurface lithology because an interface is related to a lithological boundary (Ahmad et al., 2010). A geological structure that may be considered and act as a source for structures that accumulate hydrocarbons is what the seismic interpretation seeks to achieve (Badley, 1985; Bond et al., 2012). Geophysical and geological expertise is necessary for seismic interpretation (Asim et al., 2014). This requires the interpretation to extract the maximum geological information attainable out of the selected set of seismic information observations (Bond et al., 2012). To maximize its effectiveness, the person doing the interpretation needs to be aware of which features to concentrate on when interpreting the data. The accuracy of the seismic data also influences interpretation as well. The primary objective of the conventional seismic interpretation method, commonly referred to as qualitative interpretation, is to map the earth's subsurface geology (Ahmed et al., 2018). It delineates the stratigraphic elements, such as pinch-outs, unconformities, structural elements, folds, and faults using horizontal continuous and discontinuous reflectors (Coffeen, 1984; Bendar et al., 1995). The main objective is to identify the factors that lead to the accumulation of hydrocarbons rather than quantify them. The structural traps are the focus point for conducting structural analysis. In this study, tectonics plays a crucial role. The study of structural settings, such as the various structure types and their characteristics, is enabled by tectonics (Ahmad et al., 2009). In short, understanding the region's structural style and identifying structural traps are made much easier by understanding tectonics (Sheriff, 1999). Khairpur is a district in northern Sindh. Shikarpur and Sukkur surround the district on the north, India on the east, Sanghar on the south, and Larkana on the west. District Khairpur is located at 68°5'23" E to 70°18'45" and 26°09'58" N to 27°44'38". Fig. 1 depicts the geographic position of the research region. The study area is tectonically located in lower Indus basin. It is located between the latitudes of 23° and 28°31′ N and the longitude of 66°E.

South of Karachi, sediment extends offshore and covers a 550 × 250 km region. Massive sedimentation from the Triassic to the Quaternary characterizes the lower Indus basin (Raza et al., 1990; Kazmi and Jan, 1997). Being the primary oil and gas producing basin for Pakistan, the lower Indus basin is crucial for hydrocarbon exploration. Khairpur is situated in the lower Indus basin's Thar platform region (Khan et al., 2013). Many horst and graben patterns in the Khairpur region are almost at the base of the unconformity between the Paleocene within the Cretaceous (Shuaib, 1981). The lower Goru sandstones belonging to the oldest formation of the Cretaceous time have been used for oil production. Sembar Formation of the lower Cretaceous with high organic content was deposited under controlled circulation during the early stages of the rift system's evolution (Athar, et al., 2012). It is the primary source of hydrocarbons in the lower Indus basin, including the shales encountered at the lower Goru Formation's base (Kadri, 1995). As the tectonic rifting progressed into a more developed half-Graben stage, across Thar slopes, extensional deformation generated inclined fault structures. (Ali and Ahmad, 2005). Subsidence and uplifts were caused by readjustments to the lithosphere throughout the rift system's evolution (Shuaib, 1981). Consequently, a typical normal block fault makes up the resultant structure, which is located in the west-dipping Indus plain.

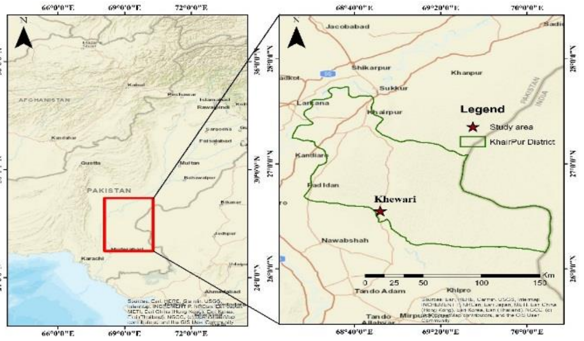

Fig.1 Location map of the study area.

Geological Setting

Lower Cretaceous Sembar Formation is well recognized in terms of potential source rock. In terms of production, Goru Formation is crucial and functions as a source, a reservoir, and a seal rock (Ehsan et al., 2018). The lower portion serves as a reservoir and partially as average source rock, while the upper part acts as a seal rock. Another component of this formation is Talhar Shale which has excellent reservoir quality (Ahmad and Khan, 2010). Ranikot, Laki, and Mughalkot formations are also excellent source rocks. Ranikot and Pab formations are regarded as potential reservoirs (Fig. 2). The Jurassic Chiltan Formation serves as a fractured reservoir. Ranikot and Pab sandstone formations, as well as the Nari and Gaj formations of the Neogene time, also serve as suitable reservoirs (Abbasi et al., 2015; Quadri and Shuaib, 1986). Sembar Formation, which caps the Chiltan Formation, is acting as cap rock and the top member of the Goru Formation is good seal rock (Iqbal, 1990). Pab Sandstone and Sui Main Limestone are capped by the Ranikot and Ghazij formations, respectively (Ahmed et al., 2018).

Materials and Methods

The positions of the seismic lines are shown on a base map. The initial location of the seismic data acquisition is also shown on the base map. It is an essential component of interpretation. Fig. 3 displays the seismic survey site locations.

The Directorate General of Petroleum Concessions provided eight seismic lines. These are utilized in the qualitative interpretation of seismic data. Out of eight lines total, three are strike lines and the other five are dip lines (Table1).

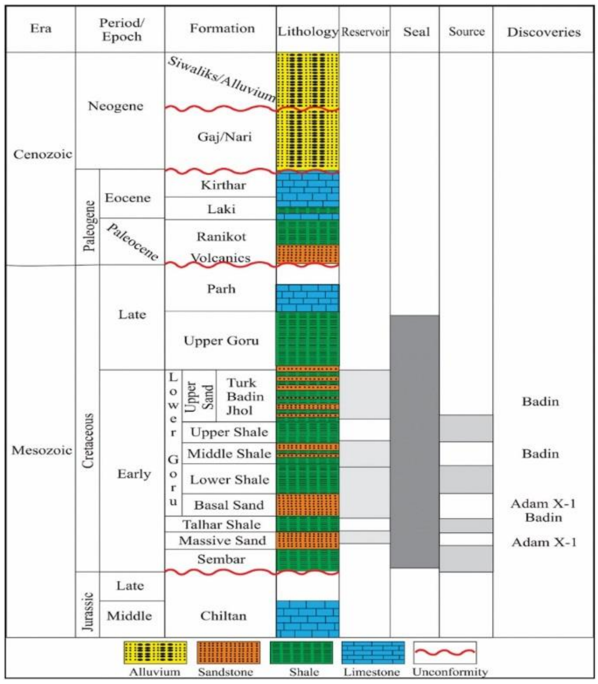

Fig. 2 Lower Indus basin generalized stratigraphic chart (Abbasi et al., 2015).

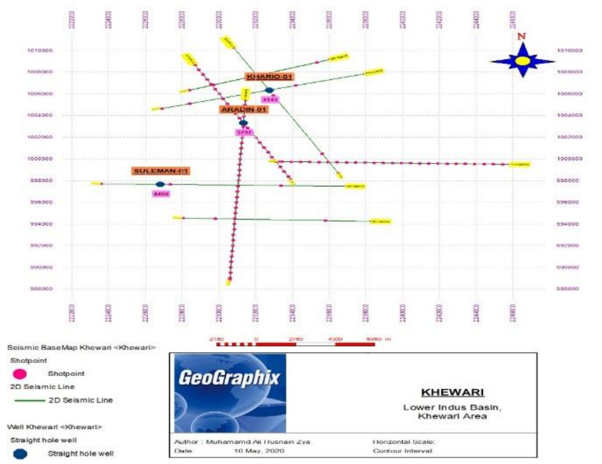

Fig. 3 Base map of the research area.

Table 1. Seismic lines and their position utilized in the present study.

Serial no	Line no	Line	Direction
1	011-KWI-25	Strike	W-E
2	047-KWI-75	Strike	W-E
3	021-KWI-40	Strike	W-E
4	011-KWI-15	Dip	N-S
5	052-KWI-79	Dip	NE-SW
6	052-KWI-78	Dip	NE-SW
7	011-KWI-14	Dip	NW-SE
8	052-KWI-77	Dip	NW-SE

The primary objective of seismic interpretation is the identification of seismic horizons. A thorough understanding of the regional structure and regional stratigraphy of a specific area is essential to achieve this requirement.

Eight 2D seismic lines acquired, have been used in this study: 011-KWI-25, 047-KWI-75, 021-KWI-40, 011-KWI-15, 052-KWI-79, 052-KWI-78, 011-KWI-14, and 052-KWI-77. Three seismic lines are strike lines 011-KWI-25, 047-KWI-75, and 021-KWI-40, while the remaining seismic lines are dip lines. Using source wavelets at a frequency of 35 HZ, a synthetic seismogram has been created for the Aradin -01 well. Using mean velocities calculated from interval velocities and time read directly from the tops of certain horizons, time and depth contour maps of reservoir formations have been created (Coffeen, 1984; Faisal et al., 2013; Ahmad et al., 2010). Seismic sections are used to identify the formation tops, and these findings are further confirmed by correlating with a synthetic seismogram. Other ways to identify faults include discontinuities in reflections, essentially linear patterns, diffraction patterns, inaccuracies in linking reflections around loops, divergence in a dip that is not associated with stratigraphy, particularly those with vertices exhibit local faulting-like lining up of vertices, and interruption or reduction of reflections below suspected fault lines (Badley, 1985; Ahmad et al., 2010; Faisal et al., 2013). Finally, a depth contour map is used to demarcate the economic region.

Results and Discussion

Marking of the Seismic Sections

Out of the eight seismic lines allocated, the 052-KWI-79 seismic line is chosen for seismic interpretation. Talhar Shales and Sembar Formation are marked manually on the horizons. These horizons are correspondingly, at 2.03 and 2.30 sec. Two faults, designated F1 and F2, are also observed along the seismic line (Fig. 4).

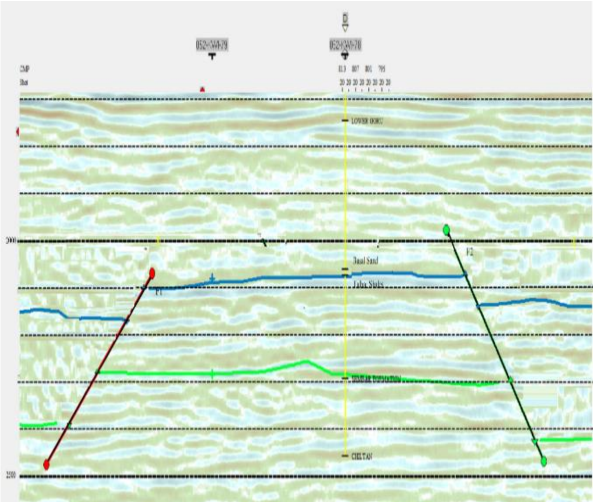

Fig. 4 Interpreted seismic section.

On the section, a horst and graben structure can be seen. Normal faulting results in the formation of these structures. This provides compelling evidence that the study area is situated within an extensional regime. These horst and graben structures formed by normal faulting are suitable structures for the trapping of hydrocarbons in the region.

Time Contour Map

A time-based horizon-level map and changes depending on time are displayed both horizontally and vertically. Figures 5 and 6 show the placement of this contour map on Talhar

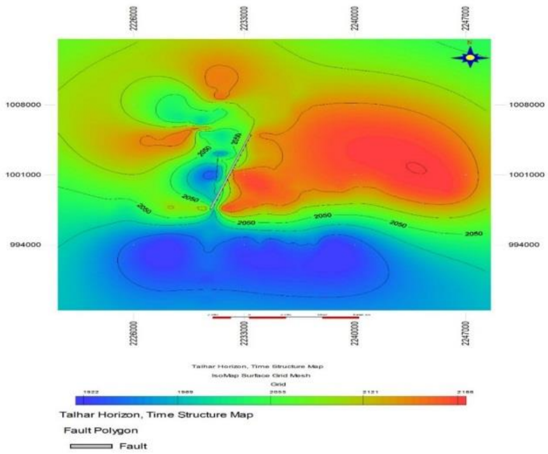

Fig. 5 Talhar Shale horizon's time contour map.

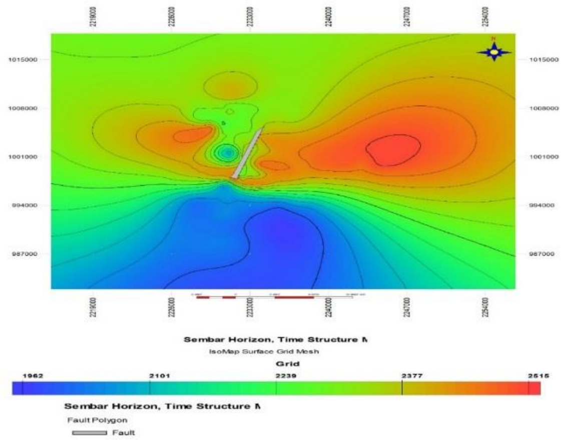

Fig. 6 Sembar horizon's time contour map along fault polygons.

Shale and Sembar Formation horizons. The color scale bars in figures 5 and 6 depict the variation in time. The Talhar Shale's time variation varies from 1922 to 2188 milliseconds, whereas Sembar Formation's time variation extends from 1962 to 2515 milliseconds. According to the scale bar, blue represents the shallowest area, while orange to red represents the comparatively deepest part. Similar color changes can be noticed in the contour map and scale bar, which clearly illustrate that the massive sand and Sembar Formation's shallowest area is purple while its relatively deepest area is reddish. Figures 5 and 6 provide the time contour map of the previously stated zones.

Depth Contour Map

Utilizing well point velocity, a depth contour map is generated. On this contour map, lateral variation with depth is shown. A similar pattern can be seen in time contour maps and depth contour maps. This is due to the fact that depth and time contour maps oth exhibit the same lateral fluctuation. In Figures 7 and 8, the Talhar Shales and Sembar Formation, respectively, are set up on this contour map.

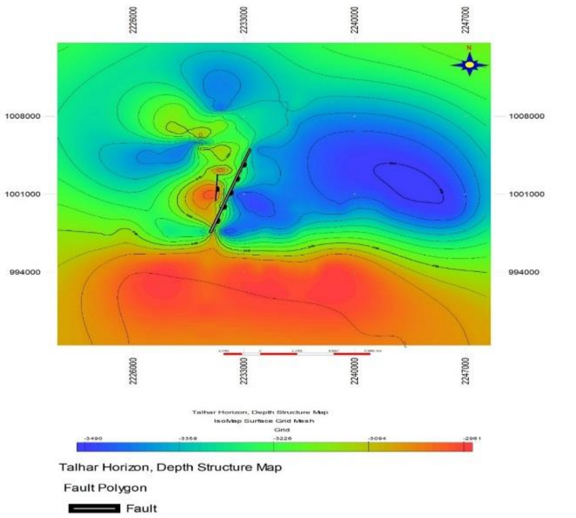

Fig. 7 Talhar Shale horizon's depth contour map along fault polygons.

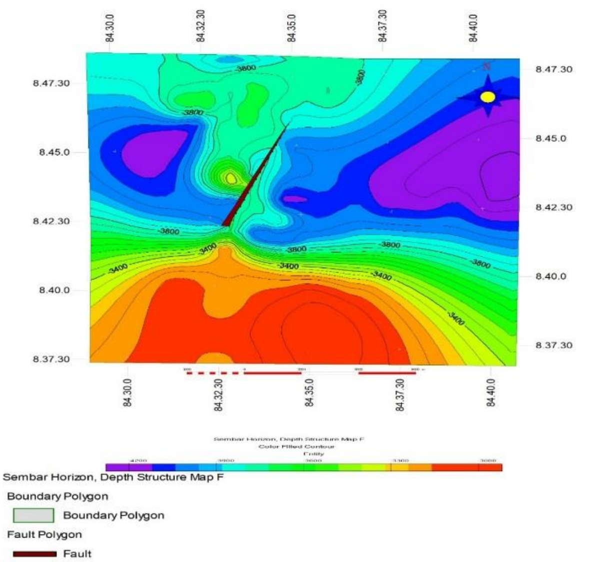

Fig. 8 Sembar horizon's depth contour map along fault polygons.

The color scale bar in Fig. 7 and 8 reveals the variation in depth (Fig.7, 8). It varies from top to bottom at -3490 m and -2951 m. The purple to the blue area (-3490 to -3359m) depicts the shallow section. However, Talhar Shale's deepest portion can be seen in the orange to red color (-3094 to -2961m). Similar to this, Sembar Formation's color changes (from -4200 to -3900 m) demonstrate that the shallowest section is purple and the relatively deepest area is reddish. The depth contour maps of the previously mentioned horizons are displayed (Fig. 7, 8) which suggest that the downthrown block is the deepest section and the up thrown block is the shallowest area.

Synthetic Seismogram

It is a technique used to calibrate seismic data to well data. A seismogram is a seismic trace generated by merging a suitable wavelet with the reflection coefficient series obtained from sonic and density logs at a well and correlated with a seismic trace at that position (Schlumberger, 1968). Logs are vulnerable to mud infiltration and poor borehole environments, and the density log is especially prone to error. Before generating a synthetic seismogram, appropriate adjustments should be performed. Similar to sonic tools, actual velocity recorded in a well may need to be adjusted for drift.

Synthetic seismograms may still have errors even after adjustments are made and safety measures are implemented which are computed under conditions that are assumed to be different from the actual ones. Figure 9 shows a synthetic seismogram produced after appropriate adjustments.

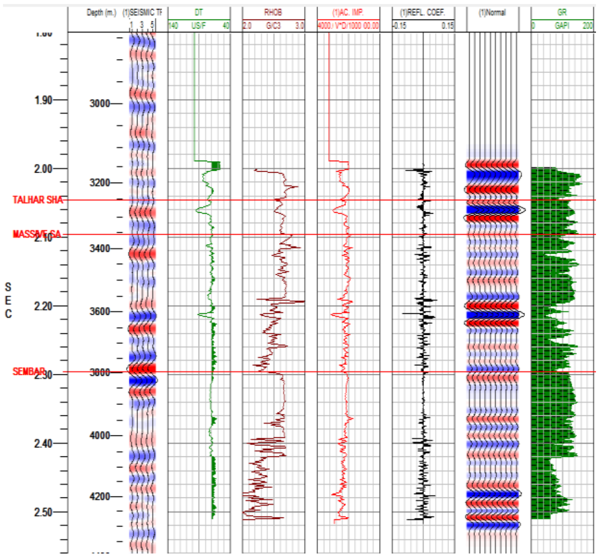

Fig. 9 A synthetic seismogram depicting massive sand sandwiched between shale layers.

The quality of the processed seismic data is revealed by a synthetic seismogram tie to the well, which also provides information on the well's placement on the surface and the types of reflections anticipated from the underlying strata (Fig. 9). Strong continuous reflection horizons in seismic data, shown by a strong reflection zone in synthetic seismogram, indicate the presence of a thick massive sand layer sandwiched between shale units. This is a bogus anomaly in which the reflections are not principal but rather multiples that necessitate data reprocessing.

Conclusion

Geographically, Khairpur district of Sindh is a site to the Khewari oil field, which is tectonically located in the lower Indus basin. The seismic section's reflectors are uniform. The theory of the extensional regime is supported by a few common inter-formational faults. The presence of stratigraphic traps, which are frequent in the lower Indus basin, is shown by the smooth reflector. Employing stratigraphic modeling, they can be identified. The middle of the interpreted time section is where suitable traps for hydrocarbons are interpreted. Horst and Graben structures are suitable for the accumulation of hydrocarbons since the study area is in an extensional regime and there are regional-scale normal faults present. According to the estimated values, variations in velocity are slight to moderate. The time range for Talhar Shale spans from 1922 to 2188 milliseconds and from 1962 to 2515 milliseconds for the Sembar Shales. The scale bar's blue color represents the shallowest area, while the comparatively deepest portion is represented by the orange to red color on the scale bar. Similarly, color changes are depicted in the contour map, with the scale bar illustrating the shallowest section in purple and the relatively deeper portion of Sembar Formation and massive sand in reddish. The depth range is between the top and bottom by -3490 and -2951 m, respectively. The shallow area is indicated with the purple to blue color section (-3490 to -3359m). The deepest portion of the Talhar Shale is visible as an orange to red color (-3094 to -2961m). Likewise, color variability in Sembar Formation (-4200 to -3900m) reveals that the shallowest region is purple and the relatively deepest area is reddish. According to the findings, the shallowest area is an up thrown block, while the deepest part is a down thrown block. Talhar Shales and Sembar Formation are dipping northeast, as indicated by the isopach maps.

References

Abbasi, S.A., Solangi, S.H., Nazeer, A., Asim, S., Habib, W., Solangi, I.A. (2015). An overview of structural style and hydrocarbon potential of Jabo field. Southern Sindh monocline, southern Indus basin, Pakistan. *Sindh Univiversity Research Journal (Science Series)*, **47**, 347–354.

Ahmad, N., Khan, M. (2010). Play fairway analysis and CRS mapping within a sequence stratigraphic framework: Screening tools for geological risk constrained exploration. In: PAPG-SPE Annual Technical Conference.

Ahmed, S., Solangi, S. H., Jadoon, M. S. K., Nazeer, A. (2018). Tectonic evolution of structures in southern Sindh monocline, Indus basin, Pakistan formed in multi-extensional tectonic episodes of Indian plate. *Geodesy and Geodynamics*, **9** (5), 358-366.

Ahmad, Z., Akhter, G., Bashir, F., Khan, M. A., Ahmad, M. (2009). Structural interpretation of seismic profiles integrated with reservoir characteristics of Bitrism block (Sindh province), Pakistan. *Energy Sources*, Part A **32,** 303-314.

Ahmad, Z., Akhtar, G., Bashir, F., Khan, M.A., Ahmad, M. (2010). Structural interpretation of seismic profiles integrated with reservoir characteristics of Bitrism Block (Sindh Province), Pakistan. *Energy Source*. **32**, 303-314.

Ali, A., Ahmad, Z., Akhtar, G. (2005). Structural interpretation of seismic profiles integrated with reservoir characteristics of Qadirpur area, Pakistan. *Journal of Hydrocarbon Research*, **15**, 25-34.

Asim, S., Qureshi, S. N., Khan, N. (2014). Study of an uplift of Sargodha High by stratigraphic and structural interpretation of an east-west seismic profile in central Indus basin, Pakistan. *International Journal of Geosciences*, **5**(9), 1027.

Athar, J., Waheed, A., Sheikh, R.A. (2012). Pakistan's major petroleum plays-An overview of dwindling reserves. *Search and Discovery*, Article 10399: 1-2.

Badley, M. E. (1985). Practical Seismic Interpretation. Boston, MA. IHRDC Publisher, 266 pages.

Bacon, M., Simm, R., Redshaw, T. (2003). 3-D seismic interpretation. Cambridge, UK: Cambridge University Press.

Bender, F. K., Raza, H. A. (1995). Geology of Pakistan. Berlin, Germany: Gebruder Borntraeger, 11-63.

Bond, C.E., Lunn, R.J., Shipton, Z.K., Lunn, A.D., (2012). What makes an expert effective at interpreting seismic images. *Geology*, **40** (1), 75-78.

Chapman, C. (2004). Fundamentals of seismic wave propagation. Cambridge, UK: Cambridge University Press.

Coffeen, J. A. (1984). Interpreting seismic data. Tulsa, Oklahoma: Penn Well Books, Penn Well Publishing Company, p65.

Ehsan, M., Gu, H., Akhtar, M.M., Abbasi, S.S., Ullah, Z. (2018). Identification of hydrocarbon potential of Talhar Shale: Member of lower Goru Formation using well logs derived parameters, southern lower Indus basin, Pakistan. *Journal of Earth Science*, **29** (3), 587-593.

Faisal, M., Rehman, F., Rehman, S., Ahsan, N. (2013). Better perceptive and enhanced visualization of seismic profiles for the exploration of hydrocarbon using a seismic and synthetic seismogram modeling of Khipro block, southern Indus basin, Sindh province, Pakistan. *Energy Sources*, **35**, 2101-2112.

Iqbal, M. (1990). The Goru Formation and its facies in Kirthar sub-basin. *Pakistan Journal of Hydrocarbon Research*, **2** (1), 75-81.

Kadri, I. B. (1995). Petroleum geology of Pakistan. Pakistan Petroleum Ltd, Karachi, Pakistan, 275 pages

Kazmi, A. H., Jan, M. Q. (1997). Geology and tectonics of Pakistan. Karachi, Pakistan. Graphic Publishers, 120 pages.

Khan, N., Konate, A.A., Zhu, P. (2013). Integrated geophysical study of the lower Indus platform basin area of Pakistan. *International Journal of Geosciences*, **4** (9), 1242-1247.

Quadri, V. U. N., Shuaib, S. M. (1986). Hydrocarbon prospects of southern Indus basin, Pakistan. AAPG bulletin.

Raza, H. A., Ali, S. M., Ahmed, R. (1990). Petroleum geology of Kirthar sub-basin and part of Kutch basin. *Pakistan Journal of Hydrocarbon Research*, **2** (1), 27-73.

Schlumberger, Sch. (1968). Log interpretation/charts. Houston, Texas, Schlumberger Well Services, Inc.,10-30.

Sheriff, R.E. (1999). Encyclopedic dictionary of exploration geophysics, S.E.G., Tulsa, Oklahoma.

Shuaib, S. M. (1981). Investigation of prospecting areas and horizons of oil and gas in Pakistan. Geol. Bull. Punjab Univ., **16**, 37-42.