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Article

A Hydrocarbon Resource Plays in Southern Pakistan´s Indus Basin

Yasir Shahzad [1,] *, Rui Pena dos Reis [2] and Maria Helena Henriques [3]

[1] University of Coimbra, Department of Earth Sciences and Geosciences Center, Rua Sílvio Lima 3030-790 Coimbra, Portugal; yasishzd@gmail.com
[2] University of Coimbra, Department of Earth Sciences and Geosciences Center, Rua Sílvio Lima 3030-790 Coimbra, Portugal; penareis.rp@gmail.com
[3] University of Coimbra, Department of Earth Sciences and Geosciences Center, Rua Sílvio Lima 3030-790 Coimbra, Portugal; hhenriq@dct.uc.pt
* Correspondence: yasishzd@gmail.com

Abstract: Due to the use of structural and seismic techniques an attempt has been made in this study to determine the hydrocarbon potential and future exploration in Pakistan's Lower Indus basin area and offshore region. In addition to the possibility of hydrocarbon accumulation, the major goals of this research are to analyze structural patterns in the subsurface of the study region, identify the horizons of various formations using surface seismic, and interpret seismic lines. Seismic data has been used to find and integrate the exposed Cretaceous/Tertiary basalt at Ranikot in the lower Indus basin to the well-known Deccan basalts of the Indo-Pak plate, which is the secondary goal of the current investigation. According to the interpretation of seismic data, the Indo-Pakistan plate has experienced rifting because of tectonic activity. Graben and horst structures have been identified in the study area horizon, which indicates that the area has undergone major structural and depositional changes. While faults provide a pathway for hydrocarbons to migrate from their source to reservoir rock, grabens are principally responsible for the accumulation of hydrocarbons. We further deduce that the prior exploration failures in the area were due to a lack of knowledge of the subsurface formations and structural trends, which are essential for characterizing the hydrocarbon play and trap features. Our results can be productive for the local hydrocarbon drilling projects as well as worldwide tectonic stratigraphy studies on passive continental edges.

Keywords: Deccan basalts; Indus Basin (Pakistan); Seismic interpretation; Hydrocarbon potential

1. Introduction

There have been various wells drilled in the Lower Indus Basin (Southern Pakistan). Technical difficulties prevented a few of these wells from reaching the targeted reservoirs, while other wells appear to have been drilled in the erroneous potential zone. This study attempted to determine the hydrocarbon potential and future exploration in Pakistan's Lower Indus basin area and offshore region using structural and seismic techniques that can reveal the subsurface architecture. It is focused at the Ranikot area, located at Pakistan's southern Indus Basin, and aims at contributing to a more accurate interpretation of the stratigraphy, nature of faults, and imaging subsurface structure, which would aid in the search for hydrocarbons. It was also possible to look at the effects of recent collisional tectonics and early rifting on subsurface structure and stratigraphy in the Southern Indus Basin, an Atlantic type passive continental border of the Indo-Pak Plate.

In addition to the possibility of hydrocarbon accumulation, the major goals of this research are to analyze structural patterns in the subsurface of the study region, identify the horizons of various formations using surface seismic, and interpret seismic lines. Seismic data has been previously used to identify and integrate the exposed Creta-

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ceous/Tertiary basalt at Ranikot in the lower Indus basin to the well-known Deccan basalts of the Indo-Pakistani plate, which is the secondary goal of the current investigation. The rock type is confirmed by geochemical data to be either basalts or basanites [1]. There are areas in Pakistan's Southern Indus basin where thin basaltic rock strata have been exposed and can be identified.

The current work is concentrated on the Ranikot basalt exposures. Sedimentary rocks from the Cretaceous to the Recent formations predominate in the study area, which includes a section of the lower Indus basin. These basalts are frequently interbedded with late Cretaceous and early Paleocene sandstones from the Pab Formation and basalts from the Khadro Formation, respectively, in their meter scale thick exposures as shown in Figure 1 [2]. Several wells have been drilled in the lower Indus basin, most notably Dasori-1 and Tallar-1. These wells ran across some quite thick stretches of basaltic rocks while drilling. The offshore, where these basalts reach a height of about 400 meters, is where they are the thickest [3]. The basalts are initially black to greenish black, although the top of the unit apparently appears reddish to brown grey due to weathering [4]. The basalt in the study area is stratigraphically interbedded with the upper Cretaceous Pab Formation, which makes upper contact with the conformable lower Paleocene Khadro Formation [5,6].

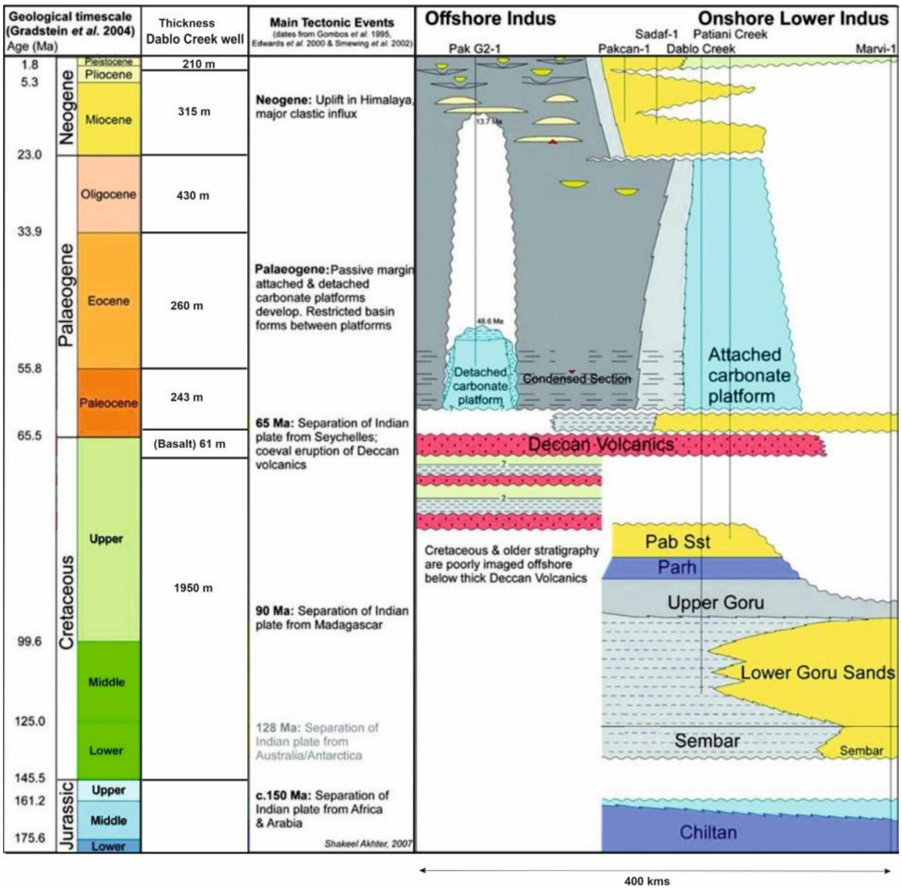

Figure 1. Stratigraphic chart of the Lower Indus Basin [25].

The exposed basalts can be given an age at the level of K/T boundary based on their stratigraphic position, which is the time equivalent of the famed continental flood basalts of the Indian Deccan traps [3,4]. In this regard, a number of tectonic settings, including the mantle plume model and extensional or rift-related tectonics, have been proposed for the emplacement of continental flood basalt [6].

The basalts in the lower Indus basin were also formed as a result of the same extensional tectonic conditions since they share geochemical characteristics with the exposed Deccan traps [5]. The stratigraphic, tectonic, and structural significance of these basalts,

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which are the consequence of past volcanic activity, can be substantial. Additionally, the Lower Indus region's Late Cretaceous Pab formation has basaltic traps [3]. This suggests that there is more than one flow or trap, representing distinct ages, revealed in the lower Indus basin. Such a large number of flows at the same stratigraphic position and date are exposed, even at distinct Deccan trap localities. Therefore, there is good stratigraphic congruence between the investigated basalts in the Ranikot area and the well-known continental flood basalts of the Deccan Traps. Consequently, it's possible that the investigated basalts are the lower Indus basin's western extension of the Deccan Traps and were formed in the same tectonic environments as those suggested for the Deccan traps [7].

2. Geological Settings

The interior of the Indian Plate was gently raised as a result of the Late Jurassic to Early Cretaceous Gondwana's continuing splitting, and eventually the Middle Jurassic carbonate platform was replaced by shales and sandstones from shallow marine to deltaic settings [8]. During the Late Cretaceous breakup of the Indo-Pak plate from Madagascar (Figure 2), the Khadro Formation erupted when a portion of the Indo-Pak plate's western margin crossed the Reunion hotspot (Deccan Trap) [9]. The aforementioned events led to the interior of the Indo-Pak plate rising and the subsequent replacement of the carbonate platform by clastic deposits [10]. The Tertiary and Cretaceous strata have been deformed by transtensional tectonics, according to seismic interpretation, and the vertical seismic section suggests a reversal fault that is 450–3500 meters deep [11]. Under the influence of eastward-directed stress, the hanging wall travels upward along the fault plane, resulting in a broad, north-south-oriented, and eastward-moving thrusted anticline [12]. The Late Cretaceous Pab-Formation, a well-known primary hydrocarbon reservoir, is topped by basalts from the Paleocene Ranikot Formation which serves as the region's seal rock [13]. Seismic and subsurface geological data interpretation and presentation provide cues that the area possesses considerable hydrocarbon potential [14].

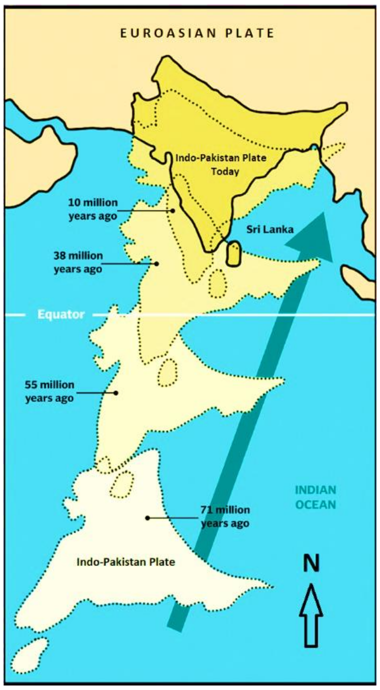

Figure 2: Map of the Indo-Pakistan Plate's current location [29].

Only 10–20 percent of Pakistan's sedimentary basins, which cover an area of almost 829,000 Km2, have been investigated so far [15-18]. Three sedimentary basins—the Indus Basin, Baluchistan Basin, and Pishin Basin—make up the region (Figure 3). Upper, Northern, and Southern basins make up the remainder of the Indus Basin. Geographically, the Southern Lower Indus Basin is situated in Pakistan's Sindh Province [19]. It

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extends roughly between 25° and 29° N and 65° E to Pakistan's southern border. The sedimentary basin has a north-south trend and a thick tertiary series that is overlain by Quaternary sediments and older sequences (Permian sequence). Its width, which is over 260 km, was largely constant during the Mesozoic [8-10].

One thick flow of basalt has been observed at the anticline's core in the Ranikot region of the Lower Indus basin. These basaltic flows are initially black, although their lithology is frequently dark green to grey. The lower Paleocene Khadro Formation can coexist with the upper contact. These basalts are vesicular or amygdaloidal. Vesicle densities differ between different flow areas. At the same time that some of the vesicles are filled with calcite or quartz grains, other vesicles are concurrently empty. Vesicles appear in a range of sizes, although they typically measure between 5 and 7 cm [20]. The discovery of fragments in the underlying formations demonstrates how some of these basalts have been eroded and turned into a detrital component of the aforementioned forms [5]. These basalts are typically found layered together with sandstone and shale. Drilling in the lower Indus basin revealed the presence of basaltic flows. This basalt is stratigraphically consistent with the Cretaceous Pab Formation and sits above the lower Paleocene Khadro Formation.

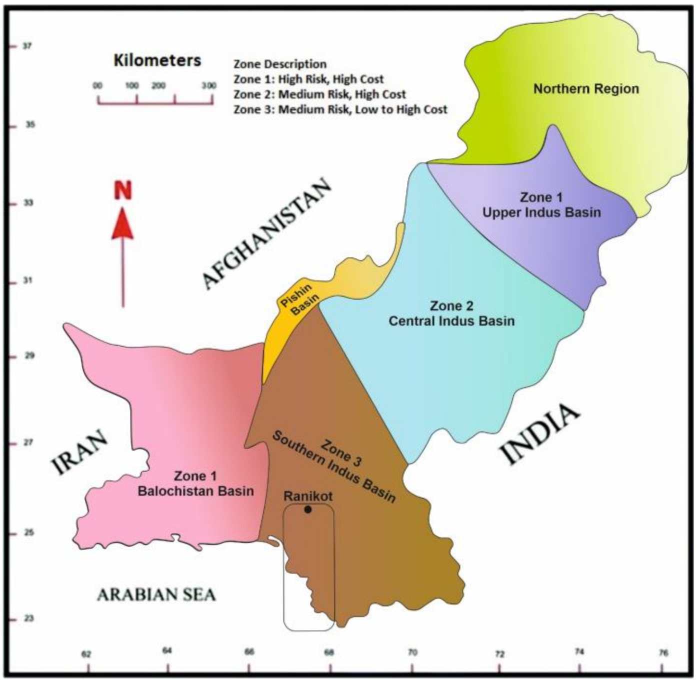

Figure 3: Basins of Pakistan, categorized into zones, with marked exploration zones [19]. The study area is highlighted in Zone 3.

3. Material and Methods

The stratigraphic, tectonic, and structural significance of these ancient volcanic basalts is substantial. Although basaltic flows have been observed in the research location for a while, there hasn't been any significant research done there yet. It is crucial to study the structural patterns and stratigraphic horizons left behind by extensional tectonic activity. This analysis of structural patterns and stratigraphic layers within the subsurface of the examined region is the main objective of this research activity, which is based on the interpretation of seismic data. For use in research and publication, seismic data from Land Mark Resources was received with permission from the Directorate General of Petroleum Concessions, Ministry of Petroleum and Natural Resources, Islamabad. Seismic data was interpreted through Kingdom Suit Simulation Software© (Figure 4).

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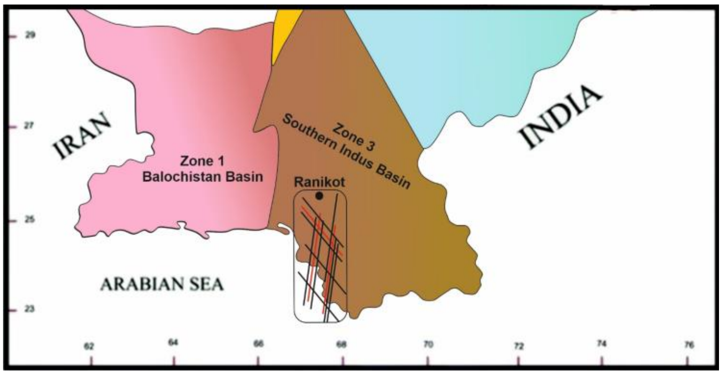

Figure 4: Location of study area and seismic lines. The red colored lines represent the seismic interpreted in the current study [19].

The data set used in this investigation includes the root mean square stacking velocities as well as seismic data from both the pre- and post-stack. Post-stack seismic data was later processed, from geometry assignment and static correction to migration. To resolve the complex geometries, time migration was performed first post-stack and then pre-stack, and the data were finally converted to the final stack [21].

The subsurface target horizons and structural geometries were defined in the first step through seismic interpretation. The horizons were determined once a correlation between time and depth had been established. Any kind of seismic inversion procedure needs the interpreted seismic horizons as inputs. A low-frequency acoustic-impedance model was created and implemented using interpreted seismic data to make up for the absence of low frequencies. Model-based post-stack seismic inversion was employed due to its reliable technique for identifying geological boundaries and structural trends with imperfect seismic data quality. The entire seismic volume is then subjected to post-stack seismic inversion to provide an impedance attribute with an inverted impedance.

Geological structures, discontinuities, and sequence boundaries can all be highlighted via the signal processing of post-stacked seismic data [22]. Due to the poor quality of the 2D regional seismic profiles, the profiles were reprocessed to reduce random noise, boost resolution, and improve reflection continuity. Despite the fact that other multichannel signal augmentation methods have been used, frequency filtering is the one that best maintains relative amplitudes and retains the signal's nature without amplitude distortion [23]. Reflection continuity may diminish if noise is still present in the post-stacked data, therefore, pre-stack seismic inversion was performed.

4. Results

In order to get insight into the depositional settings, the seismic sections are divided into their corresponding sequences, and each sequence's internal deposition of reflection events and its nature are analyzed. Based on discontinuity or abrupt conclusion in the subsurface seismic reflections and diffraction patterns, particularly those with vertices, faults on seismic sections are identified. At all levels, the consistency of the fault traces was verified. The interpreted profiles with solid black lines represent horizons and dotted solid black lines delineate faults (Figures 5 to 8). The chosen horizons were linked at several intersection sites to ensure consistency throughout all the lines of junction in the whole seismic section covering the entire survey. The analysis was evaluated once again in cases where there were closure errors.

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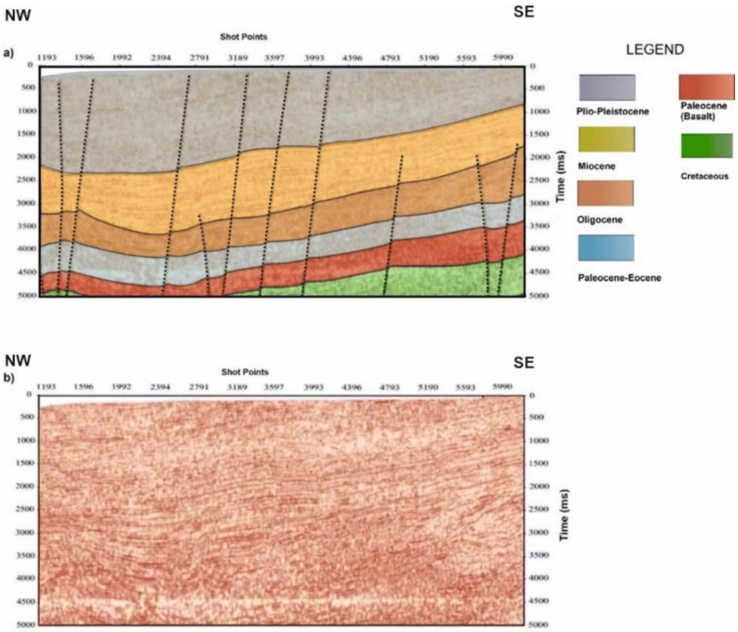

Figure 5: The interpretation of regional seismic line-1 was in a North-South direction. The black vertical lines with white dots represent geological faults, while the horizontal color lines represent defined horizons.

4.1 Paleocene Sequence (Ranikot Formation)

The Paleocene sequence, which is conformable, is bounded by the Cretaceous sequence at the base and the Eocene sequence at the top. Part of the Paleocene sequence is the Ranikot Formation. However, just a few of the platform wells have come across the Upper Ranikot, which primarily consists of limestone and shale interbedded [23]. The Khadro Formation (flood basalts of Deccan Trap), which is found in the Lower Ranikot, contains layers of basalt, sandstone, and shale. The Paleocene series has a parallel to wavy reflection structure with significant amplitudes and low frequency reflections throughout the whole research area. The lines are typically parallel close to the shelf, indicating normal sedimentation conditions. A wavy pattern can be identified in the offshore region close to southwest termination.

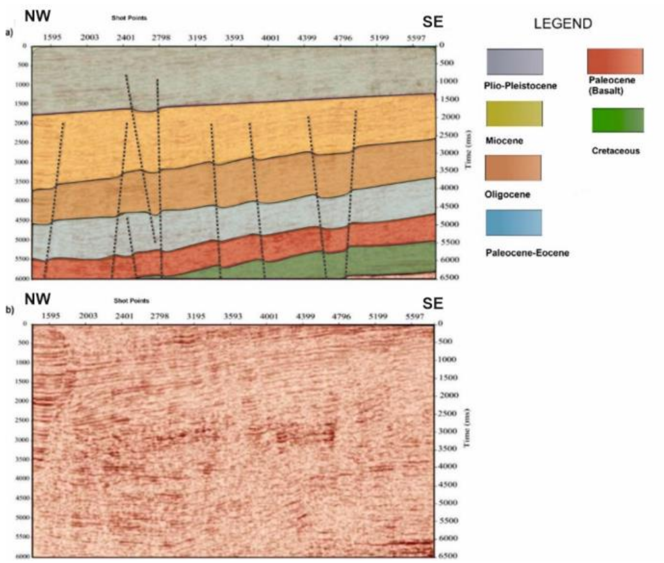

Figure 6: North-South orientation was used in the interpretation of regional seismic line-2. The black vertical lines with white dots represent geological faults, while the horizontal color lines represent defined horizons.

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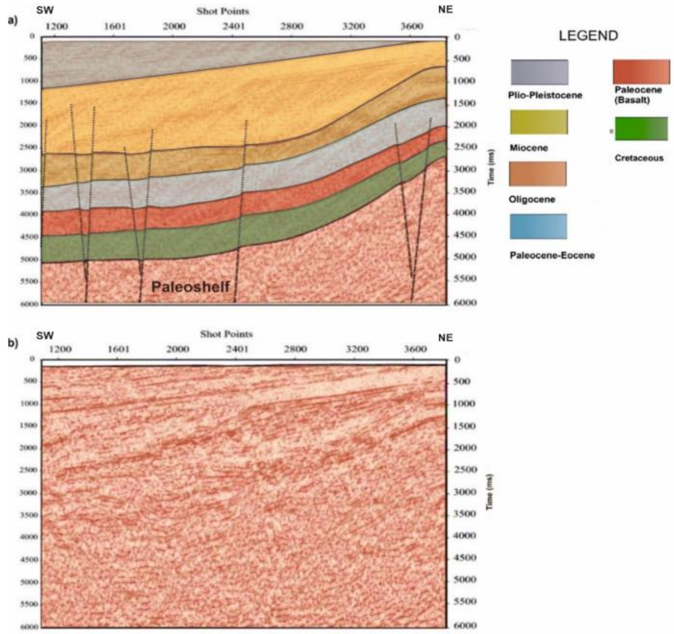

Figure 7: Regional seismic line-3 was interpreted as pointing East-West. Geological faults are shown by the vertical lines that have dots in them and by the horizontal lines that are colored.

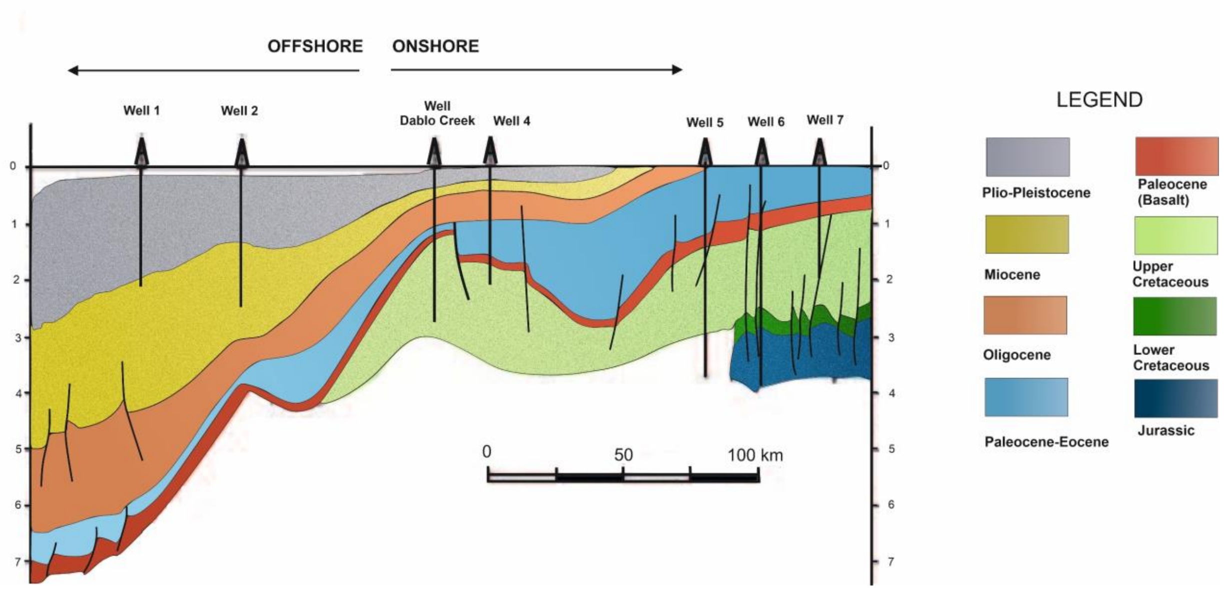

Figure 8: Pakistan's offshore Indus region regional geoseismic model [25].

4.2 Hydrocarbon potential

Seismic sections illustrate faults that collectively create horsts and grabens, which is a sign of extensional tectonics in the region. Faults in the study region demonstrate a north-west to south-east tendency. Seismic data interpretation suggests this tendency as a result of both major and minor tectonic events. The region is severely impacted and marked by extensional tectonic activity that is connected to rifting events that the Indo-Pak plate has gone through [25]. The research area has undergone significant structural and depositional changes, resulting in graben and horst features up to the Paleocene (Basalts or Khadro Formation) horizon [26].

Structures in the study area provide the vital role of the hydrocarbon system. Grabens are primarily responsible for the accumulation of hydrocarbons, whereas faults offer a route for them to migrate from their source to reservoir rocks where they are trapped. There are a significant number of known seals identified in the Pab and Khadro formations. Additionally, we have looked into areas where the Lower Ranikot serves as a

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seal rock for the Pab/Khadro formations and discovered an excellent basal muddy horizon. The base sandstones of the Ranikot Formation are also a remarkable reservoir in some regions where the formation's higher sandy part has migrated, and intraformational shale acts as a seal for migrating hydrocarbon (Figure 9).

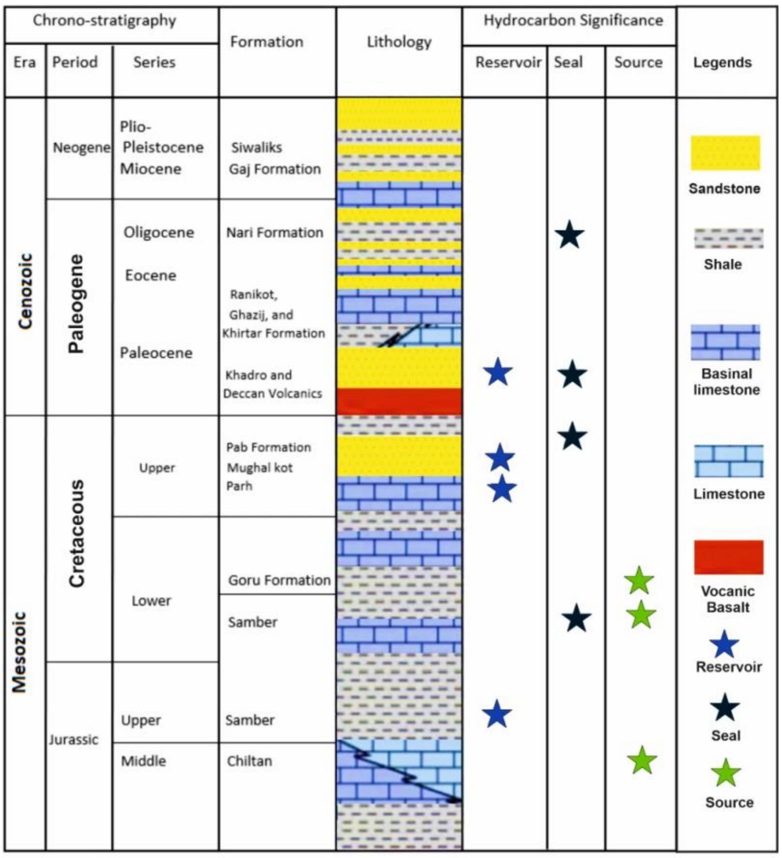

Figure 9: The lower Indus Basin's generalized stratigraphic column and hydrocarbon significance [11].

5. Discussion

Sub-basalt exploration is worthwhile because basalt-covered basins have demonstrated their ability to hold and produce hydrocarbons (for example, Faroe-Shetland, Columbia River, Paraná Basin, Deccan Traps). In fact, the potential for exploration under basalt cover can reach 800 Tcf gas and 30 billion barrels of oil [27]. Worldwide sub-basalt stratigraphic modeling in detail may provide accurate visualization of the presence of petroleum systems underneath the basalt cover [28]. The Saurashtra Basin and the Deccan traps in India, the North Atlantic continental margin of Norway and the British Islands, Greenland, the Columbia River Basin in the Western States of the USA, the Cretaceous continental margins bordering the South Atlantic Ocean of Brazil and West Africa, and the Paleozoic sediments in the Paraná basin in South America are some of the major flood-basalt basins that have been explored in the past and are currently being addressed by exploration [29]. Flood basalts in the Siberian Traps are a portion of the vast East Siberian Platform where they originated during the Permo-Triassic transition. Petroleum deposits have been found in these flood basalt locations. Other examples include the Triassic gas reservoir in the Corrib field, offshore Ireland, the oil beneath Early Cretaceous basalts of Ghana, the Kudu gas field from the Namibe offshore, and the gas and oil on Paleozoic sediments beneath Jurassic to Triassic sills in the Middle/Upper Amazon and Paraná basins of Brazil [30].

According to previous petrophysical investigations, the Lower Ranikot Formation has three hydrocarbon-bearing zones that range in thickness from 6 to 25 meters [31]. Through seismic inversion, the spatial distribution of these zones was examined. The best

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method for interpreting subsurface geometries has been shown to be seismic inversion, particularly when complicated reservoirs call for quantification of the reservoir properties in terms of porosity and lithology [32]. Pre-stock seismic inversion technique offers a variety of inversion parameters that enable us to address issues that post-stack inversion was unable to address. The top and bottom of the Lower Ranikot Formation are distinguished by pre-stack inversion data that are more abundant and improve reservoir characterization [33]. The Lower Ranikot Formation's low impedance zones are generally more noticeable and have relative considerable thickness in the pre-stack inverted sections compared to the post-stack results [34]. Thin sands of the Lower Ranikot Formation, Pakistan, have been successfully characterized as reservoirs through integrated analysis using post- and pre-stack seismic inversions and well log data. The principal target in the research region is this deposit, which presents a difficulty to tap the hydrocarbon potential due to its varied lithology and thickness [35]. Previous studies on seismic interpretation and fault mapping in the Badin area also concluded that the region's structural makeup offers the fundamental components of the petroleum system. While faults provide a migration pathway for hydrocarbons from source rocks to reservoir rocks, grabens are the primary locations for hydrocarbon formation [36].

Although the previously mentioned literature is relevant to this research project, there is still a strong need to comprehend the sequence of the tectonic evolution of the region. Doing so will help in solving issues related to subsurface structure, which will ultimately be very helpful in developing future exploration strategies in the region. The certainty of the subsurface structural behavior in the studied area will undoubtedly enhance with the preparation of geophysical models employing seismic reflection profiles. The present results and their validation show good to exceptional matching, reaffirming the validity of our investigation. However, there is always some degree of uncertainty, which can be reduced even more by combining the available geological data. The methods used will be useful for defining heterogeneous hydrocarbon resources in basins with comparable tectonic and geological settings, such as those in Faroe-Shetland, Columbia River, Paraná Basin, and Deccan Traps of India.

6. Conclusion

In the Lower Indus Basin, several wells have been drilled. A handful of these wells failed to reach the intended reservoirs because of technical issues, while other wells seem to have been drilled in the wrong prospective zone. The present study helps to a more precise interpretation of the stratigraphy, nature of faults, and imaging subsurface structure compared to past investigations, which would assist in the search for hydrocarbons. In the Lower Onshore and Offshore Indus Basin, an Atlantic type passive continental border of the Indo-Pak Plate, it was feasible to investigate the effects of recent collisional tectonics and early rifting on subsurface structure and stratigraphy. An anticlinal pushup structure and widespread normal faulting are revealed by the analysis of the seismic data collected in the research area. The pushup structure found in the Late Eocene to Recent strata is attributed to the compressive tectonics during the onset of the Indo-Pak and Eurasian plate collision and likely a basement uplift. The stratigraphic framework and actual subsurface geological formations in the Lower Indus Basin could not be fully described by earlier investigations. We concluded from the geological context and our findings that the regional stratigraphy and subsurface structure of the Lower Indus Basin in Pakistan are controlled by tectonic activity along the Indo-Pak plate, associated with uplift in Murray Ridge and/or basement. We further infer that the reason for the region's earlier exploration failures was a lack of understanding of the subsurface formations and structural trends, which are crucial for defining the hydrocarbon play and trap features. Research into the worldwide tectonic stratigraphy of passive continental margins and regional hydrocarbon exploration initiatives may benefit from our findings. According to the interpretation of the subsurface structure based on seismic data, the region is characterized by normal faulting with horst and graben geometry. There may be areas along these faults where hydrocarbons can effectively accumulate.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hooper, P.; Widdowson, M.; Kelley, S. Tectonic setting and timing of the final Deccan flood basalt eruptions. *Geology*. **2010**, *38*, 839–842.
2. Mahoney, J. Deccan Traps and Continental Flood Basalts. *Kluwer Academy of Publications, Dordrecht*. **1988**, 151–194.
3. Sheth, H. C. A historical approach to continental flood basalt pre-volcanic rifting, sedimentation, and early alkaline magmatism. *Earth and Planetary Science Letters.***1999**, *168*, 19–26.
4. Sheth, H. C. Flood basalts and large igneous provinces from deep mantle plumes: fact, fiction, and fallacy. *Tectonophysics*. **1999,** *311*, 1–29.
5. Sheth, H. C.; Foulger, G. R.; Natland, J. H.; Presnall, D. C., & Anderson, D. L. From Deccan to Réunion: Plates, Plumes, and Paradigms. *Geological Society of America*, **2005**, *246*, 103–107.
6. Richards, M. A.; Duncan, R. A.; Courtillot, V. E. Flood basalts and hotspot tracks: plume heads and tails. *Science*, *246*, **1989**, 103–107.
7. Sheth, H. C. Were the Deccan flood basalts derived in part from ancient oceanic crust within the Indian continental lithosphere. *Gondwana Research*, **2005,** *8*, 109–127.
8. Chatterjee, S.; Scotese, C. R. The breakup of Gondwana and the evolution and biogeography of Indian plate. *Proceedings of Indian National Science Academy*, *65*, **1999**, 397–425.
9. Chatterjee, S.; Scotese, C. R. The wandering Indian plate and its changing biogeography during the Late Cretaceous–Early Tertiary period. *Springer-Verlag, Berlin Heidelberg, Germany*, **2010,** 105–126.
10. Chatterjee, S. A kinematic model for the evolution of the Indian plate since the Late Jurassic. *New Concepts in Global Tectonics. Texas Tech University Press, Lubbock, United States of America*, **1992,** 33–62.
11. Abbasi, S.; Asim, S.; Solangi, S.; Khan, F. Study of fault confguration related mysteries through multi seismic attribute analysis technique in Zamzama gas feld area, southern Indus Basin Pakistan. *Geod Geodyn*, **2016,** 132–142.
12. Zafar, Z.; Shoaib, K.; Afsar, F.; Raja, Z.; Tanveer, A.; Burley, S. A radical seismic interpretation re-think resolves the structural complexities of the Zamzama Field, Kirther Foredeep, Pakistan. *PAPG/SPE*, **2018,** 11–12.
13. Kazmi, A.; Rana, R. Tectonic map of Pakistan. *Geological Survey of Pakistan*, *39*, **1982**, 283–300.
14. Kazmi, A.; Abbasi, A. Stratigraphy and historical geology of Pakistan. *Peshawar Publication*, **2008,** 181–185.
15. Jamil, A.; Waheed, A.; Sheikh, R. A. Pakistan's Major Petroleum Plays - An Overview of Dwindling Reserves. *AAPG Search and Discovery Article*, **2008,** *10399*.
16. Quadri, V.; Shuaib, S. M. Hydrocarbon prospects of southern Indus basin, Pakistan. *AAPG Bulletin*, **1986,** 730–747.
17. Raza, H. A. Estimating the volume of oil and gas resources of Pakistan. In First Pakistan Geological Congress, Institute of Geology, Punjab University Lahore, Pakistan, **1985,** 70–81.
18. Raza, H.; Ali, S.; Ahmed, R. Petroleum geology of Kirthar sub-basin and part of Kutch Basin. *Pakistan Journal of Hydrocarbon Research*, **1990,** *2*, 29–74.
19. Hanif, M.; Hart, M. B.; Grimes, S. T.; Leng, M. J. Integrated stratigraphy and palaeo environment of the P/E boundary interval, RakhiNalasection, Indus Basin (Pakistan). *Arabian Journal of Geosciences*, **2014,** *7*, 323–339.

 doi:10.20944/preprints202207.0218.v1

20. Agheem, M.; Solangi, S.; Hakro, A.; Mastoi, A.; Siddiqui, I. Major element geochemistry of basalt exposed at Ranikot area, lower Indus basin, Pakistan. *Journal of Himalayan Earth Sciences*, **2011,** *44*, 2–10.
21. Barala S.; Mohanty P.; Enhancement of geologic interpretation using a new poststack seismic attribute. *Society of Exploration Geophysicists Technical Program*, **2016**, 1677–1681.
22. Yilmaz, O.; Stephen, M. D. Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic Data. *Society of Exploration Geophysicists, United States of America*, **2000,** 255–265.
23. Jain, S. Some techniques of enhancing seismic reflection data for stratigraphic interpretation. *Canadian Society of Exploration Geophysicists*, **1985,** *21*, 15–29.
24. Raza, H. A.; Ahmed, R.; Sheikh, S. M. Exploration performance in sedimentary zone of Pakistan. *Journal of Hydrocarbon Institute of Pakistan*, **1989,** *1*, 1–7.
25. Carmichael, S. M.; Akhter, S.; Bennett, J. K. Geology and hydrocarbon potential of the offshore Indus Basin, Pakistan. *Petroleum Geoscience*, **2009,** *15*, 107–116.
26. Khan, M.; Kerr, A. C.; Mahmood, K. Formation and tectonic evolution of the Cretaceous-Jurassic Muslim Bagh ophiolitic complex, Pakistan: Implications for the composite tectonic setting of ophiolites. *Journal of Asian Earth Sciences*, **2007,** *31*, 112–127.
27. Fainstein, R.; Krueger. Salt Tectonics Comparisons near Three Continent-Ocean Boundary Escarpments. *GCSSEPM Bob F. Perkins Research Conference Series – Petroleum Systems in Divergent Continental Margins, Houston, Texas*, **2005,** 17 Pp., 177–189.
28. Fainstein, R.; Summerhayes, C. P. Structure and Origin of Marginal Banks off Eastern Brazil, Marine Geology. *Elsevier Scientific Publishing Co*, **1982,** *46*, 199–215.
29. Fainstein, R.; Richards, M.; Kalra, R. Seismic imaging of Deccan-related lava flows at the KT boundary, deepwater west India. *The Leading Edge*, **2009,** *38.4*, 286–290.
30. Fainstein, R.; Milliman, J. D. Structure and origin of three continental-margin plateaus, northeastern Brazil. *AAPG Bulletin*, **1979,** *63*, 218–238.
31. Anna, X.; Yuexia, D.; Dakuang, H.; Fengcang, Y.; Chunliang, H.; Zecheng, W.; Xiaofeng, D. Integrated description and evaluation of reservoirs based on seismic, logging, and geological data: Taking Dongying Formation Member 1 oil reservoir of No. 1 structure, Nanpu Sag as an example. *Petroleum Exploration and Development*, **2009,** *36*, 541–551.
32. Zoya, H.; Carlos, T.V. Inversion-based detection of bed boundaries for petrophysical evaluation with well logs: Applications to carbonate and organic-shale formations. *Interpretation*, **2014,** *2.3*, 129–142.
33. Williams, M.; Dean. Stratigraphy of the Lower Indus Basin, West Pakistan. *5th World Petroleum Congress. OnePetro*, **1959,** *19*.
34. Ehsan; Muhsan. A geological study of reservoir formations and exploratory well depths statistical analysis in Sindh Province, Southern Lower Indus Basin, Pakistan. *Kuwait Journal of Science*, **2018,** *45*.
35. Shakir; Urooj. Selection of sensitive post-stack and pre-stack seismic inversion attributes for improved characterization of thin gas-bearing sands. *Pure and Applied Geophysics*, **2021,** *179*, 169–196.
36. Munir, A.; Asim, S.; Bablani, S. A.; Asif, A. A. Seismic data interpretation and fault mapping in Badin Area, Sindh, Pakistan. *Sindh University Research Journal-SURJ (Science Series)*, **2014**, *46*.