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RESEARCH ARTICLE

DETECTING OVERPRESSURE ZONES USING MODEL-BASED SEISMIC INVERSION: A CASE STUDY FROM SRIKAIL-01 WELL, SRIKAIL GAS FIELD, BANGLADESH

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ABSTRACT

An overpressure zone is critical in petroleum exploration drilling, leading to potentially dangerous blowouts and other drilling-related hazards. Yet, it often contains significant hydrocarbon reserves in sedimentary basins. This research aims to determine the possible overpressure zones in the Srikail Well-1 of the Srikail Gas Field. The acoustic impedance responses of 2D seismic data for the Srikail Well-1 and its well log responses were examined to find probable overpressure zones at the Srikail Well-1. Seismic inversion is a crucial method in this study for identifying and understanding overpressure zones. Hence, the process involved extracting wavelets, conducting well correlation, determining and picking horizons, followed by model-based seismic inversion, and calibrating pressure to well logs and seismic data using Kerry 2D post-stack seismic data to derive acoustic impedance, a crucial indicator for the presence of potential overpressure. Well-log responses provided evidence for this analysis. The density and sonic log responses of the Srikail-1 well were carefully evaluated. The intervals indicating possible overpressure locations, as identified through a seismic acoustic impedance, exhibited reasonable consistency with the well-log data. The Srikail-1 well does not have enough well-log information, such as density, but it affects the changing trend of well logs. The sonic logs solely follow the rule of an overpressure zone. A cut-off frequency between 4 and 8 Hz was used to build the Srikail-01 well initial model, and the wavelet was created using well logs and seismic data. Very low acoustic impedance values are observed on the model-based inversion map of the Srikail-01 well at a depth range of approximately 3548.58m in the subsurface corresponding to the overpressure zone. Conversely, the identified overpressure zone has encountered the Bhuban formation. Bangladesh's hydrocarbon reserves are depleting due to high consumption, but unexplored areas and overpressure zones offer untapped potential. Revisiting known structures with robust methods can help to address rising demand.

KEYWORDS

Overpressure, Seismic Inversion, Srikail-1 Well, Bengal Basin, Hydrocarbon Exploration.

1. INTRODUCTION

Overpressure occurs in nearly all sedimentary basins when pore pressure surpasses the hydrostatic pressure limit within a formation. (Hunt, 1990; Fertl et al., 1994; Neuzil, 1995; McPherson and Garven, 1999; Xie et al., 2001; Zahid and Uddin, 2005; Swarbrick and Osborne, 1998). Overpressure has several vital consequences in petroleum exploration, including drilling hazards such as blowouts, the formation of shale diapirs, and growth faults, which later form hydrocarbon traps. A thorough understanding of the overpressure phenomenon can be achieved by studying the mechanisms directly linked to its formation in diverse geological environments. The origins of overpressure in sedimentary basins can be categorized into three groups involving physical, chemical, and biological processes (Zhao et al., 2018). In sedimentary basins, overpressures are usually caused by disequilibrium compaction and hydrocarbon generation (Law and Spencer, 1998; Ruth et al., 2003; Hansom and Lee, 2005). However, overpressures in shallow sedimentary sequences can also arise from vertical pressure transfer from deeper basin levels, such as faulting (Schofield et al., 2019). The escalation in horizontal stress, often attributed to tectonic loading, is acknowledged as a plausible mechanism for generating overpressure (Berry, 1973; Yassir and Bell, 1996). A robust correlation exists between the overpressure development and ongoing compressional tectonic activity globally (Ruth et al., 2003). Tectonic loading can induce overpressure by elevating the average stress, consequently leading to compaction disequilibrium (Yassir and Bell, 1996; Goulty,1998).

The exploratory wells drilled within the Fold Belt and Foredeep region in the eastern Bengal Basin overpressure zones are encountered in the Bhuban Formation at depths ranging from less than 1 km (Patharia-5) to 4.5 km (Muladi-1). Research carried out in Tertiary deltaic sequences worldwide it is evident that thick shale sequences in the Bhuban Formation are responsible for the occurrence of overpressure zones in the Bengal Basin (Law and Spencer, 1998; Swarbrick and Osborne, 1998; Imam and Hussain, 2002). Clay dehydration occurring in the shale sequences of the Neogene Surma Group may have influenced the development of overpressure in several wells within the Bengal Basin (Imam, 1994; Imam and Hussain, 2002). Furthermore, overpressure zones in the Bengal Basin can be attributed to their vicinity to the Himalayas and the Indo-Burman ranges and the rapid sedimentation associated with orogenic processes (Zahid and Uddin, 2005). The Indo-

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Burman Range tectonic compression, clay diagenesis, and incomplete dewatering of fine-grained sediments are potential explanations for the development of overpressure in the Bengal Basin (Zahid and Uddin, 2005; Imam and Shaw, 1985; Imam, 1994). While overpressure zones are recognized as hosts of abundant hydrocarbon reserves in various regions worldwide, their precise status in Bangladesh still needs to be more adequately understood (Law and Spencer, 1998). Geophysicists believe that there are huge reserves of petroleum beneath the overpressure zone. Nonetheless, considering the widespread occurrence of overpressure zones and the presence of hydrocarbons in similar deltaic sedimentary environments worldwide, the possibility of discovering hydrocarbons within the overpressure zones in Bangladesh cannot be dismissed (Imam and Hussain, 2002).

Overpressure has been ascertained through various methods, including seismic measurements, traditional log analysis, and reports from drilling events. A model-based inversion is a form of deterministic inversion method utilized in this study for identifying and understanding the overpressure zones of the Srikail-1 Well. This study aims to detect and characterize overpressure zones of the Srikail-1 Well that will provide a new perspective to the detection and characterization of overpressure zones in the gas fields of Bangladesh. The outcomes of this research will contribute to verify the applicability and effectiveness of model based seismic inversion in overpressure zone detection in other gas fields of Bengal Basin. If it's possible to develop a precise overpressure zoning map of the Bengal Basin via utilizing model-based seismic inversion, it can be an effective tool for predicting and discovering future commercial hydrocarbon discoveries within overpressure zone and will also help to take precautions to prevent overpressure-driven drilling hazards during exploration.

2. GEOLOGICAL SETTINGS

The Bengal Basin is one of the world's youngest deltaic sedimentary basins, originating from the emergence of the Himalayan and Indo-Burmese Mountain ranges (Imam and Hussain, 2002; Uddin and Lundenberg, 2004). The basin is recognized as a passive margin rift, now subducting under the Indo-Burman Ranges in Western Myanmar (Salt et al., 1986). Some researchers referred to it as a "Remnant Ocean Basin." which emerged during the Miocene when the Indian plate and the Burmese plate converged (Gani, 1999; Gani and Alam, 1999). Compressional wrench folds in the east and block-faulted unfolded attenuated continental crust in the west define the structural makeup of the Bengal Basin (Murphy, 1988). The Precambrian Indian Shield borders the Bengal Basin to the west, the Himalayan Ranges and the Shillong Massif to the north, the Indo-Burman orogen to the east, and it opens for a considerable distance into the Bay of Bengal to the south.

The basin is characterized by thick sedimentary succession and spectacular geological features necessary for an ideal petroleum system unfolded from the extensive geological and seismic investigation (Imam, 2005). The Oligocene-Pliocene sequences provide suitable conditions for petroleum accumulation due to thick, recurring intervals of organic-rich shale units and reservoir-quality sandstones in combination with various types of traps (Imam and Hussain 2002). The Bangladesh section of the Bengal Basin can be categorized into three distinct petroleum provinces based on variations in tectonic processes, basin development, and sedimentary deposition history: (i) the Eastern Fold Belt, (ii) the Central Foredeep, and (iii) the NW Stable Shelf/Platform (Shamsuddin and Abdullah 1997; Imam and Hussain 2002). The northeast-oriented central foredeep contains a sedimentary pile of over 20km, while the width ranges between 200km in the north and more than 500km toward the south (Reimann, 1993). Conversely, the CTFB in the eastern folded flank of the Bengal Basin was developed due to an ongoing collision between the Indian Plate and the Burmese Plate.

The studied Srikail gas field falls under the petroleum Block-9 and is tectonically situated on the western part of the NW-SE trending Chittagong-Tripura fold belt inside the Tripura Uplift of the Bengal Basin (Petrobangla 2009; Khan and Chouhan, 1996). The Srikail-1 (SK-01) well was drilled in 2004 after Bangladesh Petroleum Exploration and Production Company Limited (BAPEX) conducted 12-fold common depth point (CDP) investigations there in 1991–1992 (Petrobangla, 2009). Unfortunately, the main objective was unmet, and the search for commercial gas was ultimately unsuccessful. But in 2006–2007, BAPEX conducted a further seismic survey, and in 2012, Srikail-2 (SK–02) was drilled as an exploratory well. In addition, two deviated wells called SK-03 and SK-04 were recently dug in the Srikail gas field.

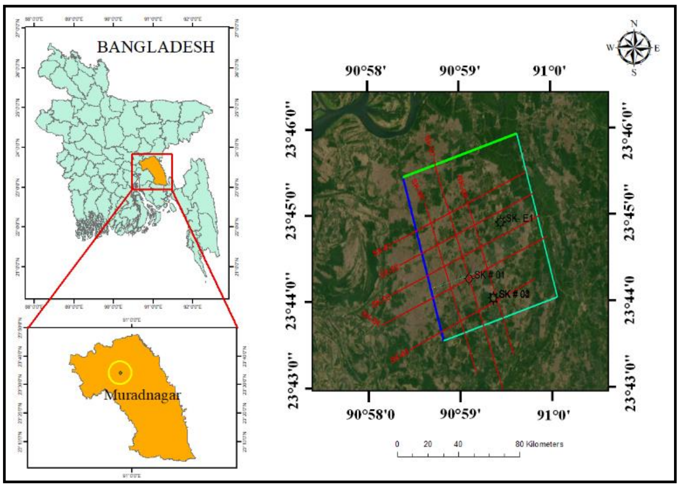

Figure 1: Tectonic framework and location of the Srikail gas field in Muradnagar, Bangladesh, highlighting the geometry of seismic lines and the locations of wells (SK-1, SK-2, SK-3) within the survey section. The left panel displays the geographic location of the study area within Bangladesh, while the right panel shows the seismic survey grid and well positions overlaid on a satellite image of the region.

This area is located between the Indian and Burmese tectonic plates and is predominantly filled with orogenic sediments originating from the eastern Himalayas and the Indo-Burma ranges (Alam et al., 2003; Hossain et al., 2020). Tipam Group and superimposed Surma Group comprise the Neogene sequence in the foredeep area (Evans,1932). Tectonic subsidence, combined with relative sea level fluctuations, led to periodic transgressive and regressive cycles delineating the Surma Group (Rahman et al., 2009). The stratigraphic succession in the Srikail structure predominantly comprises Neogene deposits (Hossain et al., 2021). Alluvium, Dupi Tila sandstone, Tipam sandstone, Bokabil, and Bhuban Formations are sedimentary strata at Srikail Gas Field (Table 1) (Petrobangla, 2009). The sediments comprise different proportions of altered shale, sandstone, and siltstone deposited in a fluvial-deltaic to shallow marine environment.

Table 1: Litho-stratigraphic succession encountered in 4 wells of the Srikail structure (Modified after Petrobangla Report 2009)

Age	Group	Formation	Lithology	Depth (m)
Holocene	Tipam	Alluvium	Alluvium	Surface-50
Pleistocene		Dupi Tila	Sandstone with thin clay layers and quartzite pebbles	50–400
Plio-Pliocene		Tipam	Predominantly sandstone inter-bedded with thin layers of lignite, clay	400–780
Miocene	Surma	Upper Marine Shale	Shale with occasional intercalation of sandstone and silt	780–900
Late Miocene		Bokabil	Alteration of sandstone and shale sequence. Predominantly, shale is interbedded with siltstone and sandstone.	900–2350
Early–Middle Miocene		Bhuban	Alternation of sandstone and thinly laminated shale sequence with minor calcareous siltstone bands. Gas-saturated sand is present.	2350–3650 (Base not seen)

3. DATASET AND METHODOLOGY

3.1 Seismic Data

For the model-based seismic inversion procedure, eight 2D seismic data (SEG-Y format) and five digital wireline log data (LAS format) were utilized provided by BAPEX (Figure 1). Seismic inversion was carried out using 2D seismic data covering about 132 Line km. The compilation of seismic data comprises check shot, wellhead, deviation, well tops, and vertical seismic profile data for Srikail-1. The overall data quality of the 2D seismic lines is fair to good, with relatively straightforward stratal patterns and reflector continuity. However, specific challenges arose in picking reflectors due to occasional channeling and inter-fingering effects. Additionally, some reflectors exhibited discontinuities, breaks, and tilts caused by energy loss in channels and near-surface noise. Despite these difficulties, no significant mis-ties were identified. The spectral content of the data within the 2000–3500 ms time range is shown in Figure 2, as the quality of the seismic data significantly deteriorates below 1600 ms.

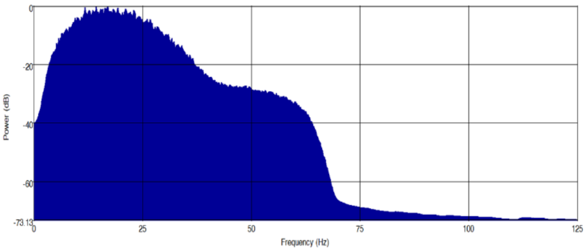

Figure 2: Spectral content of the stacked seismic data between 1500-3500 ms time range.

3.2 Well Log Data

The Srikail-1 Well caliper, gamma ray, density, and acoustic logs comprise most geophysical well logs (Figure 3) A seven-sample median filter (with a sample interval of 0.15 m) was applied to address spikes in the density and sonic logs. Typically, density and velocity increase with depth; however, in overpressure zones, these properties tend to remain constant or decrease, with an inverse relationship observed between sonic and velocity. The yellow-highlighted area represents the overpressure zone in this dataset, characterized by an increase in sonic velocity and a decrease in density (Figure 3). Both seismic and well data were integrated to derive acoustic impedance and overpressure data, with the seismic log serving to correlate subsurface features to the well logs for a more accurate delineation of overpressure zones.

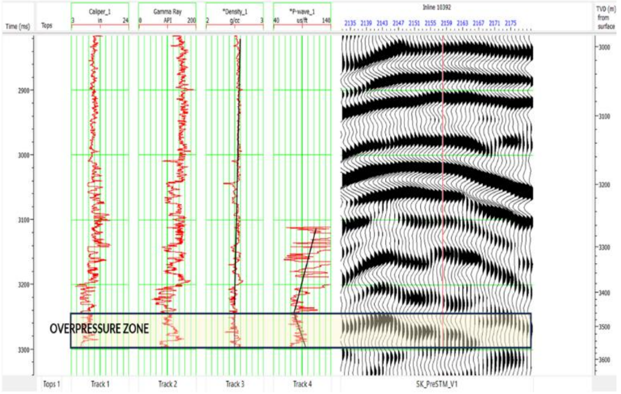

Figure 3: The figure illustrates well log and seismic data. It consists of a caliper log (in mm), a gamma ray log (in API), a sonic log (in μs/ft), a density log (in g/cc), and a seismic section. The highlighted yellow area represents the overpressure zone. Within this zone, the sonic log exhibits an increase, and the density log shows a decrease, indicating the presence of overpressure conditions.

3.3 Methodology

Seismic inversion has been applied to detect overpressure zones by integrating seismic and well-log data. The 2D seismic and well log data from Srikail-01 were inputted into Hampson Russell and Petrel Software for seismic processing. Various procedures were undertaken, including wavelet extraction, well correlation (well-tie), horizon determination and picking, and finally, model-based seismic inversion.

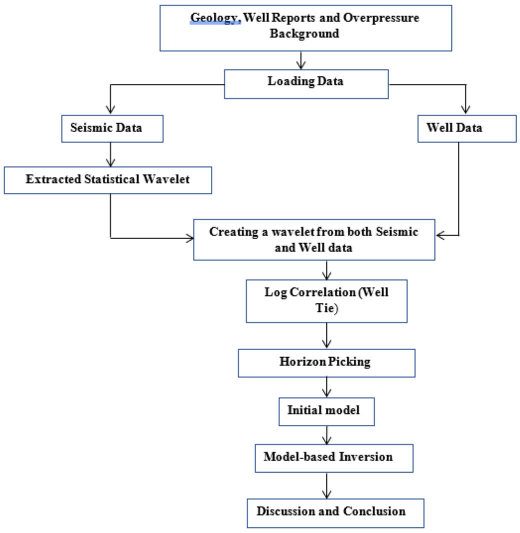

Figure 4: Workflow diagram of methodology

3.3.1 Creating Wavelets

Wavelet extraction is a vital process for correlating well logs with seismic data and for use in inversion procedures. In this study, a statistical wavelet was extracted from the seismic data within the 2000-3500 ms time range (Figure 5). This statistical wavelet demonstrated a higher correlation coefficient during the log correlation process, indicating a better match between synthetic and seismic data compared to other generated wavelets, such as Ricker wavelets with dominant frequencies of 15 Hz, 20 Hz, 25 Hz, and 30 Hz. Subsequently, a new wavelet was created using seismic and well logs after the well-tie process within the same 2000-3500 ms time range (Figure 6). This step further refined the match between seismic data and well logs, enhancing the accuracy of the inversion procedure.

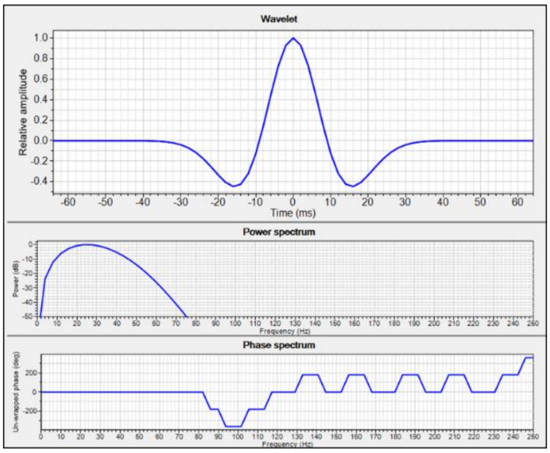

Figure 5: Extracted statistical wavelet between 1500-3500 ms time range.

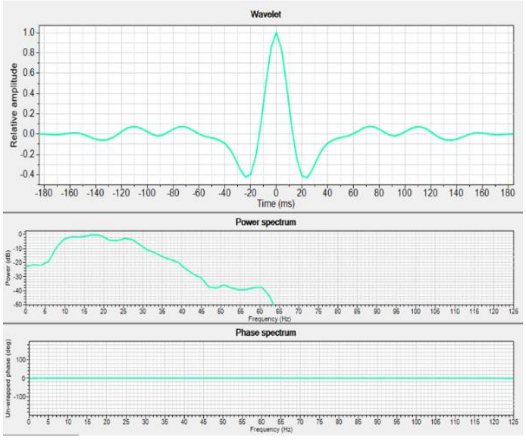

Figure 6: Extracted wavelet by using seismic and well logs between 1500-3500 ms time range after well-tie.

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3.3.2 Log Correlation (Well Tie)

The well-to-seismic tie process was conducted for the Srikail-01 well to align synthetic traces with the seismic data accurately. Check-shot corrections were initially performed to adjust the time-depth relationship of the well data. Following this, synthetic traces were shifted to match the seismic traces. Despite these adjustments, the initial correlation coefficient values were below 0.20, indicating a poor match between the synthetic and seismic data. To improve the correlation, different wavelets were tested. Among the tested wavelets, the statistical wavelet yielded significantly higher correlation coefficients compared to Ricker wavelets with dominant frequencies of 15 Hz, 20 Hz, 25 Hz, and 30 Hz. The statistical wavelet was applied to the data and squeezing and stretching procedures were carried out to further refine the alignment. This iterative process improved the correlation coefficient, achieving a value of 0.80 for the Srikail-01 well. Equal depth intervals were maintained throughout the process to ensure consistency (Figure 7).

Synthetic seismograms were generated using the sonic and density logs in combination with the statistical wavelet. The density log, spanning from 1200 to 3580 m, played a critical role in achieving higher correlation values. For missing density data, Gardner's equation was used to estimate density from the sonic log. However, this method proved to be unreliable in the overpressure zone, where direct density information was available. Consequently, the use of Gardner's equation was limited to zones outside the overpressure interval. This approach demonstrates the effectiveness of the statistical wavelet and iterative refinement techniques in achieving a robust well-to-seismic tie, critical for reliable seismic interpretation and reservoir characterization.

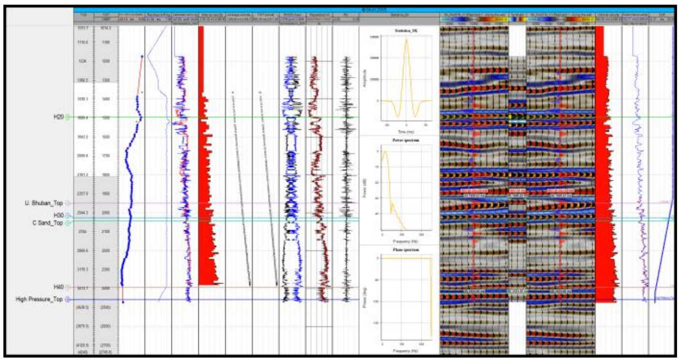

Figure 7: Well-to-seismic tie process for the Srikail-01 well, illustrating the alignment of synthetic and seismic traces. The figure highlights the use of a statistical wavelet, squeezing and stretching procedures, and the application of Gardner's equation for missing density data. Synthetic seismograms were generated from sonic and density logs, with correlation coefficients improved to 0.80 after iterative adjustments. The overpressure zone, where direct density data were available, is also indicated.

3.3.3 Horizon Determination and Picking

Before performing seismic inversion, horizon picking is one of the essential procedures. The following information was taken into consideration to determine the locations of horizons:

i. Good continuous seismic traces

ii. Overpressure zone

iii. One above the overpressure zone, the other one below the overpressure zone

Despite good continuous seismic traces distant from the overpressure zone, two horizons (horizon-1 and horizon-2) were successfully determined and picked (Figure 8**)**. Although seismic data quality could have been more optimal near the overpressure zones, three horizons (horizon-4, horizon-5, and the overpressure zone) were selected and accurately picked (Figure 8**)**.

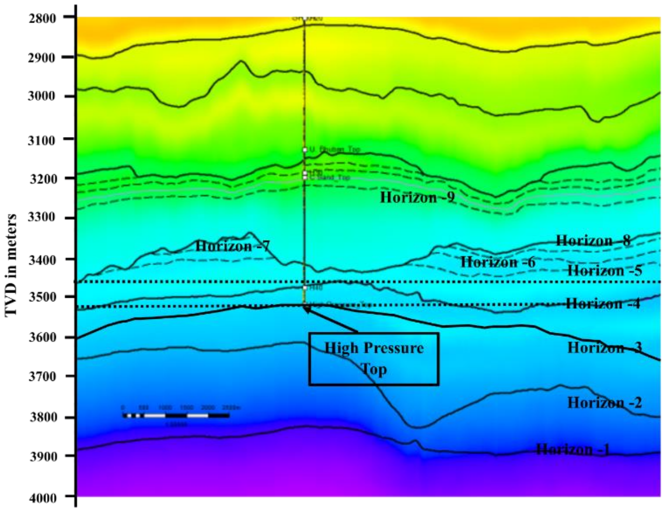

Figure 8: Interpreted horizons across the seismic section, showing key boundaries including those near the overpressure zone.

3.3.4 Post-Stack Inversion

Following these preprocessing steps, a deterministic inversion method known as model-based inversion was employed to obtain acoustic impedance values from the data. The iterative model-based inversion sought the best-matching model by comparing synthetic and real data. A primary model was generated for all wells and horizons, and subsequently, an inversion was conducted for all seismic data volumes. To compensate for the absence of density logs in other wells, an initial model was constructed using the Srikail-01 well. A 4-8 Hz frequency range was employed to obtain this initial model (Figure 9). Inversion was analyzed and implemented for all seismic data lines to acquire acoustic impedance (Figure 10). A new wavelet, and all horizons were used during the initial model and inversion process.

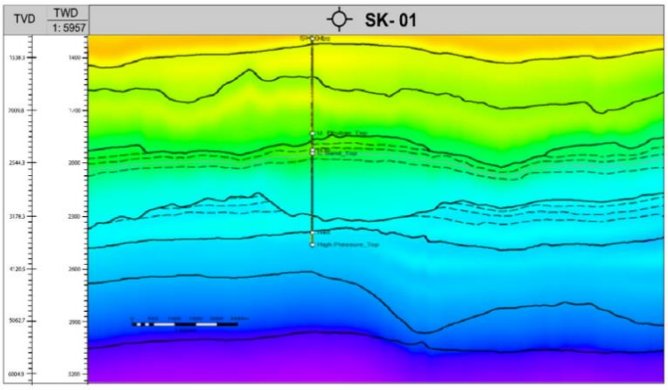

Figure 9: Built initial model whose cut-off frequency is between 4 and 8 Hz. The model was used to build the Srikail-01 well, and the wavelet was created using well logs and seismic data. (Depth in meter)

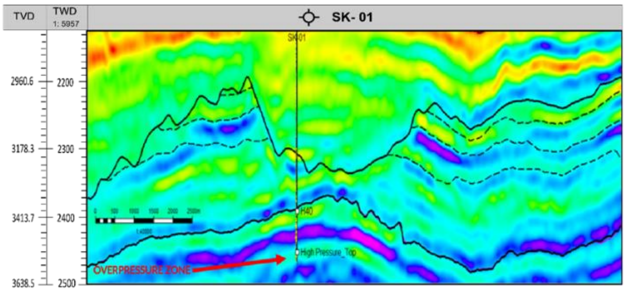

Figure 10: Model-based inversion result by using only Srikail-01 well. The red arrow shows the lowest acoustic impedance, which corresponds overpressure zone. The warm color indicates high velocity and vice-versa.

4. RESULTS AND DISCUSSION

To detect overpressure zones, seismic data, wireline logs such as sonic, density, and acoustic impedance, and drilling events such as mud weight need to be considered. In this study, post-stack seismic data were inverted using model-based inversion, a deterministic inversion method, to obtain an acoustic impedance model. Low acoustic impedance indicates that there could be an overpressure zone. A sonic log decreases with depth, while a density log increases under normal conditions. However, these logs change their trends in an overpressure zone.

The Srikail-1 well affects the changing trend of well logs. In Figure 3, it is observed that at a certain depth, the density log decreases, and the sonic log increases, indicating an overpressure zone's inauguration. The Srikai-1 well does not have enough well-log information, such as density. Their sonic logs solely follow the rule of an overpressure zone.

A cut-off frequency between 4 and 8 Hz was used to build the Srikail-01 well initial model, and the wavelet was created using well logs and seismic data (Figure 9). Figure 10 shows the model-based inversion map created by using the data of the Srikail-01 well. When we focus on the inversion map in Figure 10, it is seen that the Srikail-1 has very low acoustic impedance values at a depth range of approximately 3548.58m in the subsurface. The red arrow shows the lowest acoustic impedance, corresponding to the overpressure zone. The warm color indicates high velocity and vice-versa (Figure 10).

From Litho-stratigraphic succession encountered in 4 wells of the Srikail structure (Petrobangla Report 2009) based on well data and developed from published regional stratigraphy, it is evident that the Bhuban formation lies within the depth range of 3548.58m. Therefore, it can be clearly said that the overpressure zone identified in the Srikail-1 well is located in the Bhuban formation.

5. CONCLUSION

Most of the "easy to find '' hydrocarbon accumulation in the petroliferous Bengal Basin has been explored, and now it is time to look for more complex and unconventional hydrocarbon reservoirs. The overpressure zone may remain a prime target for petroleum explorers because hydrocarbon reserves within the overpressure zone have been discovered in several sedimentary basins worldwide and tend to contain significant reserves. The presence of overpressure in a subsurface reservoir can be associated with the migration and accumulation of hydrocarbons, and it is often a critical factor for successful petroleum exploration and production.

Geophysicists believe that there are huge reserves of petroleum beneath the overpressure zone. A large volume of gas above the overpressure zone was discovered in the Surma Basin. Finding gas reserves below the overpressure zone is crucial to combating Bangladesh's impending gas crisis. In the Bengal Foredeep and fold belt areas, most wells encountered overpressure at some depth, and the top of the overpressured zone has been delineated. In wells such as Muladi-2, BeaniBazar-1, Rashidpur-2, Kailastilla-1, Atgram, Jokiganj, and Mobarakpur, the upper limit of the high-pressure zone is situated within the depth range of 4000m - 4700m. Conversely, this boundary is significantly higher in wells like Lalmai-2, Titas-1, Semutang-1, Sylhet-2, Feni-1, and Begumganj-1, specifically within the 3000m - 3700m depth range. Additionally, in Patiya and Jaldi-3, the depth range falls between 2500m and 3000m. (Data source: BAPEX and Petrobangla annual report, 2021-2022).

The frequent overpressure in the exploratory wells drilled in the Surma Basin area and another part of the eastern folded belt indicate a huge potential for discovering commercial reserve of petroleum within the overpressure zone. Because the presence of overpressure in the subsurface of the Surma Basin reservoir can be associated with the migration and accumulation of hydrocarbons. However, little exploration activities have been carried out in the overpressure zone rather than confining within the easily gettable anticlinal plays. Recently, discovering a commercial gas pool within the overpressure zone in the Zakiganj gas field has created a new possibility to find gas in other wells in the Surma Basin that had previously encountered an overpressure zone.

However, this research is carried out via the seismic inversion method utilizing only the 2D data of Srikail well-01. Future investigations could consider the 3D high-resolution seismic data to understand better subsurface structures and hydrocarbon-bearing overpressure zones. Thereby, for a precise understanding of the overpressure phenomena in the subsurface, a basin-wide seismic inversion study of exploratory wells within the Bengal Basin may reveal the possible location or depth of the overpressure zone within the basin. Exploration in overpressure zones within the petroliferous eastern folded belt region can be increased by adopting various strategies and techniques tailored to the specific geological conditions, including advanced seismic imaging, integrated geophysical methods, well logging and testing, geochemical analysis, basin modelling, and advanced drilling techniques.

Although this study provides some significant insights into the occurrence of overpressure zones in Srikail Well-01, it is not free from certain limitations. However, these restrictions may pave the way for new opportunities for upcoming researchers. In this research, 2D seismic data was utilized. Still, future investigations could consider the 3D high-resolution seismic data to understand better subsurface structures and hydrocarbon-bearing overpressure zones. However, the outcomes of this investigation can be used, compared, and correlated to future studies for gaining deeper insights and discovering the presence of subsurface overpressure zones within the country's drilled exploratory wells and gas fields to identify new prospects across the Bengal Basin.

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