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# New Prospect Delineation at Shallower Depth in a Producing Gas Field of Bangladesh using 3D Seismic and Wireline Log Data

**Janifar Hakim Lupin [1], SM Mainul Kabir[1] *, Md Mostafizur Rahman [1], Syed Humayun Akhter [1,2] and Badrul Imam [1]**

[1] Department of Geology, University of Dhaka, Dhaka 1000, Bangladesh
[2] Bangladesh Open University, Dhaka, Bangladesh

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**ABSTRACT:** The Chittagong-Comilla-Sylhet regions of the Chittagong-Tripura Fold Belt host most of the gas fields in Bangladesh, primarily within the anticlinal structures. The Tertiary Bhuban and Boka Bil formations are the key hydrocarbon-bearing zones where hydrocarbon has been encountered at depths ranging from 1000 to 4000 m in various producing gas fields. The study aims to analyze the hydrocarbon prospects in the shallower stratigraphic successions, particularly the upper part of the Boka Bil Formation in a commercial gas field in Bangladesh where gas is being extracted from depths of 3000–4000 m. Utilizing 3D seismic and wireline log data, we assessed the shallower prospective zones above the conventional producing depth, extending up to 2000 m, which have not yet been explored for hydrocarbon potential in the field. In the study, a classical interpretation approach, precise horizon mapping, and application of various seismic attribute analysis techniques are used to highlight amplitude anomalies indicative of gas accumulation. Results suggest the existence of a new gas-bearing zone with an estimated resource potential of approximately 23.75 billion cubic feet (BCF). Correlating the new prospective zone with the similar geologic features (channel bounded strata showing higher reflection) observed in deeper producing zone of the field enhances the confidence of our findings. This study may open new prospecting avenues for exploration in the studied field as well as the adjacent fields.

**Keywords:** Shallow Hydrocarbon; Seismic; Attributes; BokaBil; Reflection; Bhuban; Reserve; Estimation

## INTRODUCTION

The studied structure is one of Bangladesh's crucial commercial gas fields, where an International Oil Company (IOC) now operating. The gas field is in the Comilla district and is housed in one of the anticlines of the eastern fold belt (Fig. 1). This field has been producing since 2006 and is essential in contributing to the national gas grid. This field has been producing gas from sand bodies at a deeper zone (3000-4000 m). The leading producing sand is 'D sand' (gas sands are designated as A to E, Well completion report, Bangora) of the Bhuban formation of the Surma Unit. The depth range of proven gas-bearing sands is about 3000-4000 m. No gas zone has been identified from the vertical sequence above, including the BokaBil section.

However, considering the inherent characteristics of the alternating sand-shale sequence within BokaBil sequences above the production zone, it potentially indicates a viable opportunity for conducting prospect analysis within the interested zone. Fine-tuned seismic interpretation of the sedimentary sequences within the BokaBil sequence can very well do this.

The availability of 3D seismic sections and wireline logs of the particular gas field area has facilitated the present research. The study is based on the 3D seismic interpretation of the shallower part of the sedimentary sequence aided by wireline logs. The area of focus has been the sedimentary section up to 1.5 sec, especially

*Corresponding author: SM Mainul Kabir
Email: smkabir@du.ac.bd

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the part stratigraphically equivalent to the BokaBil Formation. In this depth range, highly reflected zones are targeted in seismic sections. Along with it, direct hydrocarbon indicators are looked for and, if found, are targeted for further analyses have also been adopted. All these draw our attention toward the possible gas accumulation at a relatively shallower part of the drilled section in this field.

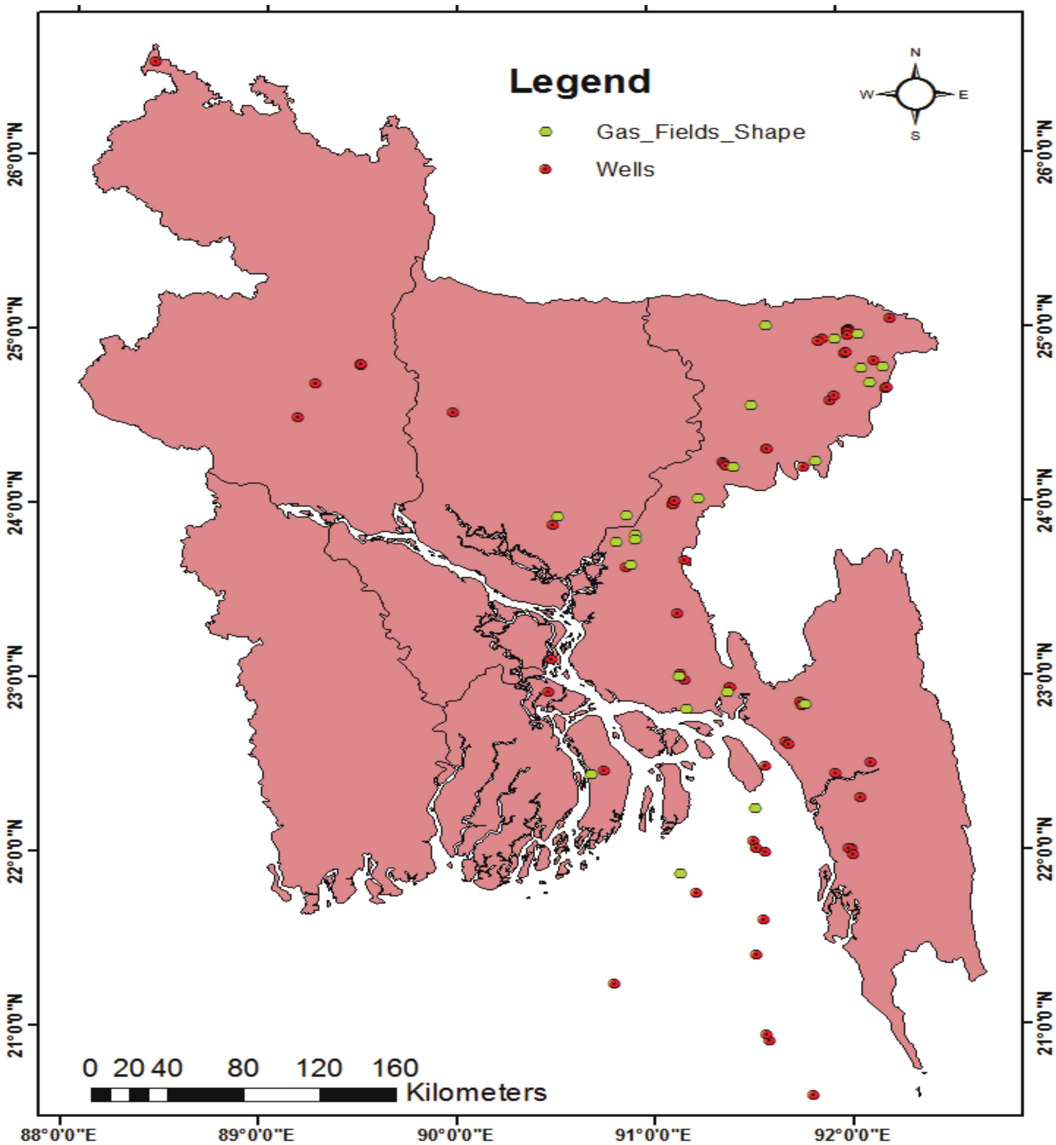



**Figure 1:** Map Showing Gas Fields of Bangladesh, Black Star One is the Studied Gas Field

## GEOLOGICAL SETTINGS

The studied structure is located tectonically in the transition zone of eastern fold belt part of Bengal basin and foredeep part of Bangladesh. It is in the western extremity of the Tripura fold belt of the Bengal basin (Najman et al., 2012). The intensity of the fold belt decreases from east to west as the zone is near the collision boundary of the Indian and Burma plates, and finally, it merges with the flat foredeep zone of Bangladesh (Salt et al., 1986).

Tectonically the area is located between two depressed areas, Surma trough in the north and Hatia trough in the south and in the transition zone of Barisal- Tripura high and Tripura uplift (Lindsay et al., 1991) (Fig. 2). Bengal Basin being in the north-eastern margin of Indian plate experienced many deformation events due to tectonic instability as major deformations occurs at plate boundary zones (Najman et al., 2012). Although the eastern fold belt zone is composed of anticlines forming hills and synclines forming valleys, the study area has no surface expression of folding rather the sedimentary layers are folded in subsurface. So, the area contains subsurface series of anticlines and synclines which form the structure of potential hydrocarbon zones.

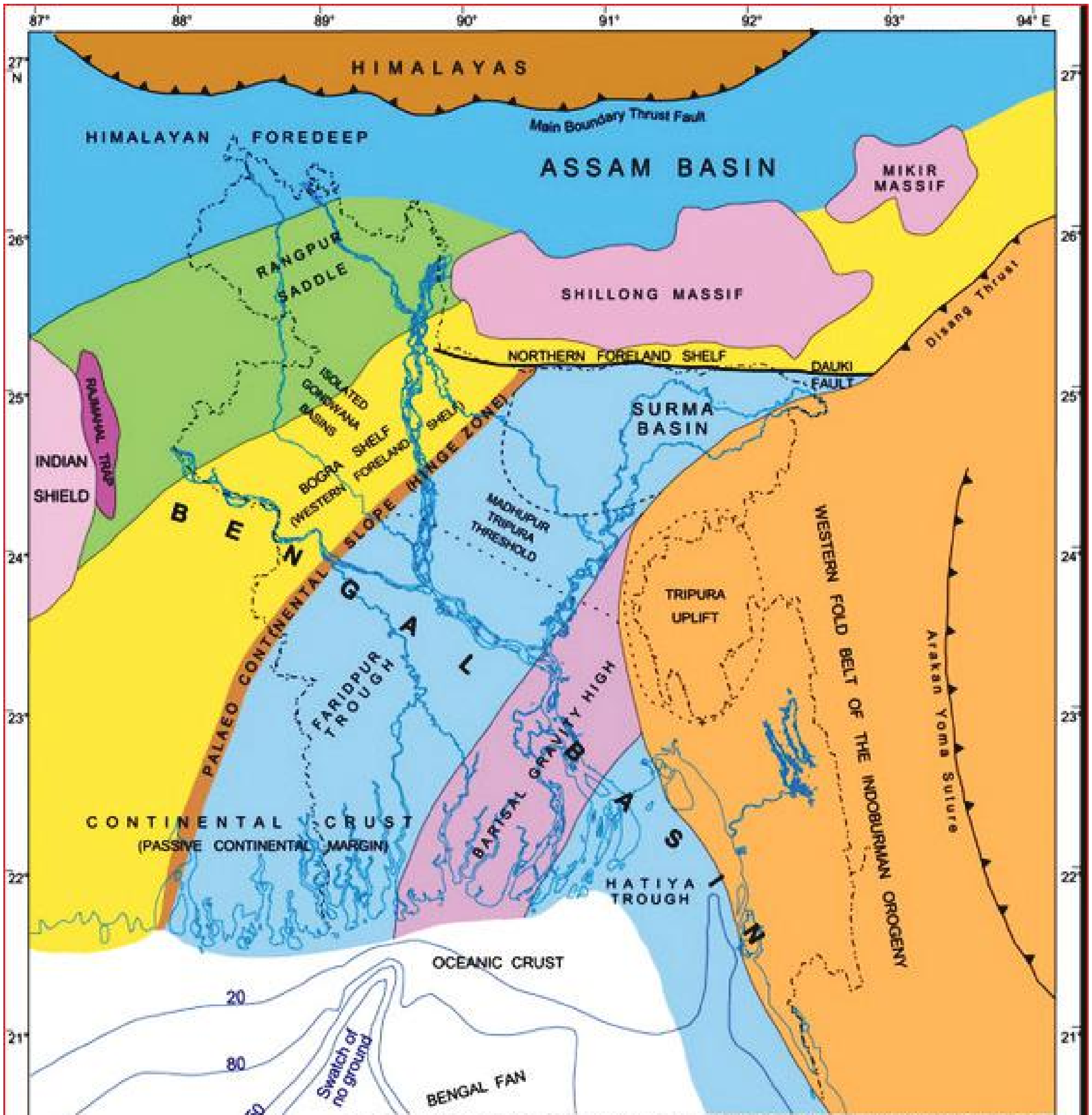



**Figure 2:** Tectonic Map of Bangladesh and Adjoining Areas (After Guha 1978, GSB 1990, Reimann 1993)

The study area lies within the geosynclinals part (Hatia trough) of the tectonic framework in Bangladesh (Fig. 3). It is surrounded by some pronounced gas fields situated in the southern end of Tangail-Tripura high. The folding of that area occurred at a very recent date. The depositional environment may be deltaic to fluvial. The identified prospect is an elongated NNW-SSE trending anticline with a number of subsidiary culminations. It is part of the great Lalmai structure, where it is already producing gas, and Lalmai is on the verge (Abdullah et al., 2013).

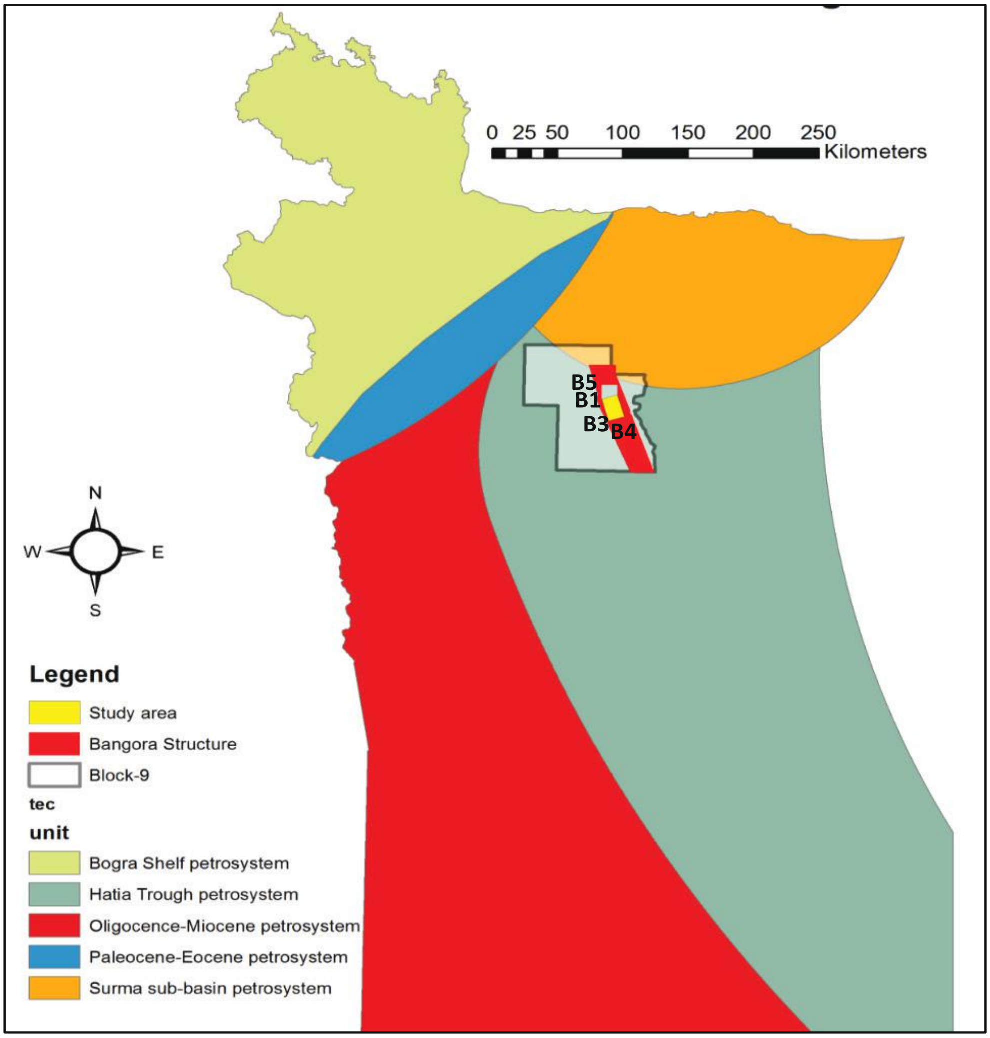



**Figure 3:** Tectonic Units and Associated Petroleum Systems of Bangladesh. The Studied Area is Marked by Box with in the Map. B1 to B5 are the Well Locations Over the Studied Structure

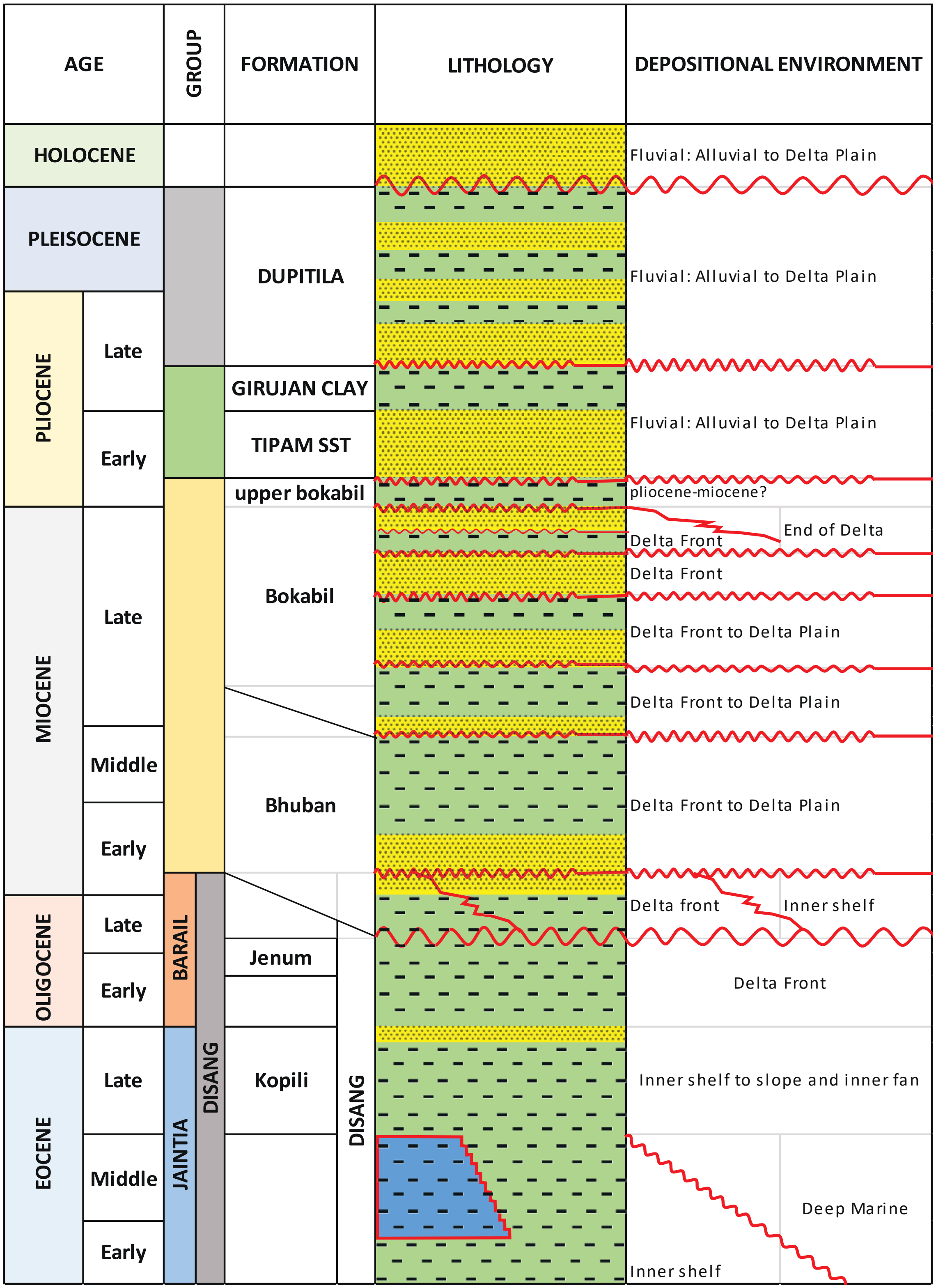
## STRATIGRAPHY

The stratigraphy of the study area is similar to the eastern fold-belt. It is characterized by an enormous thickness of Tertiary sedimentary succession, mainly deltaic to fluvial deposit. The stratigraphy of the area was established with the help of systematic lithological description derived from drilled section, core data, log data, seismic data, and correlation with neighboring wells (Srikail 1; Srikail 2). The stratigraphic succession is summarized in Table- 1.

## DATA AND METHODS

The study area of the research work was confined to Block 9 of Bangladesh. The seismic section contains 3D multichannel seismic profiles covering the entire study and adjoining areas. However, the area of research was limited to only a specific structure covering inline no 80 to 670 and crossline no 100 to 900 defined by a polygon created in Kingdom Suite, and the two-way travel time limit was 1.5 seconds. The area of study is 220.014 square km. The inline spacing of the bin is 30 m, and the crossline spacing is 15 m (Fig. 4).

**Table 1:** Stratigraphy of the South-Eastern Basinal Area (Modified After Unpublished Paper of Petroleum Potential and Resource Management by Norwegian Petroleum Directorate, 2001, also Nomenclatures are Adopted from Curray, 1991 and Evans, 1932)



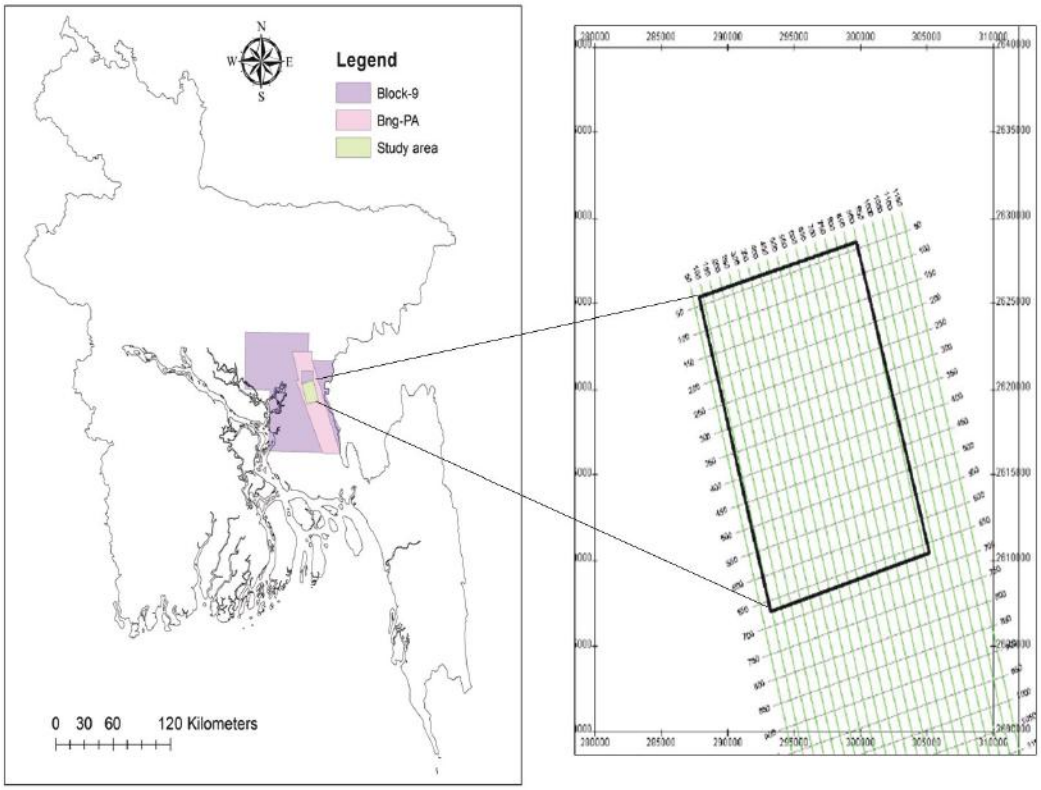



**Figure 4:** Polygon Limiting Working Area of the Research with the Block 9 of Bangladesh

The available wire line log from well 1 was used to tie with seismic section to produce synthetic seismogram as a seismic-to-well tie is an indispensable part of relating the time-domain data with depth-domain data. In shallow depth, the sonic log is not available for the wells. However, sonic log, density logs are necessary to produce a synthetic seismogram (Zhao B.L. 2008). Hence, the check shot data and the density logs were used to derive a sonic response for the shallower depth (Within 2000m depth). From the synthetic, it was found that the seismic response exactly matches the well response. Further procedures were carried out after the correlation. The selected horizons are mapped carefully and boundary polygon are extracted to calculate the area coverage. Finally, petrophysical parameters from the closest structure (Srikail Wells) are used for reserve estimation. The whole working procedure can be summarized in the following simplified flow diagram (Fig. 5)

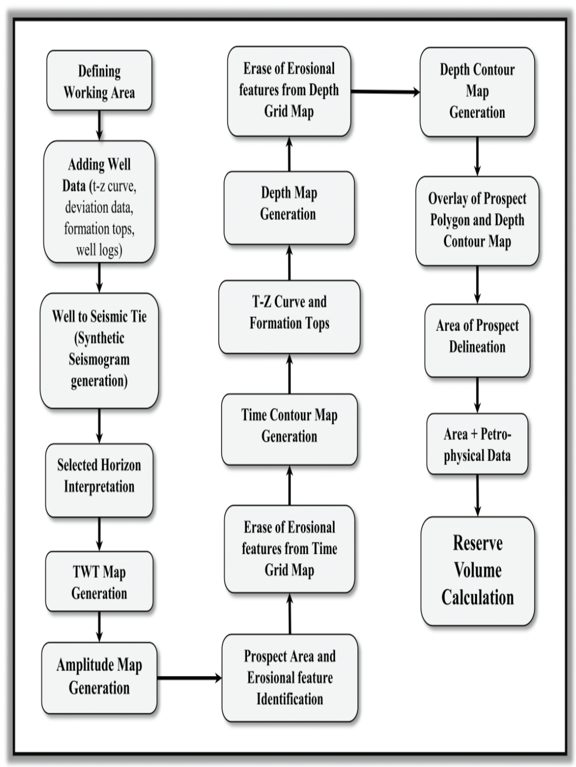



**Figure 5:** A Generalized Flow Diagram to State the Working Steps to Estimate Reserve Volume of the New Prospect

## RESULTS

### Identification of High Reflective Zones in Seismic Section

Five wells are available in the studied area as B 1, 2, 3, 4, and 5. Log data of all wells were matched with synthetic seismograms (Fig. 3, for the well locations). The seismic sections were thoroughly checked, and many high-amplitude reflective zones were identified within 1.5 seconds (Two Way Travel-time, TWT). Some of them were continuous, and some were highly channelized. At deeper depths, the main gas-producing horizons reside. Those producing horizons in deeper depth are found to be bounded by channels and show high reflectance in seismic sections. The channels are mainly mud-filled (mud log report, Hossain et al., 2020), and mud can act as a seal for the hydrocarbons in the adjacent sandy portion of the horizon. So, this feature grabbed much attention during this research work. Moreover, bright spots were identified at shallower depths. Those bright spots and highly reflected zones were the prime targets of study as they can be due to the presence of hydrocarbon because they are at the crestal part of the subsurface anticline.

Seismic sections, along with T-Z curves and log data of individual wells (B 1 to 5), were correlated to define the zone of interest. The research work was limited to the interpretation of two prospective horizons and associated erosional features. For interpretation purposes and to evaluate hydrocarbon potentiality, two particular highly reflective horizons (one flat spot with strong amplitude, Fig. 11) were selected from the correlation of seismic section and well logs (Zone with high negative separation of neutron and density logs). Their position in the time domain is correlated with the nearest seismic sections.

As representative data, wells to some seismic lines are correlated, and the two-way travel time along with true vertical depth depicted from log values are given table 2.

**Table 2:** Depth and Corresponding TWT of Two Selected Horizons in Different Wells and Seismic Lines

| Well No | Seismic Inline Number | TWT of First Horizon (sec) | TVD of First Horizon (m) | TWT of Second Horizon (sec) | TVD of Second Horizon (m) |
|---|---|---|---|---|---|
| 1 | 154 | 1.42 | 1370 | 1.72 | 1810 |
| 2 | 177 | 1.45 | 1360 | 1.74 | 1890 |
| 3 | 333 | 1.44 | 1270 | 1.70 | 1710 |
| 4 | 615 | 1.45 | 1520 | 1.76 | 2220 |
| 5 | 132 | 1.4 | 1750 | 1.72 | 1510 |

### Horizon Interpretation

Two strong reflectors have been interpreted within a 1.5-second time range (Figure 6). The troughs have been identified using well tops and chosen from a well-defined and consistent area of interest. A synthetic seismogram has been utilized to ensure that the seismic signals correlate with the correct events in the well data. The impedance contrast type in the wireline logs can identify the seismic character of each horizon.

One seismic horizon was selected below Tullow Horizon 15 and another below Horizon 20, named 050_H18 (below three sand bodies from Horizon 15) and 060_H21, respectively. Both are Upper Miocene deposits. In seismic trough-peak-trough combinations, horizons are interpreted using seismic troughs. They were calibrated from well 1 and the nearby 3D seismic area, which is summarized in the table 3.

**Table 3:** Characteristics of Interpreted Horizon (Lithology of the Horizons are Taken from Well Completion Report and also from Alam et al., 2019)

| Seismic Horizon | Seismic Event | Quality | Stratigraphic Position | Associated Lithology |
|---|---|---|---|---|
| 050_H18 | Trough | Fair to Good | BokaBil | Very fine to medium-grained, sub-angular, moderately well-sorted sandstone. Visual porosity is not poor; moderate porosity is inferred from abundant loose sand. |
| 060_H21 | Trough | Good | BokaBil | Very fine to medium-grained, sub-rounded to sub-angular, moderately well-sorted sandstone. Visual porosity is not poor; infer moderate porosity from abundant loose sand. |

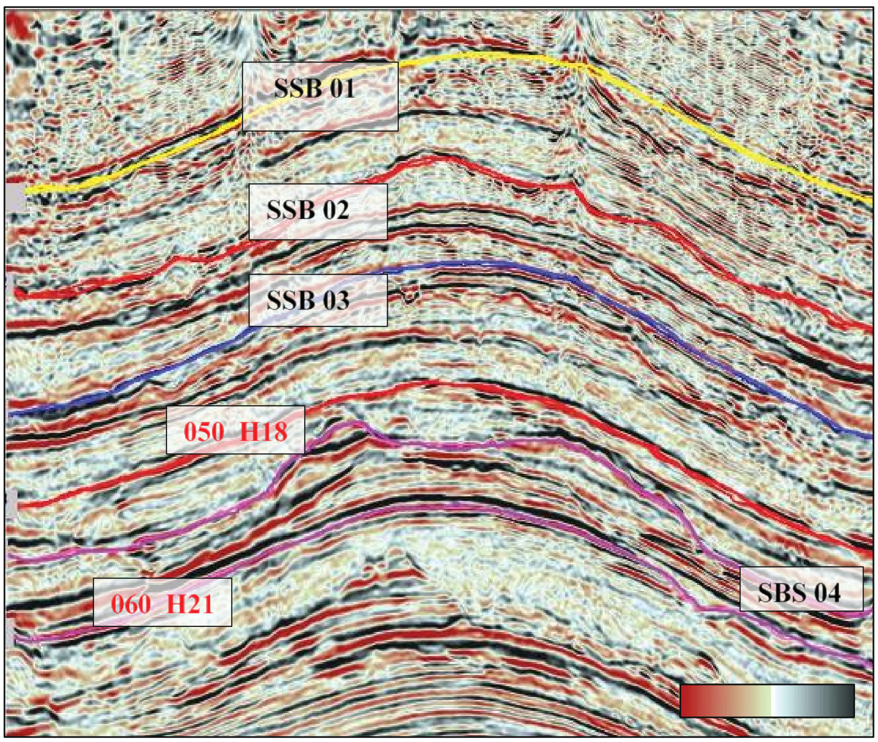



**Figure 6:** Interpreted Horizons along with Sequences within the Four-way Closure Structure. SSB- Sequence Boundary. (Depth Scales are Kept Hidden Due to Data Restriction Policy, Horizons Nomenclatures and Correlation are Done with Existing Well Completion Report of the Same Structure)

In the subsurface sedimentary sequence's horizon 050_H18 lies in sequence 4 (Sequence in between sequence boundaries 3 and 4), characterized by low to moderate amplitude, less continuous reflectors bordered by erosional truncation, and down-lapping internal reflectors (Fig. 6). Whereas horizon 060_H21 lies in sequence 5, depicting moderate amplitude, continuous reflector marked by erosional or channeling feature, SB-04 is low to moderate amplitude, less continuous reflector bordered by erosional truncation (Figs. 6 & 7)

## Horizon 050_H18

050_H18 is an almost continuous shallow reflector all over the study area and eroded in some places due to channels. The horizon was interpreted using a negative loop or trough in the seismic section. As the time pattern is almost homogeneous, no sharp contrast in time is found, so it can be said that the horizon is unaffected by faults.

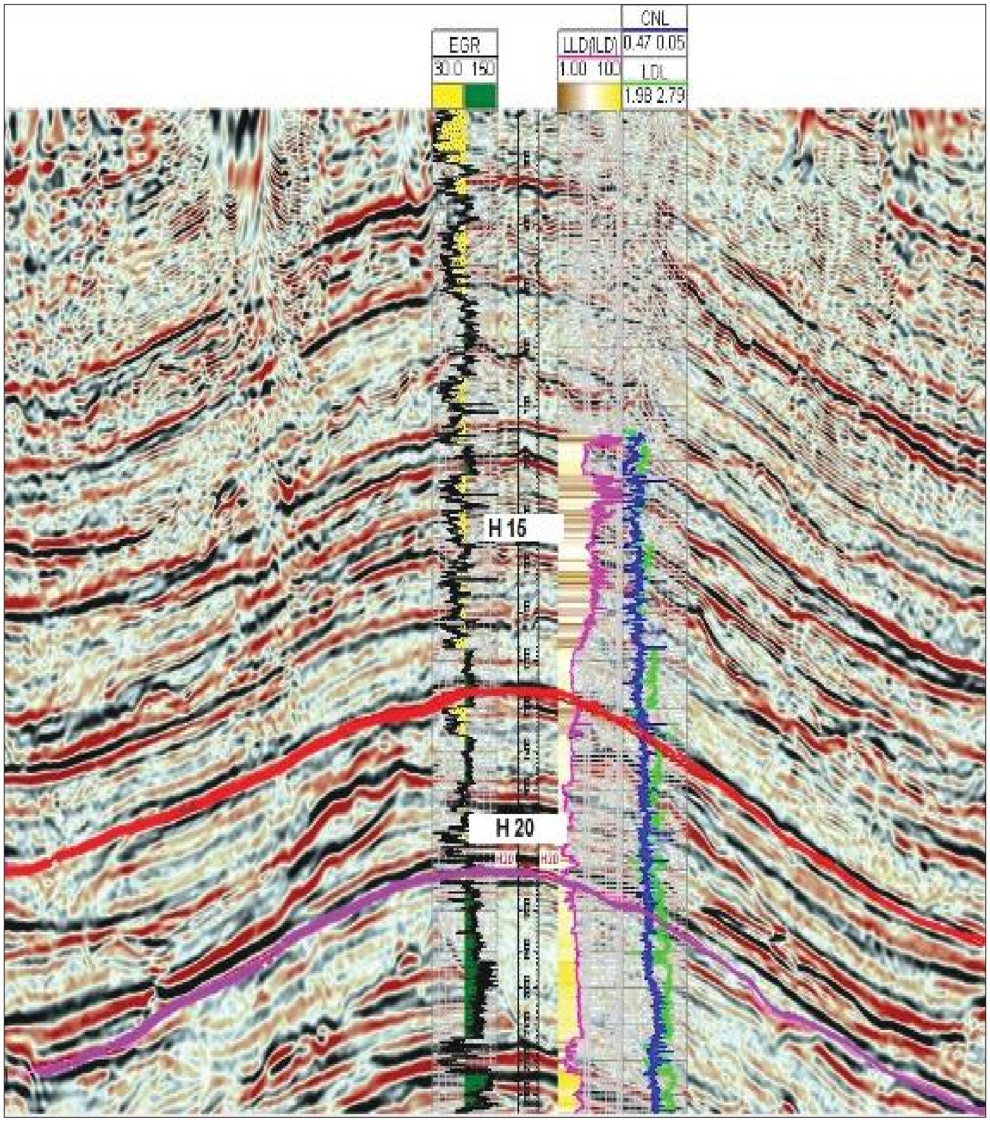



**Figure 7:** Interpreted Horizons along with Sequences on Synthetic Seismogram of Well 1. SSB- Sequence Boundary. (Depth Scales are Kept Hidden Due to Data Restriction Policy, Horizons Nomenclatures and Correlation are Done with Existing Well Completion Report of the Same Structure)

In a two-way travel time map, the horizon shows a time range of deposition within 1.066 to 1.621 seconds. The pattern of the TWT map (Fig. 8) shows that the structure is an elongated anticline trending NNW-SSE at this level. The eastern flank shows a higher time fluctuation than the western flank.

## Horizon 060_H21

Due to channels, 060_H21 is a completely continuous shallow reflector throughout the study area and comparatively less eroded than 050_H18 (Figs. 6 & 7). It was also interpreted as a negative loop or trough in the seismic section. The horizon is also unaffected by fault, as a sharp contrast in time is absent here.

In a two-way travel time map, the horizon shows a time range of deposition within 1.434 to 1.955 seconds (Fig. 9). The pattern of the TWT map shows that the structure is an elongated anticline at this level trending NNW-SSE. The eastern flank shows a higher time fluctuation than the western flank. The structure is not affected by any fault at this level.

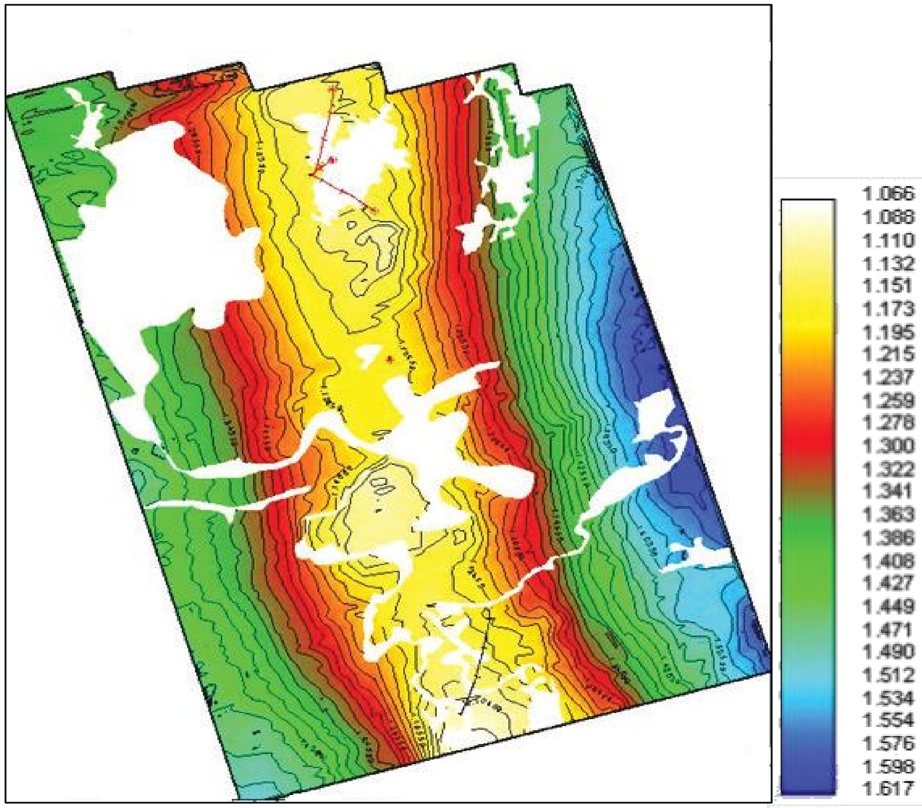



**Figure 8:** TWT Map of the Interpreted Horizon 050_H18 TWT Map of the Interpreted Horizon 050_H18

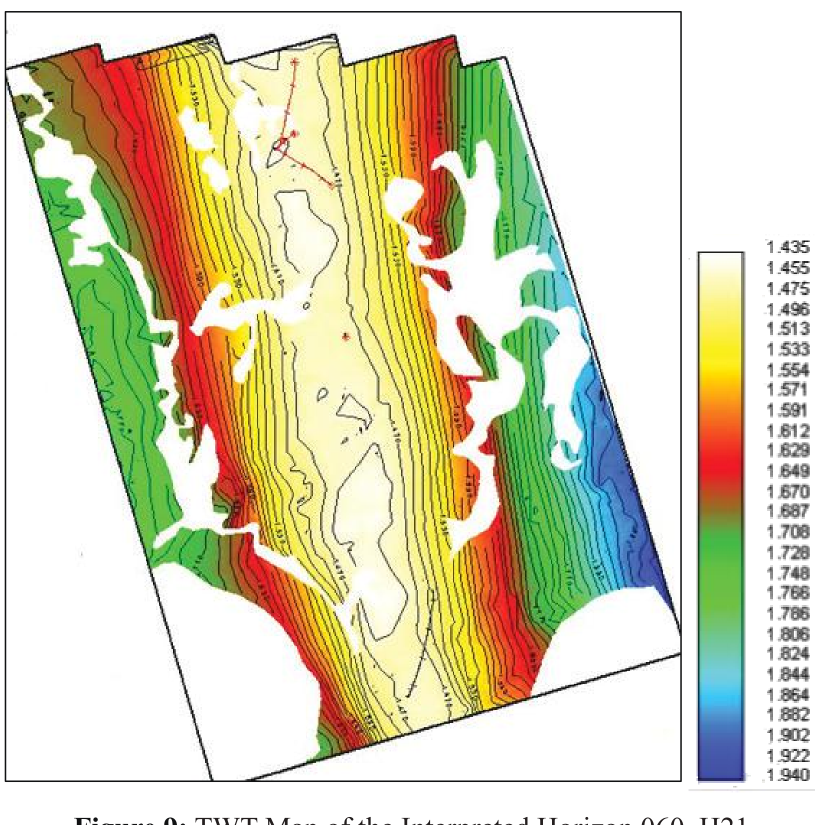



**Figure 9:** TWT Map of the Interpreted Horizon 060_H21

## Amplitude of Horizon 050_H18

An amplitude map of horizon 050_H18 was created on a scale of 1:50,000. Here, the amplitudes are absolute amplitudes with positive and negative values, where the positive amplitude value corresponds to low amplitude and the negative amplitude value is high amplitude. The amplitude value ranges from (-6.847 to 3.691). A negative amplitude value is essential for demarcating hydrocarbon prospective areas, and positive values are important for demarcating channel and eroded areas.

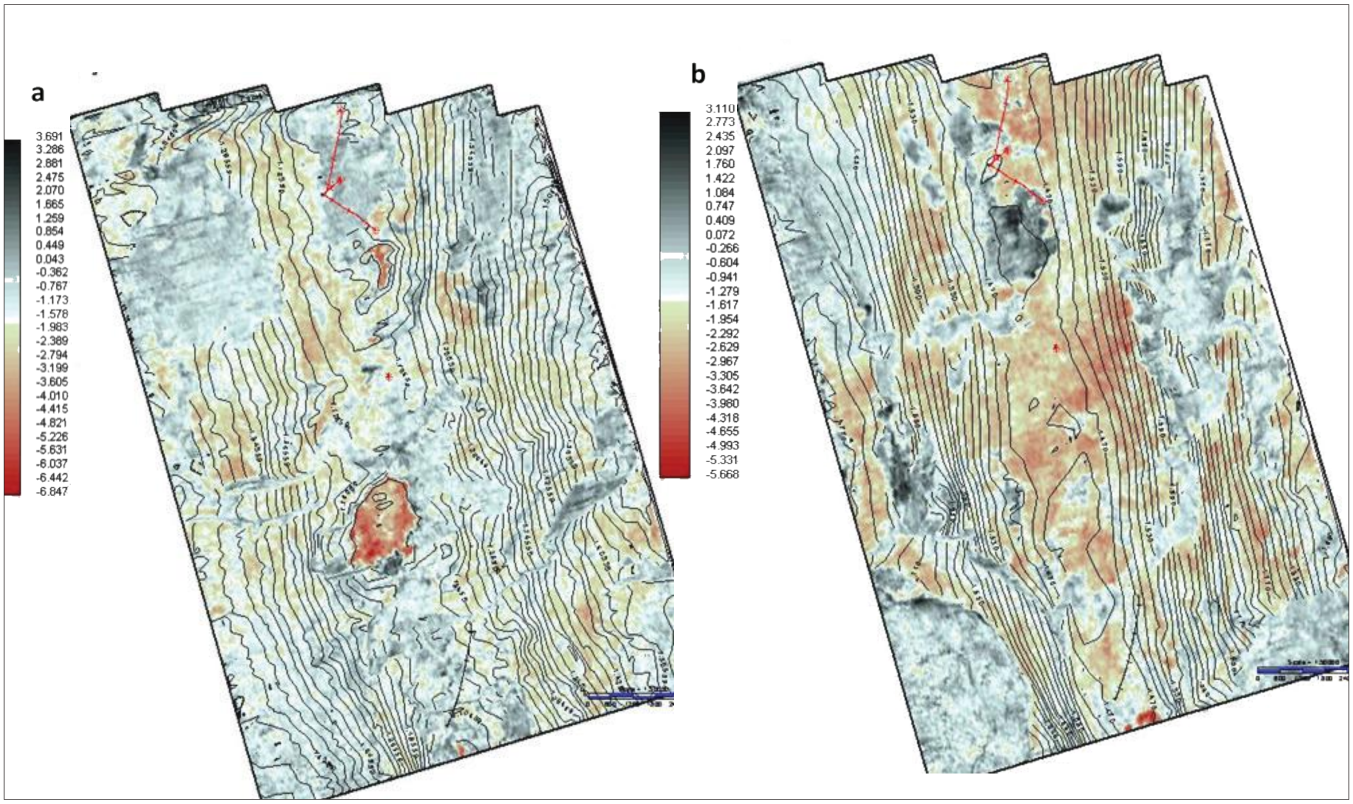



**Figure 10:** a) Time Contour on Amplitude Extraction over the Interpreted Horizon 050_H18; b) Time Contour on Amplitude Extraction over the Interpreted Horizon 060_H21

Horizon 050_H18 shows some high-amplitude zones identified by the maximum negative value of absolute amplitude (-6.847) two distinct areas with the maximum negative amplitude value formed closure. One is immediately south of well 2 and northeast of well 3, named the northern high-amplitude zone. After overlying the time contour map on the amplitude map, it is seen that the north of high amplitude formed a time closure between 1.106 and 1.126 seconds (Figure 10 a)

Another high-amplitude zone (maximum negative value in amplitude scale) was identified in the southern part of the study area. The zone is named Southern High Amplitude, southwest of Well 3 and northwest of Well 4. The southern amplitude formed a time closure between 1.106 and 1.126 seconds, found after the overlying time contour over amplitude (Figure 10 b).

The northern and southern high-amplitude areas are associated with a subsurface flat spot with strong amplitude (Figure 11) formed at the crestal part of the structural anticline. A bright spot in the crestal part of the structure and the corresponding occurrence of a maximum negative value (high amplitude) in the absolute amplitude map indicate the possible accumulation of natural gas.

## Amplitude of Horizon 060_H21

The amplitude map of horizon 060_H21 was also created on a 1:50,000 scale. The absolute amplitude value here ranges from (-5.668 to 3.110). The horizon does not possess any direct hydrocarbon indicator (Bright spot, dim spot, or flat spot) in the seismic section. Instead, it shows continuous high reflection in the study area.

As a signature of that, no maximum negative amplitude closure has been observed in the absolute amplitude map. The study area shows a continuity of high amplitude in the central, northeastern, and southwestern parts (Fig. 10 b).

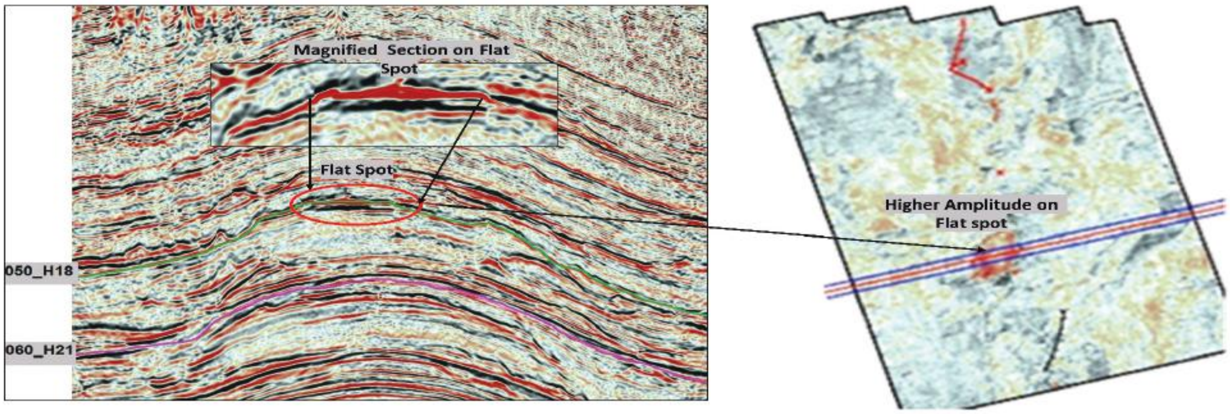



**Figure 11:** A Random Profile Showing the Bright Spot on the 050_H18 Interpreted Horizon, Corresponding Higher Amplitudes also Justify the Reflection Anomaly on the Zone

A surprising feature was identified here at this level of structure. A characteristic channel pattern with high amplitude in the southwestern part was encountered as a channel. The channel is extensive, covering almost the whole western of the study area, trending NNW-SSE. The southern part of the channel may show high amplitude, whereas it is dim and shows low amplitude in the northern part. This phenomenon drew our attention for further investigation.

## Wireline Log Signatures of Selected Horizons

The Electrical Gamma Ray log, Resistivity log, Density log, and Neutron log signatures of all five wells (B1 to B5) were studied thoroughly after interpreting horizons and their amplitudes. From log signatures, it was identified whether the high-amplitude zone is shale or sand body and whether it has high resistivity. The negative separation of neutron Density draws our attention to the possible presence of hydrocarbon in that horizon. Details are explained in the figures 12 (a, b and c).

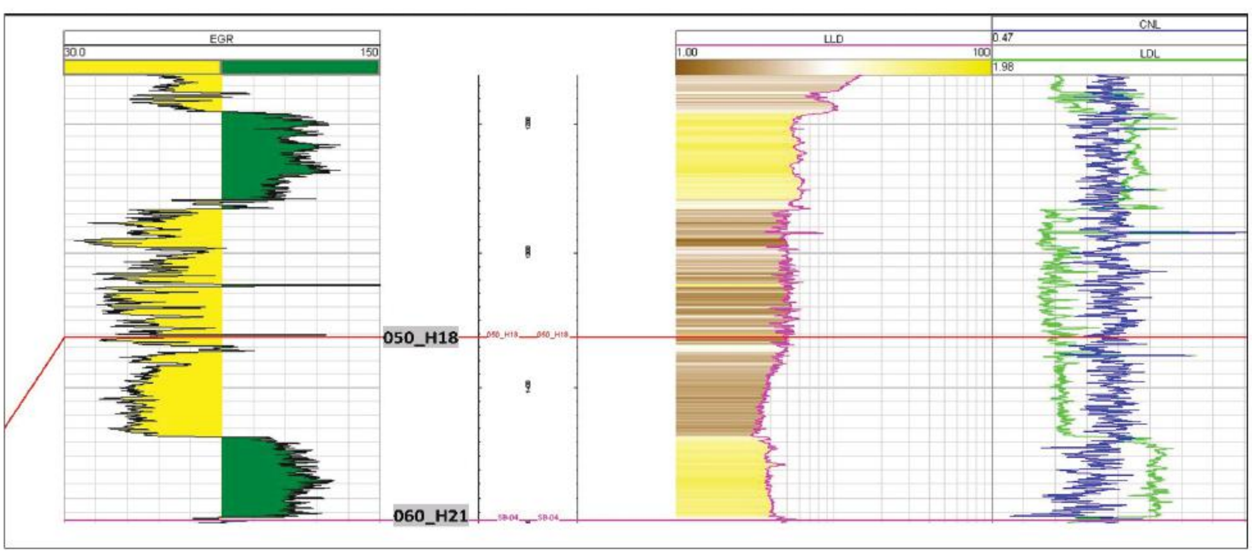



**Figure 12:** a) Well 01, the Gamma Ray Values of the Horizon 050_H18 are about 30 API, Depicting a Sand-filled Nature. Resistivity is Comparatively Very High, and Neutron-Porosity Cross-plots Show Negative Separation, Indicating Possible Hydrocarbon Accumulation

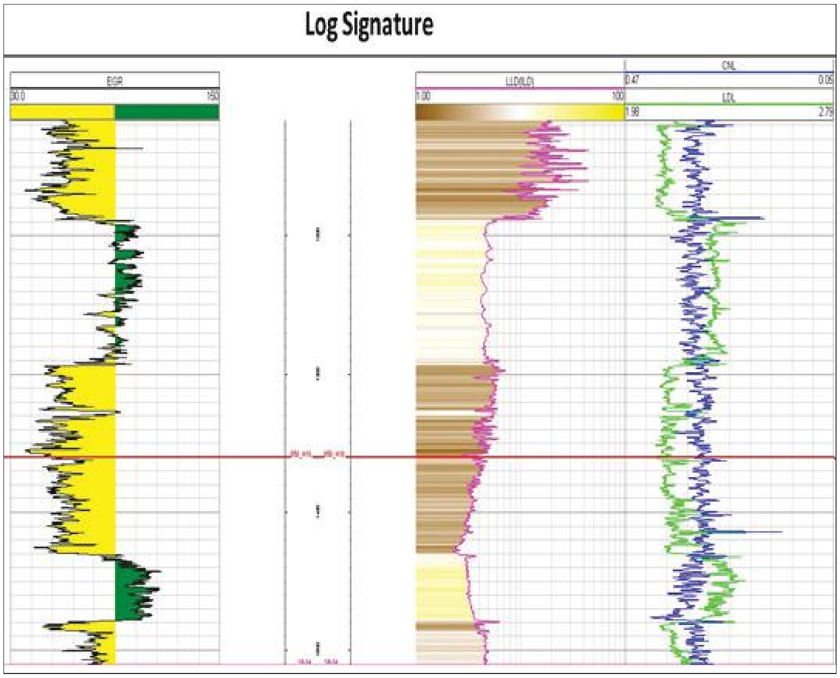



**Figure 12:** b) Well 02, the Gamma Ray Values of the Horizon 050_H18 are about 35 API, Depicting a Sand-filled Nature. Resistivity is Comparatively Very High, and Neutron-Porosity Cross-plots Show Negative Separation, Indicating Possible Hydrocarbon Accumulation

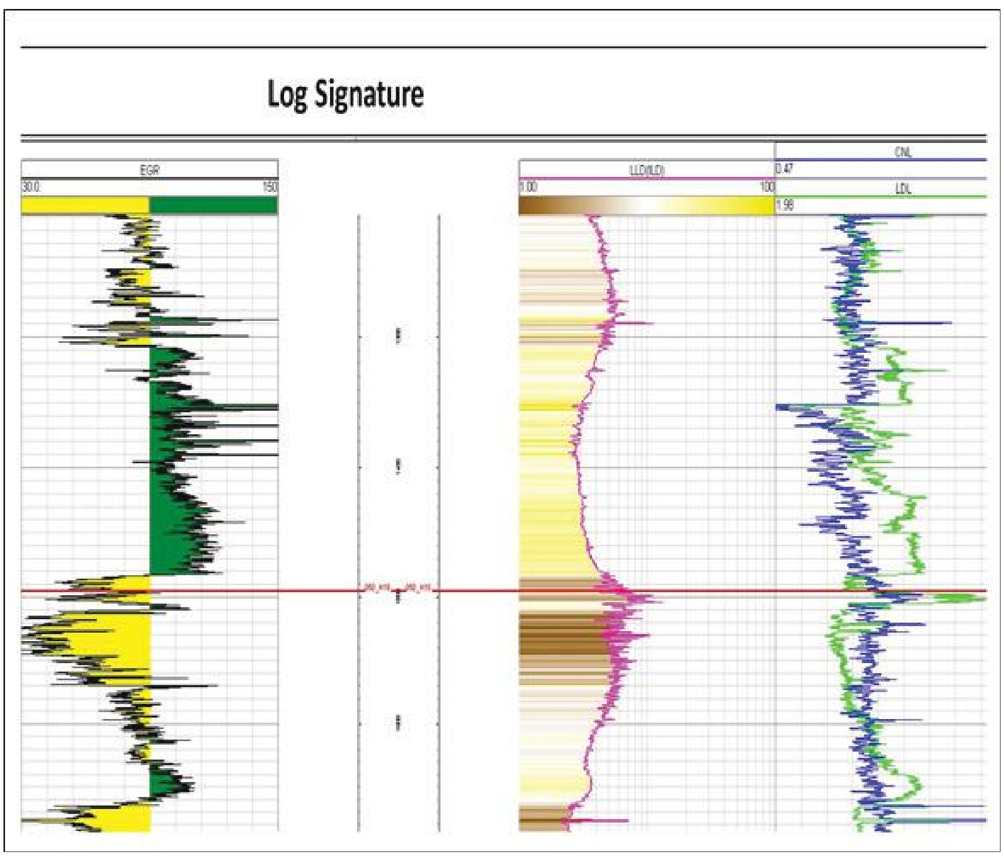



**Figure 12:** c) Well 04, the Gamma Ray Values of the Horizon 050_H18 are about 35 API, Depicting a Sand-filled Nature. Resistivity is Comparatively Very High, and Neutron-Porosity Cross-plots Show Negative Separation, Indicating Possible Hydrocarbon Accumulation

## Volumetric Reserve Estimation

In the case of Volumetric reserve Calculation, the following data are needed:

Formation volume Factor (Bgi) at reservoir pressure, p (ft3/SCF); Water saturation (Sw) at time t (Fraction); Porosity (ϕ) at reservoir pressure, p (Fraction); Reservoir Bulk Volume (Vb); Reservoir Bulk Volume (ft3) = Area of Reservoir (ft2) x Thickness of Reservoir (ft.). Moreover, the following equation is used:

$$G = \frac{V_b \emptyset_i (1-Sw)}{B_{gi}}$$

Where,

G = Gas Initial In Place, Billion Cubic Feet.

Here, the following parameter values have been used for reserve estimation. Petrophysical properties are obtained from the wireline log values and well completion report of the structure.

| Parameters | Min Value | Mode Value | Maximum Value |
|---|---|---|---|
| Porosity ($\phi_i$) | 0.23 | 0.25 | 0.28 |
| Water Saturation ($S_{wi}$) | 0.40 | 0.50 | 0.60 |
| Gas Formation Volume Factor ($B_{gi}$) | 0.008333333 | 0.008333333 | 0.008333333 |

Hence, the volume of gas initially in place was estimated using the values of all three categories of parameters separately.

***Volumetric Reserve Estimation of North Prospect in 050_H18***

Maximum Gas Initial In Place = 6.55 BCF (approx.)

Medial Gas Initial In Place = 5.93 BCF (approx.)

Minimum Gas Initial In Place = 5.36 BCF (approx.)

***Volumetric Reserve Estimation of South Prospect in 050_H18***

Maximum Gas Initial In Place = 45.88 BCF (approx.)

Medial Gas Initial In Place = 41.56 BCF (approx.)

Minimum Gas Initial in Place = 37.23 BCF (approx.)

## DISCUSSION

The primary focus of this study was understanding the occurrence of high amplitude zones observed in seismic sections in the shallow depth (up to 2000m) of a commercially producing gas field, Block 9, Bangladesh. The study area was limited to up to dip line 670. The high amplitude zones are found at a much shallower depth than the main reservoir (3000-4000m). The study was confined to interpreting two high amplitude reflectors in shallow depth compared to reservoir depth concerning their possible accumulation of natural gas.

Two high-amplitude reflectors were selected and interpreted in the shallow depth zone using a negative loop or trough. Stratigraphically, both of them are in BokaBil formation. One of them contains a direct hydrocarbon indicator (bright spot). It is below the Tullow Horizon 15 as 050_H18, depicting its five-million-year age. The reflector is of fair to good quality. It contains three channels and is moderately continuous in the seismic section. The time range of this strata is 1.066 to 1.621 seconds. This structure is affected by three channels at his level in the northwest, center, and south. An eroded surface was also observed in the central northern part. Channels are all mud-filled. Another continuous reflector ranging from 1.434 to 1.955 seconds was selected and interpreted. The reflector is just below the Tullow horizon 20 and hence was named 060_H21, depicting its six-million-year age. The reflector is seismically of good quality. It is almost continuous in a shallow depth, and the maximum part of it shows high amplitude. The structure is affected by two channels at this level.

The absolute amplitude of 2 interpreted horizons was calculated and mapped on a 1:50000 scale. 2 high amplitude zones associated with subsurface bright spots were identified in the amplitude map 050_H18. They occurred in the crestal part of the structure and formed closure. The amplitude map also depicts that the channels are shale-filled. From time slices, it was observed that the bright spot occurred at around 0.09 sec. Areal coverage was maximum at around 1.116 sec and culminated in around 1.132 sec. The absolute amplitude of 060_H21 depicts many high amplitude zones, but none formed any closure. Instead, the channel in the western flank showed spectacular structure. Part of it is sand-filled, and part is shale-filled. Moreover, surrounding areas of the filled part show dim amplitude, depicting shale filled in nature. So, there is a good possibility of forming a combination of structural and stratigraphic traps for hydrocarbon accumulation here. By overlying time contour maps on amplitude maps, it was found that the northern high amplitude zone formed closure at 1.166 seconds and the southern formed at 1.146 seconds.

Using a field compaction curve for all wells, the time of interpreted horizons was converted to depth, and depth maps were created in the 1:50000 scale. From depth maps, it was observed that the structure at the level of 050_H18 is an elongated anticline trending NNW-SSE similar to the structure. From the spacing of contours, it was found that the structure is asymmetric with a steeper eastern flank. The depth of this horizon ranges from1113 to 1954 m. The thickness of two high amplitude zones, north and south high amplitude areas, was calculated by overlying depth contour maps and amplitude maps. From that, it was found that the north and south prospects are 25 m thick.

## CONCLUSIONS

We conducted a thorough 3D seismic interpretation of the gas field to identify new prospects at shallow depths and determine whether the direct hydrocarbon indicators and channel-bounded high amplitude features are indeed associated with the presence of hydrocarbons. The primary objective is identifying potential hydrocarbon reserves, particularly in the BokaBil formations (above the present production limit). Two high-amplitude reflectors were selected and interpreted for this purpose and named 050_H18 and 060_H21, respectively, based on their relative stratigraphic positions. Their two-way travel time, amplitude, and depth were mapped and contoured. From amplitude maps, two high-reflected zones were identified, and they were associated with the presence of a direct hydrocarbon indicator (bright spot). They occurred at the crest of the subsurface anticline and formed closure. In the log signature, the particular horizon also indicates the presence of hydrocarbons, such as high resistivity value and negative neutron density separation. From master logs, it was also found that this zone has gas shows (about 4.5% in well 2). Observing all these, the volume of possible gas reserves was carried out. Two prospects were named north and south. North prospect is at around 1200 m depth and has a GIIP of about 5.63 to 6.55 BCF. The south prospect is at around 1175 m depth and has probable GIIP of around 37.23 to 45.88 BCF.

The interpreted horizons might be prospective for hydrocarbons. A detailed study of the sand distribution map, isochore map, and detailed lithological study is recommended for the further study to prove this prospect with more confidence. Finally, any future well drilling program on this structure might consider this shallow prospective zone for testing along with the conventional deeper prospects.

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