Seismic Data Interpretation of the Rashidpur Anticline: Implications for Structural Analysis and Trapping Mechanisms

Fatimatuzz Zohora Farzana,
Master of Sciences (M.S.), Department of Geological Sciences, Jahangirnagar University.
Rashed Abdullah,
Faculty, Department of Geological Sciences, Jahangirnagar University.

***Abstract*—The Rashidpur anticline, trending N-S, is a surface anticline with reverse faulting located in an area characterised by low hillocks. It is part of the youngest structural province along the western flank of the Indo-Burman Ranges, formed by the oblique subduction of the Indian plate beneath the Burmese plate. Many folds in the area are influenced by faults along their axes. Seismic transect analysis and wireline log data reveal four main reflecting horizons: Lower Gas Sand, Top Bhuban, and Upper Marine Shale. Time contour maps for these horizons show that the Rashidpur structure is an N-S trending asymmetrical anticline with a steep eastern flank. The eastern flank is thrusted and associated with west-dipping faults, though some structures exhibit pop-up features. Well log interpretation identifies gas-bearing sands within the Dupitila to Bhuban Formations.**

The onlapping geometry and thinning of reflectors toward the anticline crest correspond to the Pliocene Tipam and Pleistocene Dupitila Groups, while the base corresponds to the Surma Groups. This structure is interpreted as a syn-kinematic package, indicating that the structural development began in the Miocene. Seismic data interpretation and well information suggest that Rashidpur is a fault propagation fold. Both 2D seismic sections and time contour maps indicate fault-bounded closures to the east, previously unreported. These prospects should be further investigated using 3D data and fault seal analysis to assess the sealing ability of the fault and the potential of fault-bounded trapping mechanisms in the Rashidpur anticline.

***Index Terms*—Bengal Basin, Sylhet Trough, Rashidpur anticline, seismic data, well log, hydrocarbon exploration**

I. Introduction

THE The Bengal Basin shown in Figure 1 is located in the northeastern part of the Indian subcontinent, situated between the Indian Shield and the Indo-Burman Ranges. The Sylhet Trough of northeastern Bangladesh is a tectonically complex province within the Bengal Basin, consisting of a 12 to 16 km thick sequence of Late Mesozoic and Cenozoic sedimentary rocks [17]. The Dauki fault system, characterised by significant vertical displacements, marks the transition between the Sylhet Trough and the Shillong Plateau [12], [17].

The development of the Sylhet Trough is linked to the tectonic evolution of the Bengal Basin, which began following the Gondwana break-up during the Late Mesozoic [5]. Since the Cretaceous, the architecture of the Bengal Basin has evolved due to the collision and movement of major tectonic plates in the region. Three notable changes in basin configuration occurred during the Early Eocene, Middle Miocene, and Plio-Pleistocene times, leading to alterations in both the paleogeographic settings and the source areas [5]. The current configuration, with the Ganges-Brahmaputra delta system to the north and the Bengal Deep Sea Fan to the south, was established during the latter part of the Pliocene and Pleistocene [29], [32], [35].

The Sylhet Trough is considered the most prospective petroliferous province in Bangladesh, hosting several gas fields such as Chattak, Jalalabad, Sylhet, Kailastila, Beani Bazar, Fenchuganj, Rashidpur, Maulvi Bazar, Bibiana, and Habiganj. However, the fold geometry, kinematics, and relative timing of these structures remain poorly understood. Despite all these gas fields producing hydrocarbons from anticlinal traps, fault-bounded traps are also a possibility. Therefore, this research aims to resolve the fold geometry, kinematics, and relative timing of the structure in the Sylhet Trough using wireline logs and 2D seismic transects.

The primary aim of this research is to conduct an in-depth study of seismic data and wireline log data to evaluate the structure and stratigraphy of the study area, focusing on the Rashidpur structure within the Sylhet Trough. One of the key objectives is to provide a detailed description of the geology and tectonic framework of the region, examining the geological history, tectonic evolution, and the forces that have shaped the current structural configuration of the area. This understanding is essential for interpreting the interaction between the Indian and Burmese plates, as well as the implications of these tectonic processes for the region's geological structure.

In addition, the study seeks to develop comprehensive seismo-stratigraphy by interpreting the available seismic data. This will involve identifying the main reflecting horizons and understanding the sedimentary evolution of the area. Another important objective is to delineate the structural style and kinematics of the Rashidpur structure, including an analysis of its fold geometry, faulting, and the deformation processes that have influenced its development. The research will also integrate well log data with seismic data to create a more accurate subsurface model and improve the understanding of lithological distribution. Finally, the study will focus on understanding the trapping mechanisms in the Rashidpur structure, with particular attention to the potential hydrocarbon traps, including fault-bounded traps, which could have significant implications for future exploration effort shown in figure 1.

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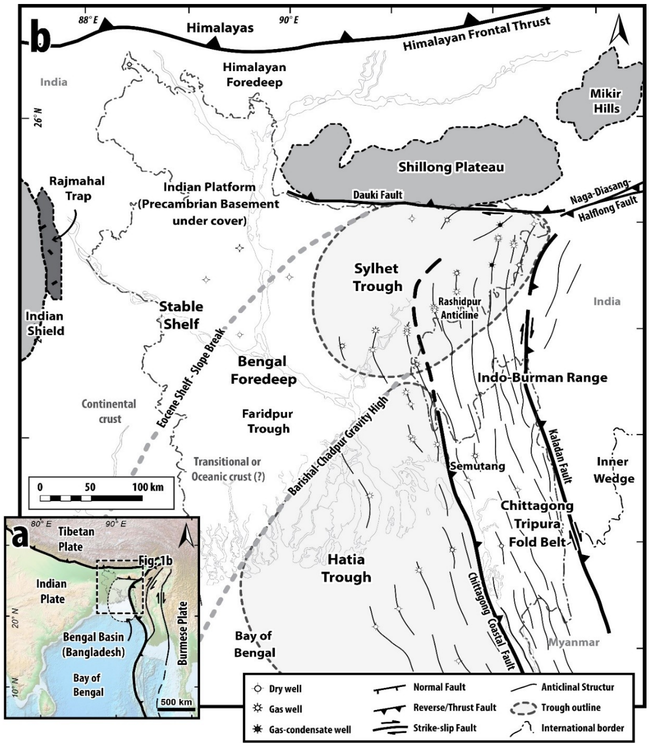

Fig. 1. (a) Map showing the location of the Bengal Basin in the regional context; (b) Location of the Rashidpur (study area) within the regional tectonic frameworks of the Sylhet Trough in the Bengal Basin and its adjoining areas (modified after [2], [5]).

A. Location of the Study Area

The Rashidpur structure is located in the district of Habiganj, approximately 72.5 km SSE of Sylhet and 137 km NE of Dhaka. Geologically, it is a part of the Surma Basin in the Bengal Foredeep tectonic province. The Surma Basin covers an area of about 10,000 square kilometers and extends westward into the Bengal Foredeep, gradually ascending toward the Eocene Hinge Zone. The Rashidpur structure, which trends north-south, is a narrow, elongated anticline measuring approximately 40.25 km in length and 4.83 km in width [27]. It spans latitudes from 24°08’ N to 24°32’ N and longitudes from 91°29’ E to 91°44’ E (Fig. 1). The Rashidpur structure is bounded by the Habiganj and Moulavibazar anticlines to the south, and by the Khowai and Srimangal synclines to the north. Neighboring hydrocarbon-producing structures include Bibiana to the north, Habiganj to the south, and Moulavibazar to the west.

II. General Geology

A. Tectonic Settings

The Bengal Basin is a complex collision foreland basin located to the south of the eastern Himalayan orogen, to the east of the Indian craton, and to the west of the Indo-Burma ranges. All three tectonic units are potential sediment sources for the Bengal Basin [5], [26]. Tectonically, the basin is bounded to the north by the Himalayan foredeep and the Precambrian basement of the Shillong Plateau, to the east by the Burman Margin, and to the west by the Precambrian Indian shield and Cretaceous Rajmahal Traps, while the south of the basin is open to the Bay of Bengal [4], [5]. Based on tectonic style, basin-fill history, and stratigraphy of the Bengal Basin in Bangladesh, it can be divided into three subdivisions [5], [19], [31].

- **Province 1:** The northwest region includes the Precambrian platform (also known as the Rangpur Saddle) and the pre-collisional Stable Shelf (also known as the Bogra Shelf).
- **Province 2:** The central deep basinal parts extending from Sylhet in the north towards Hatia in the south.
- **Province 3:** The eastern region, including the Chittagong-Tripura Fold Belt [7], [13], [19], [29].

The Surma Basin is a geophysically and geologically defined area in northeastern Bangladesh that contains a thick sequence of Tertiary sedimentary strata. It lies to the south of the Precambrian Shillong Plateau, which has been thrust upwards along a footwall of Tertiary sediments. Geologically, the Bengal Basin is divided into the Indian Platform (Stable Shelf) and the Bengal Foredeep, which includes the Chittagong-Tripura Fold Belt and the Surma Basin. The Surma Basin is characterised by a large negative gravity anomaly, minimal topography (5-20 m elevation), and active subsidence [7], [11], [17]. The basin is oval-shaped, covering an area of about 10,000 sq. km, and includes several structural features.

B. Tectonic Evolution

The Bengal Basin’s tectonic evolution is shaped by the interaction of the Indian, Antarctic, and Australian plates, the Burma Plate, and the Eurasian Plate. These interactions have influenced basin formation, sedimentation, and the overall structural development of the region. The thick sediment cover in the Bengal Basin obscures the basement configuration, making it difficult to precisely locate plate boundaries and suture zones [5]. Earlier plate reconstruction models considered the eastern limit of the Indian continental crust along the Hinge Zone, with the oceanic part of the Indian Plate subducting beneath the Burmese plate [3], [5], [15], [34].

The proto-Bengal Basin originated as a rifted basin around 126 Ma, following the breakup of the Gondwana supercontinent [5]. Although the initial separation of the Indian plate from the Australian and Antarctic plates was northwestward during the early Cretaceous, a reorganisation in the late Cretaceous around 90-96 Ma caused a shift towards a northward movement, forming an Atlantic-type passive margin along the eastern edge of the Indian plate [36]. A “Soft collision” occurred between India and the Lhasa Terrane (South Tibet) around 59 Ma, followed by a “Hard collision” in the Middle Eocene, marking the commencement of the Himalayan Orogeny [3], [15], [24] shown in figure 2This period of collision led to the oblique subduction of the Indian Plate beneath the Burmese Plate, and the Bengal Basin became a remnant ocean basin shown in figure 3 [5], [13].

By the Pliocene, the Bengal Basin began to take its present-day shape, with all three tectonic subdivisions beginning to develop [5]. The uplift and exhumation of the Shillong Plateau to the north further contributed to the sedimentation and tectonic evolution of the region [10].

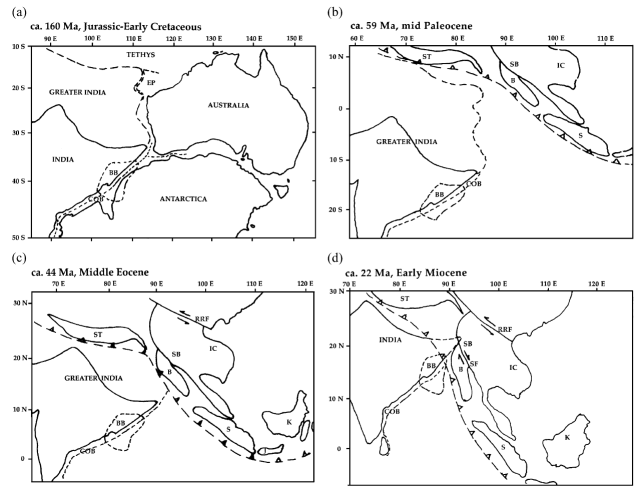

Fig. 2. Plate reconstructions modified mainly from Lee & Lawver (1995). EP= Exmouth Plateau; COB= Continent Ocean Boundary; ST = South Tibet; B = Burma Block or IBA (Indo, Burma, Andaman); SB = SIBUMASU (Siam, Burma, Malaysia, Sumatra); IC = Indochina; S = Sumatra; BB = Bengal Basin; K= Kalimantan; J = Java; RRF = Red River Fault; SF = Sagaing Fault. (a) Eastern Gondwana fit of the margins of "Greater India", Australia and Antarctica. (b) Plate reconstruction at about 59 Ma, Mid-Paleocene, the start of "soft collision" between India and Southeast Asia. (c) About 44 Ma, Middle Eocene, the start of "hard collision" between India and South Asia. (d) About 22 Ma, Early Miocene, a time of major collision between India and South Tibet in the north and India and Burma in the east.

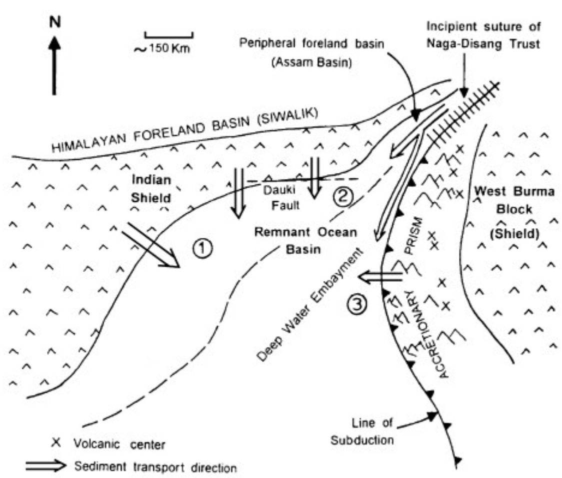

Fig. 3. Schematic Early Miocene Paleogeographic representation of the Bengal Basin and surrounding region in term of the plate tectonic model position of the three geo tectonic provinces of the basin are shown by encircled number (1) The stable shelf, (2) The central deep basin, (3) The Chittagong Tripura Folded belt [5], [6].

C. Stratigraphy

The stratigraphy of the Surma Basin has been largely established based on exploration drilling results since the 1930s [9]. Outcrops are confined to the basin margins, with Paleogene sediments exposed in the northern fringe of the basin, south of the Shillong Plateau. The youngest sediments exposed in the basin are from the Upper Miocene [12]. The Surma Basin's stratigraphic framework shown in Table I has evolved through various sedimentation phases, with limited outcrop data but a comprehensive understanding developed through drilling and seismic surveys.

III. Methodology

A. Well Log

Wireline logs are sophisticated geophysical measurements recorded along a borehole, with the measured values plotted continuously against depth. Common wireline geophysical well measurements include spontaneous measurements like Gamma Ray. In this study, Gamma Ray logs for boreholes RP 03 and RP 04 were obtained from a previous study [8], [18]. The key purpose of Gamma Ray log interpretation is to identify lithology and key horizons, followed by well-to-seismic tie for structural mapping.

B. Seismic Data

Seismic data used in this research were obtained from previous investigations shown in Figure 4 [18]. Fifteen 2-D seismic lines from the study area were analysed, consisting of two strike lines and the remaining as dip lines. An overview of the seismic sections is provided in Table II.

For interpreting seismic sections, seismic marker horizons were selected, and reflection times were picked with care to construct the time structure map using Petrel software. The marker horizons shown in Table III were tied to exploration wells available in the area. Additionally, tectonostratigraphic analysis was conducted by identifying the kinematic packages.

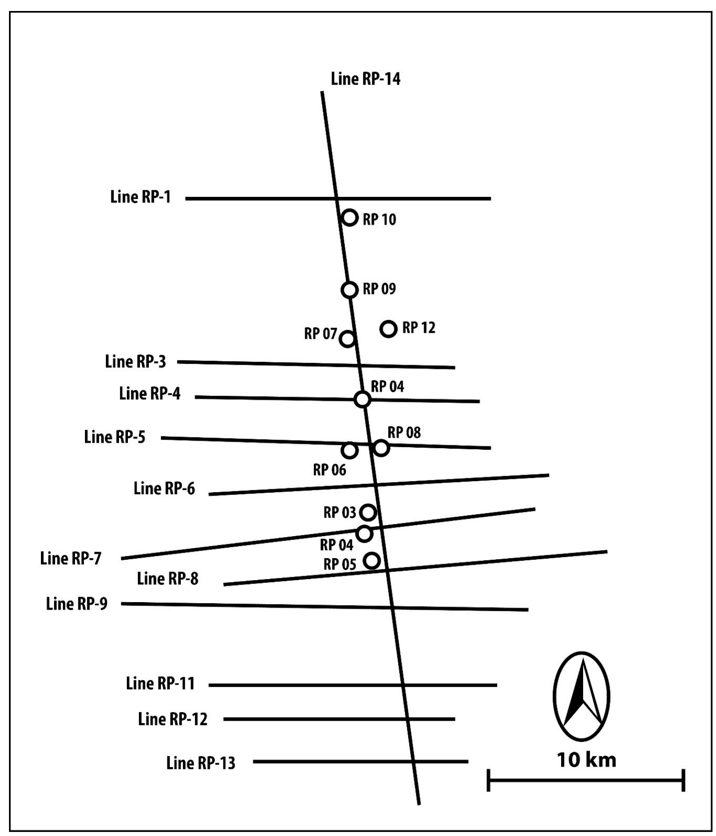

Fig. 4. Location of the wells and seismic transects in the Rashidpur structure

TABLE I
STRATIGRAPHY, LITHOLOGY, AND THICKNESS OF THE SURMA BASIN (AFTER REIMANN, 1993).

Age	Group	Formation	Lithology	Thickness (Max.) in m
Recent	Alluvium	-	Sand, silt, clay, peat etc.	3,350 (Kudhists Trough)
Pleistocene	Dihing	Dihing Formation	Sandstone and pebbly sandstone	-
		Upper DupiTila	Coarse ferruginous sandstones with layers of quartz pebble, a few clay intercalations, and large pieces of petrified wood.	-
Pliocene	Tipam	Lower DupiTila	Cross bedding and cross lamination are common.	-
		Girujan Clay	Alternation of clay, sandy clays, and sandstones, missing in the central Surma Valley, Chittagong Hill Tracts, and Tripura Hills. Shale progressively more common towards the top.	3,500 (Goyain Trough)
		Tipam Sandstone	Mainly coarse-grained to pebbly sandstone with up to 10–20% argillaceous beds. Pebbles consist of Upper Marine Shale, Shillong granite, quartzite, shale, hornblende, quartz, and muscovite.	-
Miocene	Surma	Bokabil Formation	Alternating shales, sandy shale, and fine-grained sandstone, with limestone bands at the bottom.	3,350 (Atgram IX)
Oligocene	Barail	Renji Formation	Predominantly compacted fine to medium-grained sandstones with few intercalated shales.	860 (Atgram IX)
Eocene	Jaintia	Kopili Shale	Dark gray shales with sandstone layers and limestone bands at the bottom.	14–700 (Assam)
Pliocene	-	Cherra/Disang	Not exposed	-

TABLE II
OVERVIEW OF THE SEISMIC SECTIONS OF THE RASHIDPUR STRUCTURE [18], [30].

Sl. No.	Seismic Lines	Coverage	Orientation	Length (km)	Type
01	RP-01	24-Fold	W-E	15.25	Dip Line
02	RP-02	24-Fold	W-E	15	Dip Line
03	RP-03	24-Fold	W-E	15	Dip Line
04	RP-04	24-Fold	W-E	14.5	Dip Line
05	RP-05	24-Fold	W-E	16.5	Dip Line
06	RP-06	24-Fold	W-E	17.75	Dip Line
07	RP-07	24-Fold	E-W	21	Dip Line
08	RP-08	24-Fold	W-E	20	Dip Line
09	RP-09	24-Fold	W-E	20.5	Dip Line
10	RP-10	24-Fold	W-E	15.25	Dip Line
11	RP-11	24-Fold	W-E	14.5	Dip Line
12	RP-12	24-Fold	W-E	12.25	Dip Line
13	RP-13	24-Fold	W-E	10.75	Dip Line
14	RP-14N	24-Fold	N-S	26.5	Strike Line
15	RP-14S	24-Fold	N-S	11.75	Strike Line

IV. RESULTS & ANALYSIS

A. Wireline log interpretation

This chapter attempts to construct a lithostratigraphy of the study area from the well data. To construct litho-stratigraphy, gamma ray logs were used in this research. A short description and interpretation procedure of the logs from boreholes RP 03 and RP 04 are given below.

1) Rashidpur Well No. 3 (RP 03): The gamma ray log from the RP 03 shows relatively lower gAPI values from surface to 1202 m, where the gamma ray value is lower. This indicates that the section mainly consists of sand or loosely consolidated sandstone. The main shale unit is recognised over the interval 1202 to 1389 m. This zone is often silty, where the gamma ray log shows higher values. This zone may be the cap-rock of underlying gas reservoirs. There are two thinner shale units found in logs from 1020 to 1033 m and 1057 to 1100 m, where the gamma ray log shows relatively higher values.

Within the depth range of 1432 to 1737 m and 1905 to 2234 ft, variations in the gamma ray logs indicate alteration of sand-shale sequence with some sandy shale. According to log response, pure shale seems to be found within the depth ranges from 1778 to 1841 m, 2235 to 2353 m, 2380 to 2452 m, and 2625 to 2676 ft. The gamma ray log at these depths shows very high values, indicating the presence of shale.

From the previous investigation [18], two main gas sands were reported. The Upper Gas Sand (UGS) is at depths ranging from 1389 to 1431 m, while the lower one is from 2682 to 2758 m. The thickness of the UGS is 137 ft, and the Lower Gas Sand (LGS) is 250 ft. Within these depth ranges, the resistivity log shows very high values, and SP deflection could indicate a highly porous, permeable formation which may indicate the presence of hydrocarbons at this depth [18]. Information on the additional gas zone and important horizons are given in Table III.

2) Rashidpur Well No. 4 (RP 04): The gamma log response from approximately 91 to 1126 m is characterised by moderate to low gAPI values and indicates possibly sandstones (Fig. 5). Occasional shale layers are also identified by high gAPI within this zone. Sandy shale and/or silty shale is characterised by moderate gamma-ray log values. According to gamma-ray log, alteration of sand, shale, sandy shale, and silty shale occurs at depths of 1126 to 2486 m. Within this depth range, sandy shale is more dominant than others because of moderate to

TABLE III
INFORMATION FOR IMPORTANT HORIZONS IDENTIFIED IN THE WELLS AND TIED WITH SEISMIC TRANSECTS ACROSS THE RASHIDPUR STRUCTURE (RPS ENERGY, 2010).

Well Identifier	Surface	MD (in m)	TWT (in ms)
RP 03	Upper Marine Shale (UMS)	1203.37	1041.84
	Upper Bokabil Sand-1a (UGS-1a)	1389.00	1183.93
	Upper Bokabil Sand-2 (UGS-2)	1462.91	1242.13
	Top Bhuban	2457.62	1874.55
	Upper Bhuban Sand-1a (LGS-1a)	2682.91	1981.52
	Upper Bhuban Sand-2 (LGS-2)	2872.46	2072.99
RP 04	Upper Marine Shale (UMS)	1149.89	1014.66
	Upper Bokabil Sand-1 (UGS-1)	1448.12	1239.89
	Top Bhuban	2352.76	1809.57
	Upper Bhuban Sand-1a (LGS-1a)	2584.93	1928.85
	Upper Bhuban Sand-1 (LGS-1)	2695.94	1983.44
	Upper Bhuban Sand-2 (LGS-2)	2785.77	2026.37

high gamma values. From the gamma ray response, the pure shales seemed to be found between 1126 to 1280 m, 2098 to 2164 m, and 2225 to 2270 m. The depth range from 2486 to 2804 m is characterised by alteration of sand-shale sequence with some silty and sandy shale. The pure shales occur within the depth range from 2530 to 2691 m and 2761 to 2786 m, which are identified by high values of gAPI.

Based on the previous work [18], [30], two gas sands were reported. The Upper Gas Sand is at a depth ranging from 1374 to 1524 m, while the Lower Gas Sand (LGS) from 2696 to 2761 m. Minor clay and shale layers are also found within the zone. Information on the additional gas zone and important horizons.

B. *Interpretation of Seismic Transects*

Fifteen seismic transects of the Rashidpur Structure have been used in this study. However, a description of some important seismic transects is given in the following section.

1) Seismic Transect RP 01: The apparently E-W trending seismic transect RP 01 (Fig. 6) is a dip line that crosses the northern part of the Rashidpur Structure. The length of the transect is approximately 15.25 km. Data quality of the seismic reflection is good, although reflection quality continuously decreases downwards.

Interpretation of the seismic transect RP 01 shows an anticlinal structure at depth. In general, two flanks are dipping in opposite directions (to the east and west). Offset of reflection packages indicates that the anticlinal structure is faulted on both the flanks across this section. Well-developed fault in the eastern flank and relatively weakly developed fault in the western flank together form an approximate positive flower structure or a pop-up structure. The central part of the structure is upthrown, which suggests that both the faults are reverse faults.

Based on lapping geometry, reflection quality, and configuration, two seismic packages can be identified. The lower seismic package is characterised by relatively high amplitude, low frequency, and poorly continuous parallel to sub-parallel reflectors. Borehole information and reflection characters indicate that the package is equivalent to Surma Group and/or older sedimentary rocks. Also note that, all the hydrocarbon-bearing horizons are present within this package. At the top

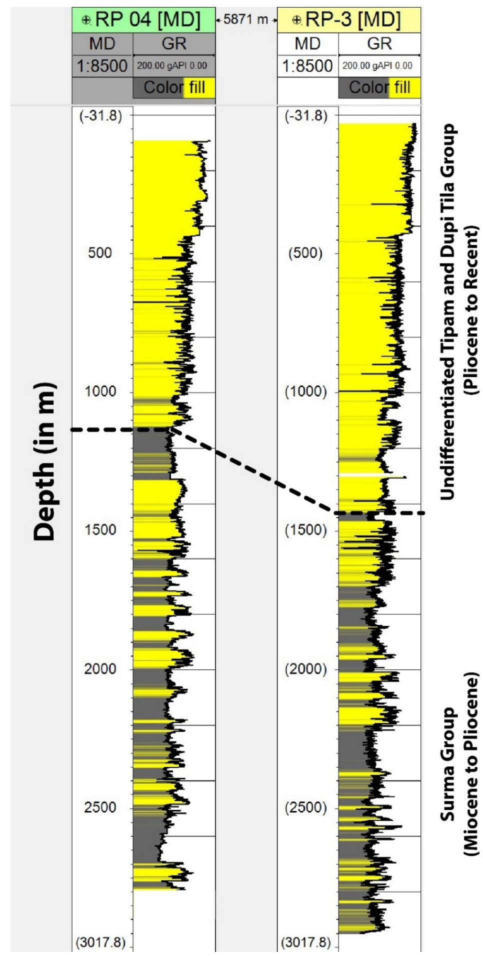

Fig. 5. Gamma ray log response of the well RP 03 and Well 04 and possible lithological interpretation.

of this seismic package, reflection quality is of relatively low frequency and high amplitude, with sub-parallel to parallel reflectors visualising uniform thickness that includes reflections from Lower Gas Sand (LGS) to Upper Marine Shale (UMS). This part of the lower seismic package is mostly correlatable to the Miocene Surma Group (Boka Bil Formation and parts of Bhuban Formation). In general, this lower seismic package shows relatively uniform thickness across the section. Therefore, the package can be interpreted as a pre-kinematic

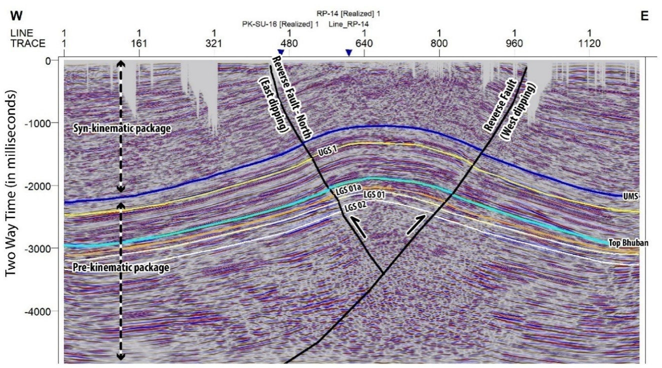

Fig. 6. Interpretation of the seismic transect RP 01 across the northern Rashidpur anticline.

package (i.e., deposited prior to the structural activation).

The overlying reflection package is characterised by moderately continuous, relatively low amplitude, and high-frequency reflectors. This topmost seismic package corresponds to the undifferentiated Pliocene Tipam and Plio-Pleistocene Dupi Tila Group sediments. In general, this reflection package is poorly onlapping above the Upper Marine Shale (UMS) of the underlying package. This reflection package is thickening towards the synclinal parts and thinning towards the anticlinal crest (Fig. 6). This reveals that the upper seismic package was deposited during the time of structural activation (i.e., the syn-kinematic package).

2) Seismic Transect RP 04: The 15 km long seismic transect RP 04 is an E-W trending dip line and passes through the middle part of the Rashidpur Structure (Fig. 7). The overall seismic reflection quality is good, although reflection quality continuously decreases downwards.

Interpretation of the seismic transect reveals an anticlinal structure at depth where the flanks are dipping in opposite directions (to the east and west). Offset of the reflection packages indicates that the anticlinal structure is faulted on both the flanks across this transect as well. Well-developed fault in the eastern flank and relatively weakly developed fault in the western flank together form an approximate positive flower structure or a pop-up structure. The upthrown central part of the structure suggests that both the faults are reverse faults.

Based on reflection quality and lapping geometry, the seismic transect is divided into two distinguished seismic packages. The lower seismic package is characterised by relatively high amplitude, low frequency, and poorly continuous parallel to sub-parallel reflectors. Borehole information and reflection characteristics suggest that the package can be correlated to the Surma Group and/or older sedimentary successions. Moreover, all the hydrocarbon-bearing horizons are present at the top of this package that ranges approximately from 1300 to 2300 ms TWT near CDP 640 (Fig. 7). This part of the lower seismic package is correlatable to Miocene Surma Group (Boka Bil Formation and parts of Bhuban Formation). The lower seismic package can be interpreted as pre-kinematic package (i.e., deposited prior to the structural activation) as it shows relatively uniform thickness throughout the section (Fig. 7).

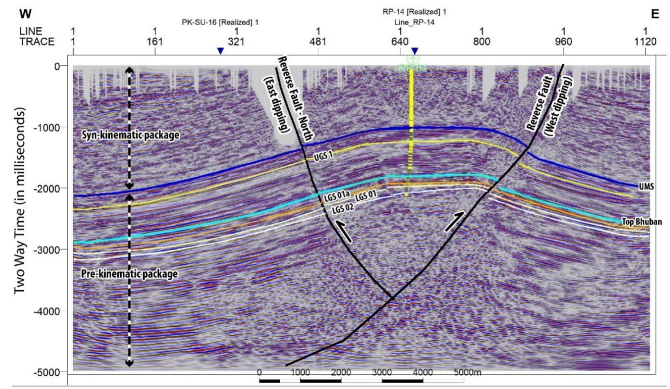

Fig. 7. Interpretation of the seismic transect RP 04 across the middle part of the Rashidpur Structure.

The younger seismic package located above the pre-kinematic package is characterised by moderately continuous, relatively low amplitude, and high-frequency reflectors that are equivalent to undifferentiated Pliocene Tipam Group and Plio-Pleistocene Dupi Tila Group sediments. This reflection package is gently onlapping above the Upper Marine Shale (UMS) of the underlying pre-kinematic package. Moreover, this package is thickening towards the synclinal parts and gently thinning towards the crest of the Rashidpur Structure (Fig. 7) suggesting that the seismic package was deposited during the time of the structural activation (i.e., the syn-kinematic package).

3) Seismic Transect RP 07: The 21 km long E-W trending seismic transect RP 07 is a dip line passing through the central part of the Rashidpur Structure (Fig. 4 & Fig.9). The reflection quality of the seismic section is seen to gradually decrease with depth. Interpretation of the transect RP 07 shows an anticlinal structure at depth with the limbs dipping in opposite directions (to the east and west). Offset of the reflection packages indicates that the anticlinal structure is faulted on both flanks. The upthrown crestal part of the structure suggests that both the faults are reverse faults resembling a positive flower structure or a pop-up structure (Fig. 8).

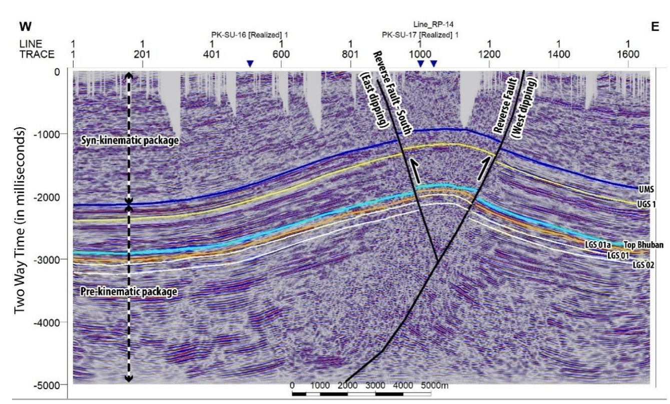

Fig. 8. Interpretation of the seismic transect RP 07 across the middle part of the Rashidpur Structure.

Observation of the reflection quality and lapping geometry aids in dividing the seismic section into two distinguished packages. Relatively high amplitude, low frequency, and poorly continuous parallel to sub-parallel reflectors characterise the lower seismic package. Borehole information suggests that the package is equivalent to the Surma Group and/or older sedimentary rocks. Moreover, the gas zones are also present within this package (Figure 8). The gas-water contact of the Lower Gas Sand (LGS) is found at 2150 m depth [1], [2]. The blue line at the top of the lower seismic package (Figure 8) corresponds to the Upper Marine Shale (UMS), which may act as a seal that inhibits the migration of trapped hydrocarbons. Uniform thickness throughout the package suggests that deposition took place prior to any structural activation and thus can be interpreted as a pre-kinematic package.

The upper seismic package is characterised by moderately continuous, relatively low amplitude, and high-frequency reflectors that are equivalent to undifferentiated Pliocene Tipam Group and Plio-Pleistocene Dupitila Group. Gradual thickening towards the synclinal parts and thinning towards the crestal part suggests that the upper seismic package was deposited during the time of the structural activation and thus can be interpreted as a syn-kinematic package.

4) Seismic Transect RP 13: The E-W trending seismic transect RP 13 is the southernmost dip line passing through the Rashidpur Structure (Fig. 4 & Fig.9) with a length of approximately 10.75 km. The reflection quality of the section is poor, which continuously becomes poorer at the deeper portion of the transect. From the visual interpretation of the section, it is clear that the seismic transect is free from any visible faulting both at the shallower and deeper parts (Fig.9). The section presents an open anticline with a high interlimb angle (Fig.9), suggesting that the southern part of the Rashidpur Structure is free from major compressional forces.

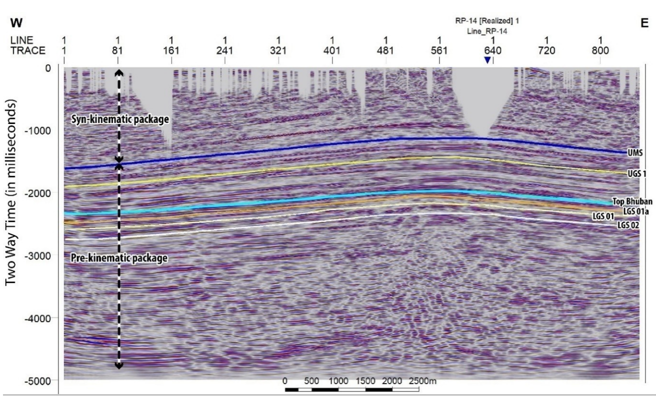

Fig. 9. Interpretation of the seismic transect RP 13 across the southern Rashidpur anticline.

Based on reflection quality and lapping geometry, the seismic section can be divided into two distinguished packages. The lower package shows unclear reflections with high amplitude and low frequency and evenly distributed nearly parallel to sub-parallel reflectors. The gas zones are found at the top of this package (Fig.9). Borehole information suggests that the package is equivalent to the Surma Group and/or older sedimentary rocks. Since the lower seismic package is equally thick across the transect (Fig.9), it can be interpreted as a pre-kinematic package.

The younger seismic package located above the pre-kinematic package is characterised by moderately continuous, relatively low amplitude, and high frequency reflectors that can be correlated to undifferentiated Pliocene Tipam Group and Plio-Pleistocene Dupitila Group sediments. This seismic reflection package is gently onlapping above the Upper Marine Shale (UMS) of the underlying pre-kinematic package, which gradually thins towards the crest from the synclinal parts (Fig.9), hence, can be interpreted as a syn-kinematic package.

5) Seismic Transect RP 14: The N-S trending seismic transect RP 14 is a strike line (Fig. 4 & Fig.10) running parallel to the axis of the Rashidpur Structure. This seismic line passes across all the dip lines (Fig. 3.1). The reflection quality of the section is good at the top, whereas at the deeper parts, the section becomes obscure. The fault splay of RP 03 is visible at the central part of the section, which is absent below 2700 ms TWT (Fig. 4.6). As the seismic transect is a strike line, it is difficult to identify kinematic packages. However, the top of Lower Gas Sand (LGS) is marked at 2100 ms TWT near CDP 1600 (Fig.10). Similarly, 1800, 1300, and 1000 ms TWTs near CDP 1600 represent the top of the Bhuban formation, the top of Upper Gas Sand (UGS), and the Upper Marine Shale (UMS), respectively (Fig.10).

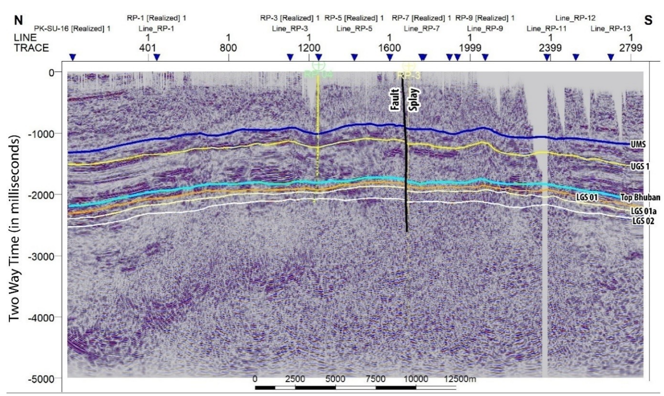

Fig. 10. Interpretation of the strike line seismic transect RP 14 across the central or axial part of the Rashidpur Structure.

Structural interpretation across transect 14 does not provide much information as the line is oriented along the strike. In general, the seismic transect does not show any evidence of structural deformation. However, at the top, the reflectors show clear evidence of plunging both in the north and south directions (Fig.10).

C. Interpretation of Time Contour Maps

Time Structure map is a subsurface map that shows the vertical time interval from a datum to a stratigraphic horizon in a two-way time section. Time structure maps are constructed to display the geometry or structural style of selected reflection times. In the Rashidpur structure, six horizons are mapped at 50 milliseconds time intervals. In the following sections, general descriptions of the five maps are given.

1) Time Contour Map of the Upper Marine Shale (UMS): The time contour map (Fig.10) at the top of the Upper Marine Shale shows an asymmetrical elongated anticlinal structure with two N-S trending reverse faults. Displacements of the faults in the western and eastern flanks gradually diminish to the north and to the south. In the western flank, continuity of the fault is poorly imaged in the middle part. Thus, this reverse fault in the western flank has been interpreted as segmented or a combination of two faults. [16]

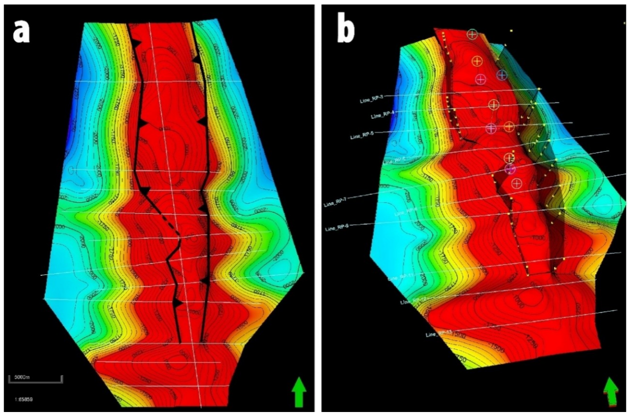

Fig. 11. Time contour map at the top of Upper Marine Shale (UMS).

In general, this time contour map is showing N-S trending anticlinal axis where contours are relatively widely spaced to the north and south. This indicates that the structure is plunging to the north and to the south. The contour spacing is much higher in the eastern flank compared to the western flank, which supports the relatively steeper eastern flank interpreted in the seismic transects. The time map covers a wide depth range that varies between 750 to 2250 milliseconds two way time. The shallowest is the 750 milliseconds two time which occurs along the axial region of the anticlinal axis. The deepest is the 2250 milliseconds two way time and occurs in the synclinal region. The map shows a clear four way closure for the anticlinal trap. Additional small closures against the faults are also possible in the foot wall blocks.

2) Time contour map of the Upper Gas Sand (UGS)): In the Rashipur structure, the time contour map (Fig.12) at the top of the Upper Gas Sand also exhibits an N-S-trending, elongated, asymmetrical anticline structure with two axis parallel reverse faults. The time map covers a wide depth range that varies between 1250 to 2250 milliseconds two way time. The shallowest is the 1250 milliseconds two way time which occurs along the axial region of the anticlinal axis. The deepest is the 2250 milliseconds two way time and occurs in the synclinal region. The map shows a clear four way closure for the anticlinal trap. Additional small closures against the faults are also possibe in the foot wall blocks.

3) Time contour map of the Top Bhuban: The time contour map on the top Bhuban Formation (Fig.13) shows that the time varies between 1750 and 3000 milliseconds two way time. To the east, contours are very narrow, indicating that the eastern flank is steeped in the NW trending Rashidpur ancticline. Similar to the other time contour maps of the area, the structure shows two axis parallel reverse faults.

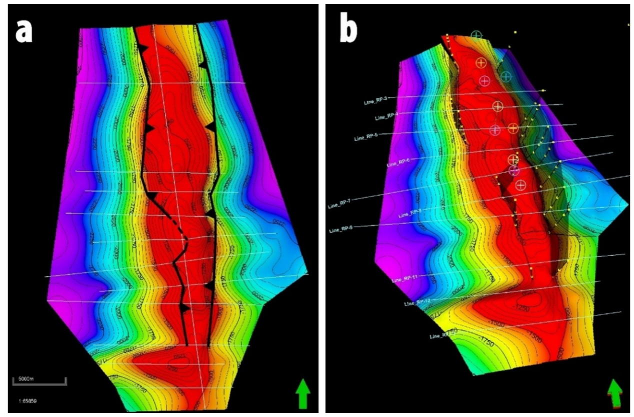

Fig. 12. Time contour map at the Upper Gas Sand (UGS).

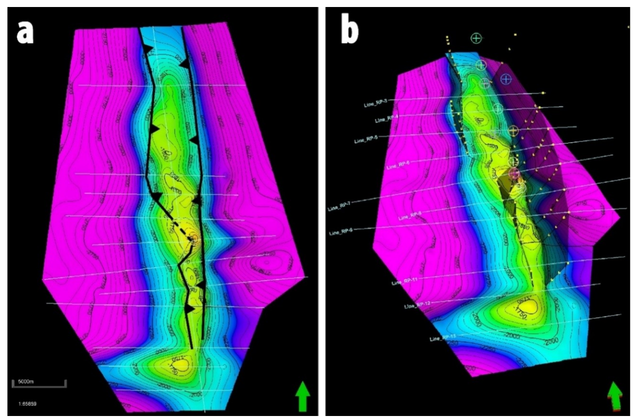

Fig. 13. Time contour map at the Top of Bhuban Formation.

4) Time contour map of the Lower Gas Sands 01a (LGS01a): The time contour map on the top of the Lower Gas Sand 01a (Fig.14) shows that the depth variation from 1850 to 3000 milliseconds two way time. The map indicates a similar asymmetrical elongated anticlinal structure with two reverse faults. A dotted line connecting those two faults in the middle portion of this map (Fig.15), which signifies they are merged or lined in the central part. In general, the displacement of the faults gradually diminishes to the north and south. The map shows a clear four-way closure for the anticlinal trap. Additional small closures against the faults are also possible in the foot wall blocks.

5) Time contour map of the Lower Gas Sands 01 (LGS01): The time contour map on the top of the Lower Gas Sand 01 shows a depth range from 1800 to 3000 milliseconds two way time (Fig.15). The map also shows an elongated N-S trending anticlinal structure. In the contour map, the contours are relatively widely spaced to the north and south, implying that the structure is plunging to the north and to the south. The map shows a clear four-way closure for the anticlinal trap. Additional small closures against the faults are also possible in the foot wall blocks.

D. Structural style and kinematics of the Rashidpur Structure

Based on the interpretation of the seismic transects and time contour maps, the Rashidpur structure can be described as

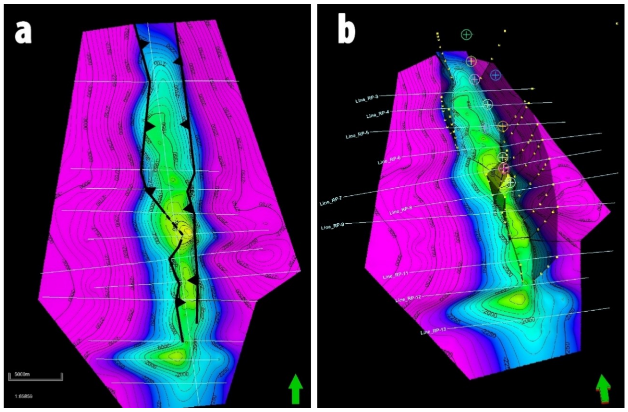

Fig. 14. Time contour map at the Lower Gas Sand 1a (LGS01a).

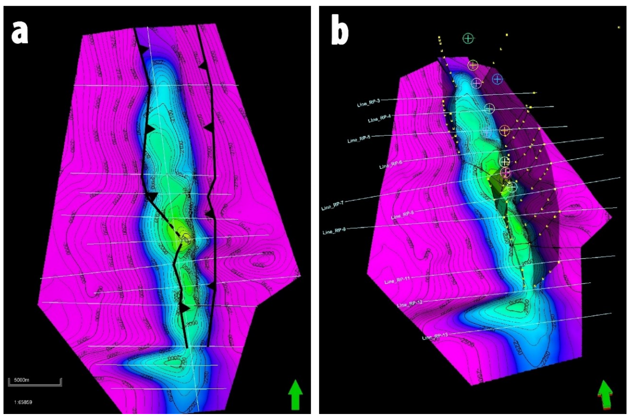

Fig. 15. Time contour map at the Lower Gas Sand 1 (LGS01) of the Rashidpur structure.

an asymmetrical, double plunging elongate anticline with a simple four-way dip closure. The eastern flank is steeper than the western flank. Both flanks of the anticline are associated with reverse faults dipping in opposite directions. General trends of the faults are in NNW-SSE direction, which is parallel to the direction of the fold axis.

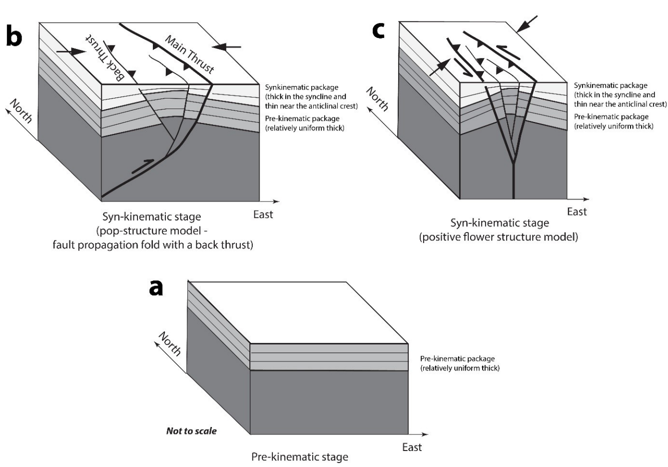

Fig. 16. Schematic Diagram a) pre-kinematic stage b) Syn-kinematic stage (positive flower structure) c) Syn-kinematic Pop-structure model-fault propagation fold with a back thrust

Interpretation of the fold and fault geometry shows that the fold intensity is greater in the middle part of the anticline. The geometry of the faults also varies significantly in space. To the north and the south, displacement of the faults is progressively decreasing. However, the displacements of the faults become highest in the middle. The presence of west and east dipping reverse faults in the Rashidpur anticline resembles a pop-up structure [21] associated with a fault propagation fold model. Alternatively, it can be explained by a positive flower structure (Fig.16). However, results from seismic interpretation of the Rashidpur anticline appear more similar to the pop-up structure model associated with a fault propagation fold, where the west-dipping fault acts as the main thrust and the east-dipping back-thrust fault.

E. Timing of fault activation and tectonic evolution of the Rashidpur anticline

Tectonostratigraphic analysis of the seismic transects across the Rashidpur anticline shows that the parallel to sub-parallel reflection package (below the Upper Marine Shale shown in Fig.6, Fig.7 & Fig.8) corresponds to the Surma Group (or equivalent) and older sediments. This Miocene sedimentary package is representative of pre-kinematic packages and was possibly deposited when there was no evidence of fault activation.

Above the Miocene pre-kinematic package (overlying Upper Marine Shale; Fig.9 & Fig.10), the reflectors are gradually onlapping toward the crest of the anticlines. These overall wedge-shaped growth strata are thinnest at the top of the anticlines and thickest at the geosynclinal parts. The overall reflection configuration of these reflectors resembles a syn-kinematic package and thus indicates the time of fault activation. Stratigraphic equivalents of this syn-kinematic package are the undifferentiated Plio-Pleistocene Tipam Group (or equivalent) and younger sediments. If this is the case, then the maximum time of fault activation in the Rashidpur Anticline is Pliocene. The variation in onlapping reflection configuration along some of the structures indicates a possibility of multi-phase fault activations. However, due to the lack of detailed borehole information, these phases were not distinguished. Additionally, the deposition of syn-kinematic sediments is not uniform, which implies that the deformation rate was also variable in space. Finally, the absence of post-kinematic sediments in the interpreted seismic transects indicates that the deformation process is still ongoing. [37]

F. Trapping mechanism

The Sylhet Trough is a gas-condensate-producing province. In the trough, the Rashidpur anticline is also well known for being a gas field associated with an anticlinal trap [18], [20], [22], [23]. The total reserve of the field is 3650 Bcf [14], [28], [30]. This total reserve is calculated from the identified gas horizons within the anticlinal trap.

Results from the present study also support the anticlinal trapping mechanism. All the gas-bearing horizons in this study show four-way closures with some internal variations and culminations. Additionally, some small closures against the fault have also been identified Fig.17. If the faults are acting as seals, then these small closures can be considered as potential traps for the corresponding gas-bearing sandstone layers. [25], [33]

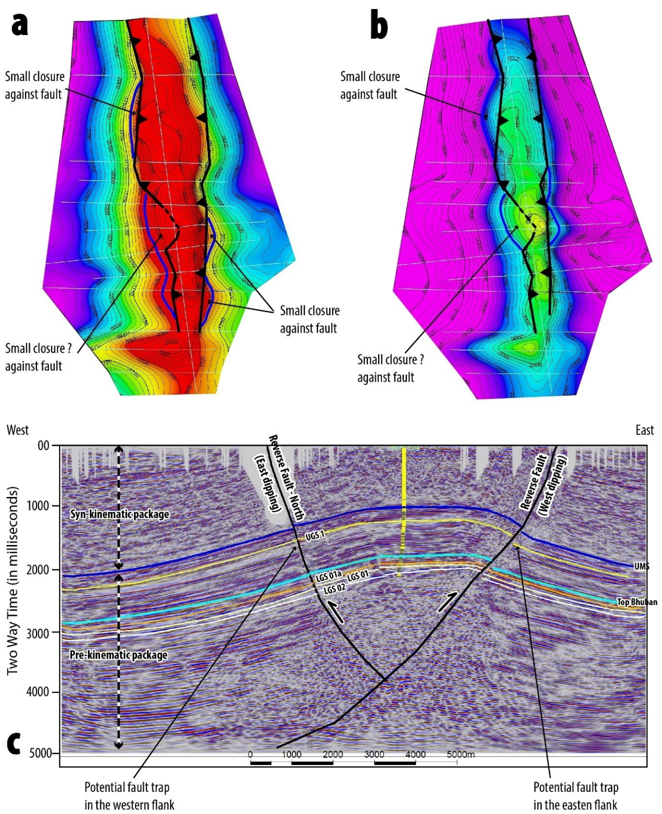

Fig. 17. Time contour maps at (a) Upper Gas Sand (UGS) and (b) Lower Gas Sand 01a (LGS01a) of the Rashidpur structure show small closures against the faults. (c) The seismic section RP 04 also shows that the gas-bearing horizons may create fault-bounded trap in the footwalls.

V. Conclusion & Future Work

Interpretation of 2D seismic data, wireline logs, and time contour maps of the Rashidpur Anticline led to several conclusions. Gamma ray logs from the Rashidpur wells RP 03 and RP 04, along with previous reports, identified five gas-bearing horizons. The stratigraphic succession of the Rashidpur structure was also developed based on this well's information. The lithological sequences encountered in this structure span from Miocene to Plio-Pleistocene, including the Bhuban, Bokabil, Tipam, and Dupitila Group sediments. The gas-producing sand zones are located in the Bokabil and Bhuban formations of the Surma Group. Wireline log results reveal a number of gas-bearing horizons, such as the Upper Bokabil Sand, Lower Bokabil Sand, Top Bhuban, Upper Gas Sand, and Lower Gas Sand.

The seismic transects suggest a pop-up structure, indicating the presence of possible perpendicular compression stress acting in the area. The geometry of the reflectors, including their onlapping configuration and variation in thickness, has been used to identify the syn-kinematic package. The study indicates that the structural development has been active from the Late Miocene to the Pliocene and may still be active today.

The time contour maps and 2D seismic sections show that the Rashidpur structure is characterised by an elongated, asymmetrical anticline with a NNW-SSE axial trend and a west-dipping reverse fault. Based on the geometry and fault-fold interaction, the Rashidpur anticline can be interpreted as a fault propagation fold. Furthermore, the 2D seismic sections and time contour maps of the gas-bearing horizons indicate the presence of a few small fault-bounded closures on both flanks, which had not been previously reported.

Based on the present research, several recommendations are suggested for future work. Further interpretation of the Rashidpur structure should be carried out using 3D seismic data along with all the available wireline log data, to gain a more comprehensive understanding of the structure. Additionally, detailed fault seal analysis should be performed, including methods such as the Shale Smearing Factor (SSF), Shale Gouge Ratio (SGR), juxtaposition against fault blocks, fault aspect ratio, and Allen-Allen diagram, among others.

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