ISSN 1028-6845
BGJ
BANGLADESH GEOSCIENCE JOURNAL VOL. 25, P. 01-21, 2019

Geomorphology, Structural Model and Active Tectonics of the Rashidpur Structure, Bengal Basin, Bangladesh

MD. SHARIF HOSSAIN KHAN, MD. SAKAWAT HOSSAIN* & RAFIQUL ISLAM

Abstract

The Rashidpur Structure is a NS trending, moderate in amplitude and asymmetric anticline situated at the north western end of the Chittagong-Tripura Fold Belt (CTFB) and the southern edge of the Sylhet Trough. This structure and related fold belt of the Bengal Basin developed as a consequence of the oblique collision between Indian and Burmese Plates. The neotectonic activity is still continuing and shaping the geomorphology of this area. This study is conducted based on the geomorphological observation of the topo maps and satellite images, analysis of the seismic sections, and surface geology. Three geomorphic indices: Standard Sinuosity Index (*SSI*), Mountain Front Sinuosity (S_{mf}), and Valley Floor Width-to-Height Ratio (V_f) have been analyzed to understand geomorphic implications and active tectonics of the Rashidpur Structure and its adjoining area. The *SSI* values for the two channels, one in east and another in west side of the structure, are close to 1, indicating sinuosity controlled by topographic factors in turn active tectonics. The S_{mf} also indicates that the area is tectonically active. However, the high V_f value might be related to soft sediments exposed in the area and the signatures of the tectonic activities are eroded by the weathering processes, which implies that V_f values from soft sedimentary terrain may not be suitable for interpreting active tectonics if the area is subjected to intense weathering. A 3D schematic structural model, based mainly on the seismic sections and geomorphic observations, reveals thrusts controlled wedge-shape upliftment of the central part as a pop-up anticlinal structure. Finally, the findings not only heighten the understanding of geomorphic evolution and active tectonics of the Rashidpur Structure but also provide the overall tectonic and geomorphic evolution of the north-westernmost folded part of the CTFB.

Keywords: Rashidpur Structure, Topographic Sinuosity Index, Hydraulic Sinuosity Index, fault, active tectonics

Introduction

The important geological processes shaping the geomorphology of a fold fringing area are the interactions between tectonic uplift, river erosion and alluvial deposition (SCHUMM *et al*. 2002). Thus, the geomorphic features of an area may help to infer the neotectonic activities and related processes. An attempt has been made to decipher the active tectonics of the Rashidpur Structure and adjacent area. The Rashidpur Structure is situated at the northern end of the western quiet zone of the Chittagong-

Authors' Addresses: MD. SHARIF HOSSAIN KHAN, MD. SAKAWAT HOSSAIN*& RAFIQUL ISLAM, Department of Geological Sciences, Jahangirnagar University, Dhaka 1342, Bangladesh. *E-mail: sakawat@juniv.edu*

Tripura Fold Belt (CTFB) and immediate south of the Sylhet Trough (Fig. 1). Tectonically, the study area is bounded by Sylhet trough to the north, in the east and south the area is bounded by northern margins of Chittagong Tripura Fold Belt (CTFB), the western boundary is marked by Old Brahmaputra River. The area offers significant variations in landforms within a very small area consisting of hillocks, piedmont plains, floodplains, paleochannels and rivers. This part of Bangladesh is characterized by alluvial plains which are traversed by various rivers as well as streams, haors; and is vulnerable to flash flood and earthquake. Considerable numbers of inhabitants are residing at the nearby Habiganj town; and the Rashidpur Structure hosting the Rashidpur gas field and there are two other gas fields namely Habiganj and Jalalabad in the adjacent area. According to the earthquake zonation map of Bangladesh (HOSSAIN 1988), the Rashidpur Structure is situated in earthquake zone I. The area has already experienced a few earthquakes, which is the evidence of active tectonics (HOSSAIN *et al*. 2019; HOSSAIN *et al*. 2020b). The neotectonic activity in the area is manifested by fault scarps, small incised streams, river shifting and a few earthquakes in the recent past.

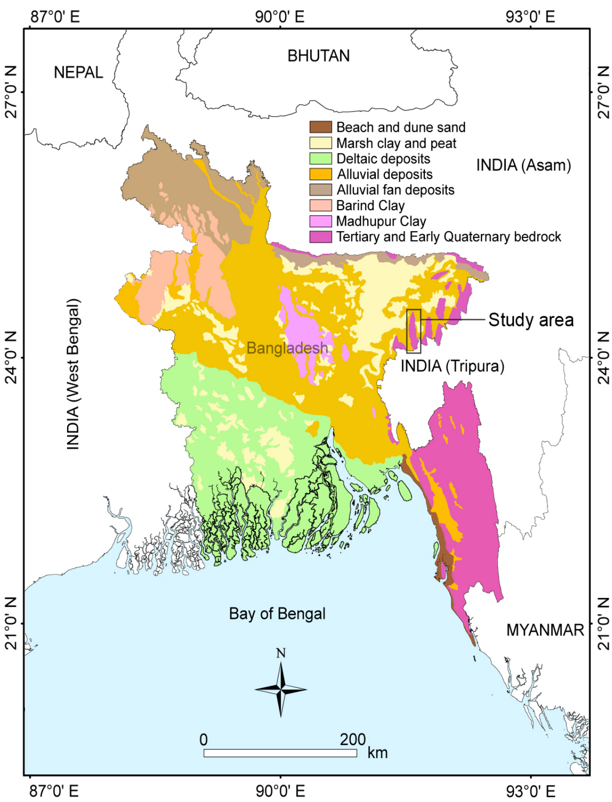

Fig. 1. Generalized geological map of the Bangladesh (modified after HOSSAIN *et al*. 2020c) showing the location of the study area.

A number of researches have been carried out on the geology (MORGAN & MCINTIRE 1959; KHAN 1991), geomorphology (OVI *et al*. 2014; BRAMMER 2012), structure (MORGAN & MCINTIRE 1959; ISLAM *et al*. 1991; KABIR & HOSSAIN 2009), stratigraphy (JOHNSON & ALAM 1990; KHAN 1991; REIMANN 1993; HOLTROP & KEIZER 1970) and sedimentology (ALAM *et al*. 2003; RAHMAN 1999) of the study area. This study is an attempt to integrate the surface geology and geomorphology with the subsurface geological information to infer the geomorphic evolution, tectonic activity and fault kinematics of the area. Therefore, the purpose of this research will help identify the overall geomorphic evolution and to find out the signature of active tectonics in and around the study area based on topo maps, satellite images, and published seismic reflection data. This research work will not only enhance the understanding of geomorphic evolution and active tectonics of the study area but also help comprehend the structural, tectonic and geomorphic evolution of the northernmost part of the folded flank of the Bengal Basin as a whole.

Geomorphology, Geology and Tectonic Setting

The study area Rashidpur Structure is situated in Habiganj District that lies between latitudes 24° 05′ N to 24° 35′ N and longitudes 91° 30′ E to 91° 40′ E (Fig. 2).

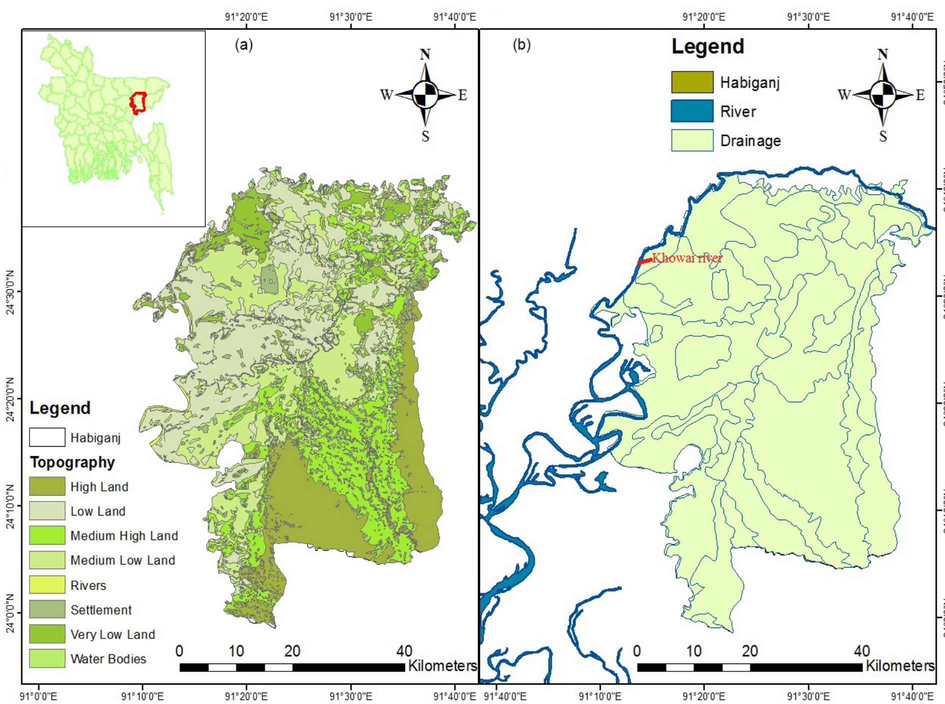

Fig. 2. Geomorphology of the Habiganj district. (a) Physiographic map of Habiganj district, and (b) Drainage map of Habiganj district.

Physiographically, the area is bordered on the east and south by the hills of the northern margins of Chittagong Tripura Fold Belt (CTFB); on the west by the Old Brahmaputra River; and on the north by the Sylhet Trough.

Geomorphology

The study area represents different geomorphic elements such as river, streams, haors and hills. Some important rivers are Khowai River, Sutang River and Karangi River. In Habiganj district, there are 14 haors. These haors are vast depressed area lying between the Surma-Kusiyara Floodplain and the Old Brahmaputra Floodplain. Gently sloping piedmont plains are found in the study area. These plains are comprised of small alluvial fans. According to BRAMMER'S (2012) physiographic classification of Bangladesh, Rashidpur Structure and its adjacent area (Habiganj district) occupies five physiographic units namely Old Meghna Estuarine Floodplain, Surma-Kusiyara Floodplain, Sylhet Basin, Northern and Eastern Piedmont Plains and Northern and Eastern Hills.

Topography and relief

The Rashidpur Structure and its adjacent area exhibits varied topography including hills, piedmond plains, rivers, floodplains and haors (Fig. 2a). The structure is approximately 50 km long, about 10 km wide in the middle, and covers an area of about 200 sq. km. The average elevation of the Rashidpur Structure is approximately 45 m above Mean Sea Level but central peak rise up to 70 m or more. The elevation of the southern part of the structure is relatively higher than the northern part. Most areas are strongly dissected, with short steep slopes, but there are some areas with rolling to nearly-level relief (BRAMMER 1996). The prominent haors are situated on the western and eastern side of the structure. The relief of floodplain is almost level, with little difference in elevation between ridges and basins.

Drainage

Some important rivers in the study area are Khowai River, Sutang River and Karangi River. Other important rivers in the Habiganj and adjacent area are Kushiyara, Kalni, Khowai, Sutang, Korangi and Barak rivers (Fig. 2b). The Kushiyara receives left bank tributaries from the Tripura hills, the principal one being the Manu. Between the Surma and Kushiyara, there lays a complex basin area comprised of depressions or haors, meandering channels, and abandoned river courses. The two rivers rejoin at Markuli and flow via Bhairab as the Meghna to join Padma at Chandpur. The Surma and Kushiyara in association with other minor hilly streams like Manu, Khowai, Jadhukata, Piyain, Mogra and Mahadao form the dense drainage network of the haors. These rivers are primarily responsible for providing inputs rainwater and sediment load to the plains including haors. The studied area is transected by the Khowai River, which is a trans-boundary river that originates in the eastern part of the

Atharamara hills of Tripura in India and joined the Khushiyara River near Adampur in Lakhai upazilla, Kishoreganj district. Old meander scars, ox-bow lakes, and paleo-channels mark the area. Numerous small ephemeral streamlets become active during the periods of heavy rainfall and build up an overall dendritic drainage pattern in the study area. More of such channels occur in the central and southern parts than in the northern part.

Geology

The Rashidpur Structure and its surrounding area are located along the north westernmost part of the Chittagong Tripura Fold Belt (CTFB) of the Bengal Basin (Figs. 1, and 3). CTFB formed due to the still-ongoing collision between the Indian Plate and the Burmese Plate and exposing the Miocene to Recent deposits (Steckler *et al*. 2008; Hossain *et al*. 2014; Wang *et al*. 2014; Khan *et al*. 2015; Hossain *et al*. 2019; Hossain *et al*. 2020a). The study area received huge amount of sediment from Eocene to Miocene when it was mainly in a deltaic environment. But during the post collision stages, this area was uplifted to form hilly region. Later, due to the formation of Dauki Fault this region including the other parts of the Sylhet trough area stopped uplifting rather subsiding but recent studies suggest the area again uplifting (Khan *et al.* 2006). At present sediment thickness of the area reaches 18-20 km at some places. Exposed sedimentary rocks of the Sylhet Trough cover broad ranges of lithological formations, including Jaintia Group, Surma Group, Tipam Group, Dupi Tila Group, Dihing Group and Alluvium (Fig. 1) (Alam *et al*. 2003).

Tectonic Setting

With comprehensive aspects of tectonic settings, the discussion begins with the regional tectonic setting of the Bengal Basin and followed by the CTFB and Sylhet Trough. Later local tectonic setting in context to the position of the Rashidpur Structure has been discussed.

Regional Tectonic Setting

The Bengal Basin is a foreland basins consists of a section of Mesozoic and Tertiary deposits covered by Recent alluvium. This is one of the largest and thickest sedimentary basins of the world consisting more than 20 km thick Early Cretaceous–Holocene sedimentary succession (Curray 1991; Curray & Munasinghe 1991). Geographically, the major portion of the basin belongs to Bangladesh and also covers a part of the Indian states of West Bengal, Assam, Tripura, and Mizoram. The Bengal Basin is bordered on the west by the Indian Shield, to the north by the Shillong Plateau, the Indo-Burman Range (IBR) to the east, and the Bay of Bengal to the south.

The basin evolution has gone through three major geodynamic episodes: (i) Extension – rifting, (ii) Drifting, further breakup and isolation, and (iii) Compression –

collision. In the first episode, the basin initiated as an intra-cratonic rift basin within Gondwana landmass close to the triple junction between India, Antarctica and Australia (AITCHISON *et al*. 2019). The process started during the Late Paleozoic–Mid Mesozoic time, and till the Mid Mesozoic, this rift basin received the continental Gondwana sediments. The first episode of basin development ended with widespread volcanism (Mid-Cretaceous) as continental flood basalts known as the Rajmahal Trap covering the Gondwana sediments. The second episode of basin development began in the Late Mesozoic with drifting and further break-up of Gondwana (HOSSAIN *et al*. 2019). In this stage, the Indian Plate appears to have reached its maximum level of isolation after being jettisoned by the Seychelles block. The second episode ended at the Late Paleocene. In the third or final episode of basin development, the evolution of the greater Bengal Basin is fundamentally related to the compression and collision pattern of the Indian Plate with the Eurasian Plate to the north and the Burmese Plate to the east. As a result, the Himalayan and Indo-Burman orogen have commenced in the Eocene-Oligocene transition and the Early Miocene, respectively (WANG *et al*. 2014; ZHANG *et al*. 2019; YANG *et al*. 2020).

Due to oblique subduction of the Indian Plate beneath the Burmese Plate to the SE, the Bengal Basin turned into a remnant ocean basin at the beginning of the Miocene (INGERSOLL *et al*. 1995; GANI & ALAM 2003). As a result of the eastward subduction component of the oceanic part of the Indian Plate, the thick pile of sediments of the Bengal Basin has been deformed into accretionary wedge and give rise to fold-thrust belt, which is known as the Chittagong Tripura Fold Belt (CTFB) (STECKLER *et al*. 2008; HOSSAIN *et al*. 2019). From the Late Oligocene onward, when the remnant ocean basin took shape due to the collisional orogeny to the north and northeast, central part of the Bengal Basin has undergone its own tectonic evolution. In the north central part of the basin, a major change in sedimentation pattern probably occurred in the Mid Pliocene by the major thrust related uplift of the Shillong Plateau along the Dauki Fault in the south and Oldham Fault in the north (BILHAM & ENGLAND 2001; BISWAS & GRASEMANN 2005; YIN *et al*. 2010; NAJMAN *et al*. 2016; HOSSAIN *et al*. 2020c). To its immediate south, a large depositional basin has been developed due to flexural loading and is known as Sylhet Trough.

Local Tectonic Setting

The Sylhet Trough, a depositional basin of thick sedimentary strata with a structural relief of about 20 km between the trough and the Shillong Plateau separated by the ~E-W running Dauki Fault (JOHNSON & ALAM 1991; HOSSAIN *et al*. 2016). Approximate thickness of the sediment in the Sylhet Trough is ~18 km with a minimum Bouguer anomaly of -80 mgl (HILLER & ELAHI 1984; SINGH *et al*. 2016; UDDIN & LUNDBERG 2004). The Sylhet Trough is an oval shaped trough about 130 km long and 60 km wide (HOLTROP & KEIZER 1970). The basement rock is continental crust beneath the northwestern half of this basin, whereas oceanic crust is

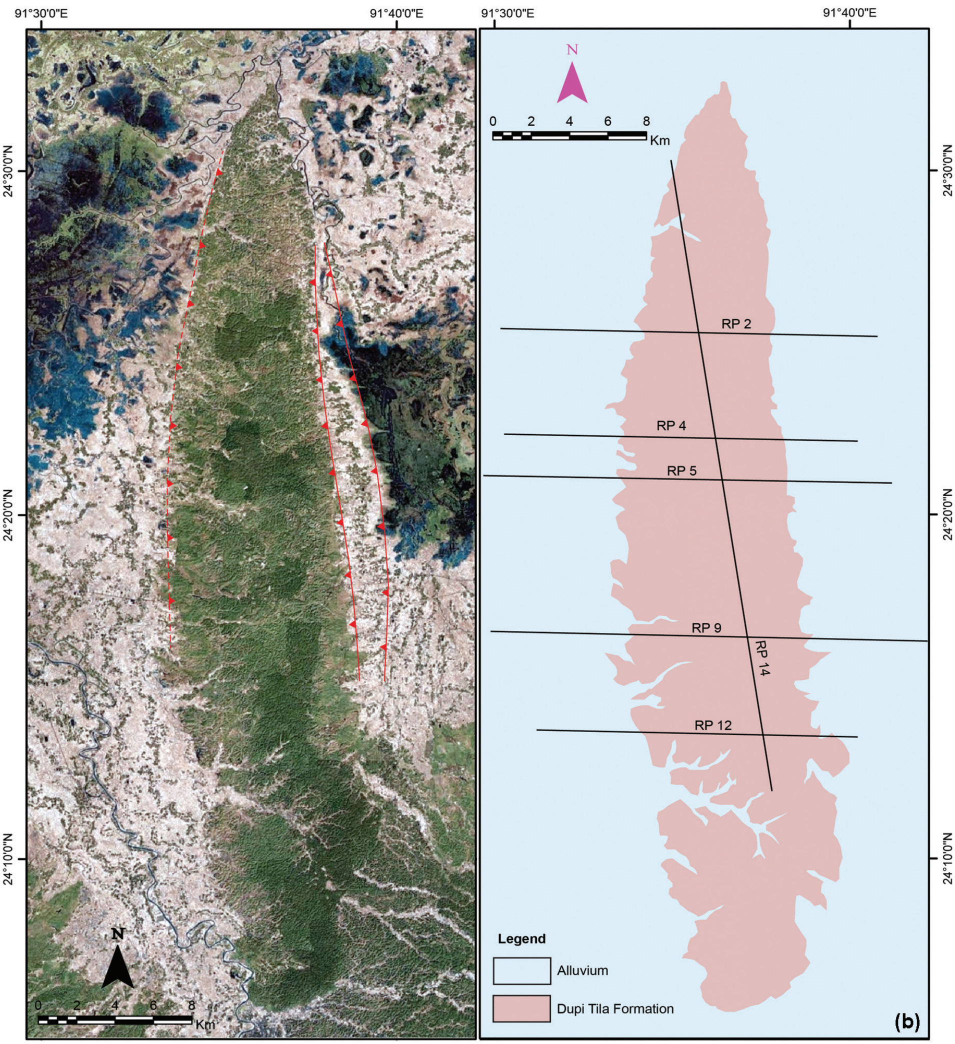

Fig. 3. (a) Google Earth Image shows the structural outline and drainage pattern of Rashidpur Structure and its adjacent area. Red solid lines suggest proven thrust faults, and red broken line suggest probable thrust fault. (b) Geological map of the Rashidpur Structure shows the surface geology. Black lines on the map are the locations of the seismic sections (seismic lines are taken from KABIR and HOSSAIN 2009 and ISLAM and HABIB 2015).

beneath southeastern half. Except for the western edge, all structural features framing this basin are the results of mostly the Pliocene-Recent compressional tectonics in the north, east, and southeast. Recent GPS measurements suggest tectonic convergence, which causes overall E-W and N-S shortening of this basin at the rate of 7 mm/yr and 18 mm/yr to the northern and eastern margins, respectively (NIELSEN *et al*. 2004; STECKLER *et al*. 2016). This shortening produces complex anticlinal and synclinal systems as well as overlapping thrust systems in and around this basin. The anticlinal folds of Habiganj, Rashidpur, Bibiana, Maulvi Bazar, Fenchuganj, Harargaj, Patharia, Beani Bazar, and Kailas Tila which occupy the southern rim of the basin have sub-meridional trend in contrast to sub- latitudinal trending Chhatak, Jalalabad, Sylhet, Dupi Tila and Jatinga structures. These two structural trends form a syntaxial pattern at the northeastern tip of the Sylhet Trough. The current study area the Rashidpur Structure situated at the south central part of the basin.

Stratigraphy

The stratigraphy of the Sylhet Trough in which the current study area belongs has been described in details by HILLER & ELAHI (1988) and ALAM *et al*. (2003). The Dupi Tila Formation is mainly exposed at the Rashidpur Structure. The variegated color of unconsolidated Dupi Tila Formation is composed of medium to very fine grained sandstone, siltstone, silty clay, mudstone and shale with some occasional clasts of petrified/silicified wood. However, the low-lying peripheral part of the structure is covered by the Holocene Alluvium. The overall stratigraphic succession of the area is given in Table 1.

Table 1. Generalized stratigraphy of the study area and its surroundings (HILLER & ELAHI 1988).

Age (approx.)	**Group**	**Formation**	**Lithology**	**Thick-ness** (m)
Holocene	Dihing	Alluvium	Unconsolidated clay, silt and occasional sand.	3350
Pleistocene		Dihing	Gravels of metamorphic and igneous origin & very find sand.	
Late Pliocene	Dupi Tila	Upper Dupi Tila -----unconformity----- Lower Dupi Tila -----unconformity-----	Variegated color containing few mica with light grey claystone and siltstone.	
Mid-Pliocene	Tipam	Girujan Clay	Laminated claystone with minor clayey sands and massive sand.	3500
		-----unconformity----- Tipam Sandstone	Ferruginous fine to coarse brownish sandstone.	

Early Pliocene-Miocene	Surma	Upper Marine Shale Upper (Boka Bil) Lower (Bhuban) -----unconformity----- Undifferentiated	Alteration of shale, siltstone and sandstone (fine to medium, grey to light brown).	3900
Oligoceen	Barail		Massive fine to medium grain sandstone with subordinate siltstone.	7200

Methodology

This study attempts to infer the geomorphic evolution and tectonic activity of the Rashidpur Structure and its surrounding through geomorphological observation from the topo maps, satellite images, and 2D seismic data. Lithologic features and possible location of the faults have been registered along with the stream and surface morphological features. Here, river morphology particularly stream straightness, stream initiation, stream confluence/convergence, stream bends (Fig. 3a) as well as the surface morphology were carefully observed on the topo maps and have been checked in the satellite images to explore their significance/causes. These observed nick points of the streams of the mapped area have been further checked to correlate with geology of the area in particular the lithologic control or the structural control. Drainage map (Fig. 2b) has been prepared based on the satellite imageries. Mueller's Index (Mueller 1968), Mountain Front Sinuosity (S_{mf}), and Valley Floor Width-to-Height Ratio (V_f) have been calculated to understand whether the area is tectonically active or not. Finally, to construct a 3D schematic structural model, the procedures have been followed are: i) perceiving the regional structural style from the seismic section and previous investigations (Sikder *et al*. 2003; Kabir & Hossain 2009; Khan *et al*. 2017; Khan *et al*. 2018), ii) establishing the relationship among the stratigraphic units from sub-surface lithology and well data (Kabir & Hossain 2009; Islam & Habib 2015), iii) outlining the distribution of the surface geology and possible location of the faults based on this research work.

Results

Geomorphic Indices

Stream Sinuosity through Standard Sinuosity Index (*SSI*), Mountain Front Sinuosity (S_{mf}), and Valley Floor Width-to-Height Ratio (V_f) have been calculated from the Rashidpur Structure to understand/explore the relative level/status of tectonic activity.

Stream Sinuosity

Temporal pattern of drainage/river plan-form can be measured with the help of Mueller's Sinuosity Index (Mueller 1968) to unfold the magnitude of river instability, which in turn will help to understand the tectonic activity. Mueller (1968) has described the sinuosity index to integrate hydraulic sinuosity and topographic sinuosity. Mueller's method attempted to infer the hydraulic or topographic controls over the channel plan-form. For the calculation of MUELLER's Index, the hydraulic sinuosity index, and topographic sinuosity index have been calculated (Table 2) using the following equation:

HSI (Hydraulic Sinuosity Index) = {(CI-VI) / (CI-1)} x100%
TSI (Topographic Sinuosity Index) = {(VI-1) / (CI-1)} x100%
SSI (Standard Sinuosity Index) = CI/VI
Channel Index (CI) is CL/Air, and Valley Index (VI) is VL/Air. Air is the shortest air distance between the source and mouth of the stream. *CL* is the length of the channel (thalweg) in the stream under study. *VL* is the length of the valley measured along a line which is everywhere midway between the bases of the valley walls and calculated using the following equation:

VL = (VLL+VLR)/2

Table 2. Result of Mueller's Index calculation for two channels in the study area.

River Name	Channel	CL (km)	VL (km)	Air (km)	CI	VI	HSI (%)	TSI (%)	SSI
Khowai	Channel-1	54.0	52.75	37.0	1.46	1.43	6.52	93.48	1.02
	Channel-2	39.6	39.45	29.9	1.324	1.319	1.543	98.46	1.003

The Standard Sinuosity Index (*SSI*) values for the channel-1 and channel-2 are 1.02, and 1.003, respectively (Fig. 4). These low values of sinuosity suggest that channels are almost straight. The *HSI* and *TSI* values of measured reaches of the these rivers indicate that almost all the reaches of both the rivers are controlled by topographic factor and the effect of hydraulic factor is very insignificant.

Mountain front sinuosity (S_{mf})

The Mountain Front Sinuosity (S_{mf}) is an index to measure the relative amount of tectonic activity (KELLER & PINTER 2002). Mountain-front sinuosity is calculated (Table 3) by using the following equation:

$$S_{mf} = L_{mf} / L_s$$

Where, L_{mf} is the length of the mountain front along the base of mountain, at the pronounced break in slope; and L_s is the straight line length of the mountain front. This index has been used to evaluate the relative tectonic activity along mountain fronts (KELLER & PINTER 2002; SILVA *et al*. 2003). In active mountain fronts, uplift will prevail over erosional processes, yielding straight fronts with low values of S_{mf}. Along less active fronts, erosional processes will generate irregular or sinuous fronts with high values of S_{mf}. Some studies have proposed that the lower values of the S_{mf} index (<1.4) are indicative of tectonically active fronts, while higher S_{mf} values (>3) are normally associated with inactive fronts in which the initial range–front fault may be more than 1 km away from the present erosional front (Bull 2007). The S_{mf} has been calculated in the western and eastern front of the Rashidpur Structure (Fig. 5).

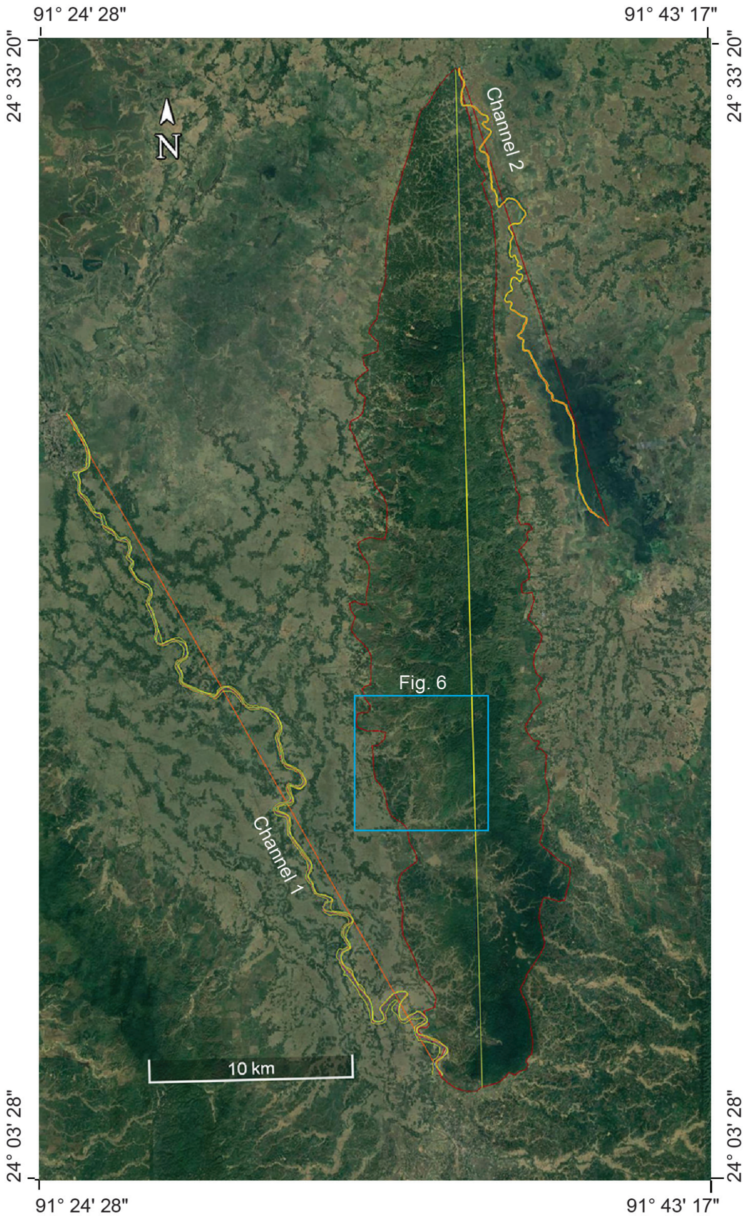

Fig. 4. Sinuosity measurement from the channel-1 and channel-2 (channel length & valley length) of the study area.

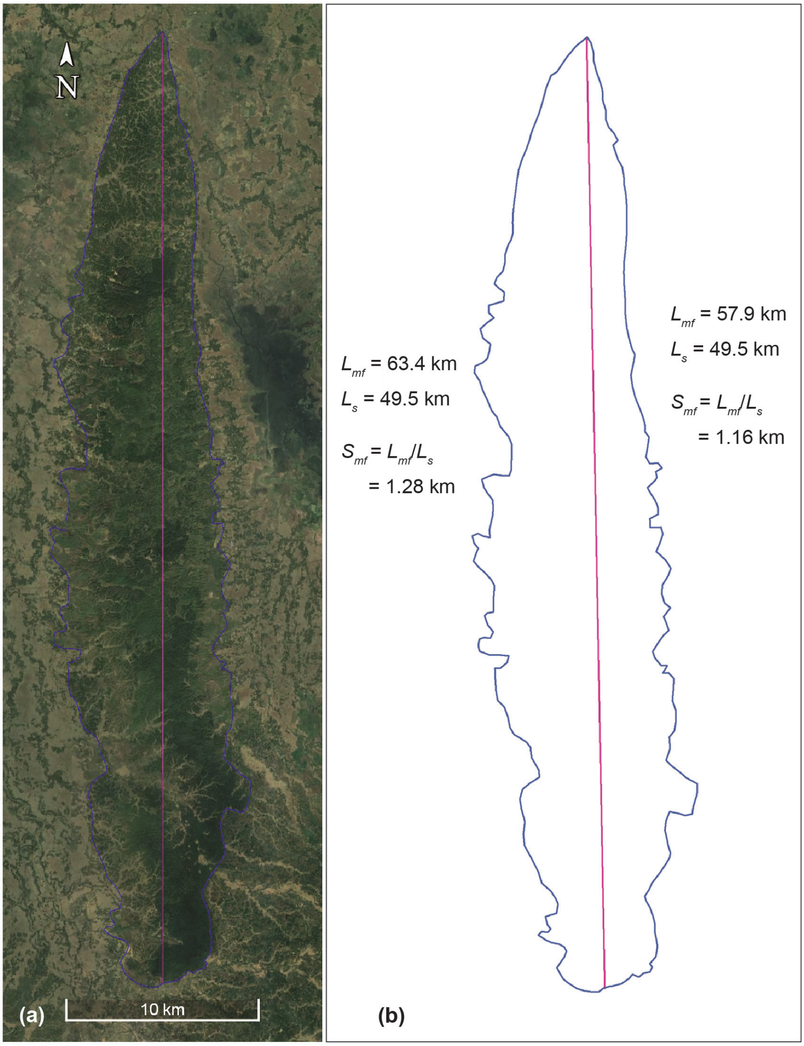

Fig. 5. (a) Outline of the Mountain Front of the Rashidpur Structure on the Google Earth Image, and (b) Calculated Mountain Front Sinuosity (S_{mf}).

Table 3. Measurement of the Mountain front sinuosity (Smf) of the Rashidpur Structure

Year	Side	L_{mf}	L_s	S_{mf}
1984	East	57.9	49.5	1.16
1984	West	63.4	49.5	1.28

The calculated values of the S_{mf} in the western and eastern front of the Rashidpur Structure are 1.28, and 1.16, respectively.

Valley Floor Width-to-Height Ratio (V_f)

The Valley Floor Width-to-Height Ratio (V_f) allows comparison of erosional patterns between watershed. The index was originally used to distinguish V-shaped valleys from U-shaped valleys (BULL & MCFADDEN 1977). V-shaped valleys are common in areas of active uplift and deep linear stream incision (where low V_f values, often close to 0). U-shaped valleys are representative of formerly glaciated or tectonically stable areas where stream valley bottoms tend to be wider (higher V_f values). When calculated for several streams draining a mountain range (or larger region), the index can reveal spatial variations in incision and differential uplift. The valley floor width-to-height ratio (V_f) has been calculated (Table 4) using the following equation:

$$V_f = 2V_{fw} / [(E_{ld} - E_{sc}) + (E_{rd} - E_{sc})]$$

Where, E_{rd} is the elevation of the river-right valley divide (ridgeline), E_{ld} is the elevation of the river-left valley divide (ridgeline), E_{sc} is the elevation of the valley floor (canyon), and V_{fw} is the width of valley floor. The V_f value has been calculated for the five valleys in the Rashidpur Structure (Fig. 6).

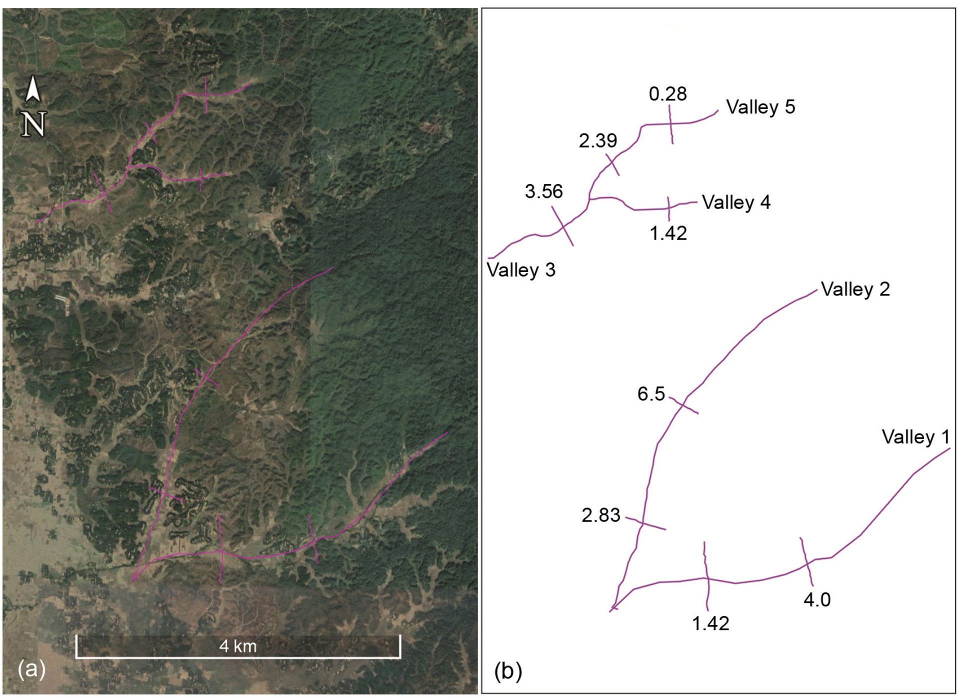

Fig. 6. Schematic illustration of the Valley Floor Width-to-Height Ratio (V_f) calculation of the Rashidpur Structure.

For valley-1, the V_f value at first measurement location is 1.42, which indicates that the valley is moderately active and at the second location, the value is 4.0, which indicates that the valley is tectonically stable. For valley-2, the V_f value at first measuring location is 2.83 and at the second location is 6.5, which indicate that the valley is tectonically stable. For valley-3, the V_f value at the measuring location is 3.56, which indicates that the valley is tectonically stable. For valley-4, the V_f value at the measuring location is 1.42, which indicates that the valley is moderately active. From valley-5, the V_f value at the first measuring location is 2.39, which indicates that the valley is tectonically stable and at the second location, the value is 0.28, which indicates that the valley is tectonically active.

Table 4. Measurement of valley floor width-to-height ratio (V_f) of the Rashidpur Structure.

Valley's Name	**Locations**	V_f
Valley-1	Location-1	1.42
	Location-2	4.0
Valley-2	Location-1	2.83
	Location-2	6.5
Valley-3	Location-1	3.56
Valley-4	Location-1	1.42
Valley-5	Location-1	2.39
	Location-2	0.28

3D Schematic Structural Model of the Study Area

The seismic sections along the six lines (Fig. 3b) are considered to understand the 3D structural set up of the Rashidpur Structure. Among these lines, one is strike line (RP-14), and the others are dip lines (RP-2, RP-4, RP-5, RP-9, and RP-12). All the dip lines pass across the structure. 3D schematic structural model has been constructed based on the seismic reflection data along the line RP-4 (Fig. 7), outlining the distribution of the surface geology and possible location of the faults based on satellite images, and perceiving the regional structural style from the seismic section and previous investigations (SIKDER *et al*. 2003; STECKLER *et al*. 2008; KABIR & HOSSAIN 2009; MAURIN & RANGIN 2009; HIRSCHMILLER *et al*. 2014; ISLAM & HABIB 2015). The dip line RP-4 passes across the middle of the structure and is almost perpendicular to the strike of the thrust fault zone. From the reflectors discontinuities, it is observed that the eastern flank is deformed by a major thrust whose two branches (FB1, and FB2) reach to the surface. The thrust FB2 extends from the line RP-2 in the north to the line RP-12 in the south (Fig. 3b). The reflectors discontinuity in dip lines RP-2 to RP-12 suggest an approximately N-S trending thrust zone, which is almost parallel to the strike line having highest throw in the middle part of the structure with value ~500 m to 600 m. It is also observed that the width of the fault zone in the east flank is highest along the line RP-4, i.e., at the middle of the structure.

Discussion and Conclusion

Tectonically, Rashidpur Structure is situated at the southern edge of the Sylhet Trough and to the northern edge of the Chittagong Tripura Folded Belt (CTFB). This

Structure is surrounded by Khowai Syncline in the west, Bibiyana Anticline to the north, and Srimangal Syncline in the east. Geomorphologically, the area is comprised of hills, piedmont plains, haors, rivers and floodplains. The floodplains and haors area have almost level reliefs with little difference in elevation between ridges and basins (Fig. 2). Piedmont plains have gently sloping relief, whereas the hills have steep slopes. Lithostratigraphic succession ranges from Bhuban to Alluvium and total sediment thickness is approximately 15-20 km (HILLER & ELAHI 1988).

Based on distribution of the surface geology (Fig. 3b), meticulous observation of the satellite images (Fig. 3a), seismic reflection data, and perceiving the regional structural style from the previously published seismic section (KABIR & HOSSAIN 2009; ISLAM & HABIB 2015), probable 3D schematic structural model and locations of the faults have been determined (Fig. 7).

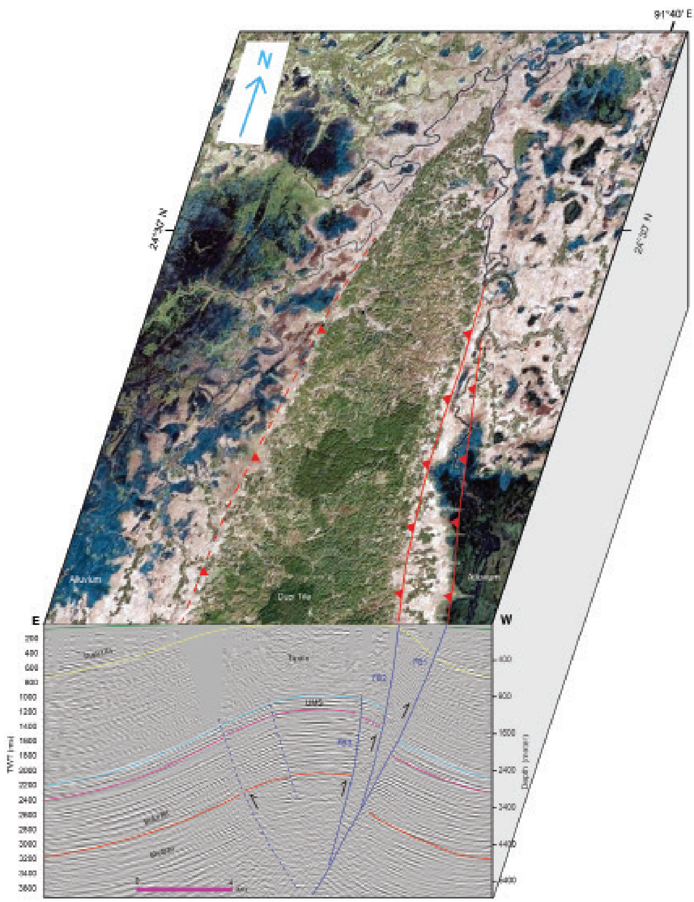

Fig. 7. 3D schematic structural model of the Rashidpur Structure along the line RP-4 (see location in Fig. 3b). Branches of the major thrust fault in the eastern flank of the structure are labeled as FB1, FB2 and FB3 (planar view shown in Fig. 3a). Red solid lines suggest proven thrust faults, and red broken line suggest probable thrust fault. Note: UMS –Upper Marine Shale, TWT-Two way travel time.

Surface geology and geomorphological observation in the satellite images during this research identified two faults at the edge of the eastern flank based on relief features as the eastern boundary of the Rashidpur Structure is sharply raised from the adjacent low land, whereas in the western part there is a minor relief break and it merges gradually to plain land (Fig. 3a). The surface observations, seismic sections (RP-2, RP-4, RP-5, RP-9, and RP-12) as well as the structural style of the surrounding area suggest that these two apparently separate faults are related to a major east verging and west dipping thrust fault (Fig. 7). This major thrust is branched into a number of segments and forms a wide fault zone, in which two segments reached to the surface (FB1 and FB2) as shown in Figures 3 and 7. The study of seismic sections by KABIR & HOSSAIN (2009) and ISLAM & HABIB (2015) also suggest similar nature of faulting in the eastern flank that has been developed along with folding in very recent time. On the other hand, presence of very weak reflector discontinuity suggests that the west flank is also probably subjected to thrusting but the displacement is indistinct, which signature is also observed in the satellite images. Well-developed thrust zone in the east flank and weakly developed thrust in the west flank together form an approximate positive flower structure with dip towards the core of the structure. Low amplitude of the structure along the line RP-2 in the north and RP-12 in the south indicates that the Rashidpur Structure is gradually plunging to the north and south. Continuous tectonic compression has taken place by movement along these thrusts, and resulted wedge-shaped upliftment of the central part as pop-up structure. On the other hand, based on the geological observation and satellite image analysis, it has been found that the eastern flank of the Rashidpur Anticline is in higher elevation than the western flank. The *Smf* of the eastern and western flank are 1.16, and 1.28, respectively (Fig. 5). The result of *Smf* and the study of seismic section suggest that the faults have been developed along with folding in very recent time.

In general, surface geological observation, analysis of the seismic sections, and 3D schematic structural model reveal that the Rashidpur Structure is a narrow, N-S elongated asymmetrical anticline. Our analysis and previous investigations suggest that the eastern flank of the structure is steeper than the gently dipping west flank. The anticline and thrust faults were formed possibly due to oblique compression related to subduction of the oceanic part of the Indian Plate beneath the Burmese Plate. It is highly likely that the Rashidpur Structure is currently tectonically active as suggested by the recent geodynamic model (HOSSAIN *et al*. 2020a) of the Bengal Basin.

Sinuosity indices for channel-1 (Khowai River) and channel-2 using MUELLER's method (MUELLER 1968) suggest that Topographic Sinuosity Index (TSI) is the major control on river morphology (93.48-98.46%), whereas Hydraulic Sinuosity Index (HSI) has little effect on river morphology (1.54-6.52%). From the sinuosity measurement it has been observed that both channel-1 and channel-2 (Fig. 4) are nearly straight as the values are close to 1. The calculated Mountain front sinuosity (S_{mf}) of the

Rashidpur Structure indicates that the eastern side (S_{mf} ~1.16) is straighter and has a higher elevation then the western side (S_{mf} ~1.28) and both the mountain fronts are tectonically highly active (Recent tectonics).

Valley floor width to height ratio (V_f) is measured at five stations and the results suggest that the area is tectonically stable to moderately active (Fig. 6). For valley-1, the V_f value ranges from 1.42 to 4.0, which means the area adjacent to the valley is tectonically moderately active to stable. The V_f value for the valley-2 (2.83 to 6.5) and valley-3 (3.56) suggests that these two valleys are tectonically stable. The V_f value for the valley-4 is 1.42, which means the valley is tectonically moderately active. The V_f value for the valley-5 ranges from 0.28 to 2.39, which indicates the area adjacent to the valley is tectonically stable to active. According to BULL & MCFADDEN (1977), the tectonically active and moderately active valleys are "V" shaped, and stable tectonic is "U" shaped. All these V_f data sets mean that the study area is stable which is in contrast with the values calculated for sinuosity index (*SSI*) and mountain front sinuosity (S_{mf}) as they indicate active tectonics.

Although the calculated high valley floor width to height ratio (V_f) indicates that the area is tectonically stable to less active or past tectonic activity, the tectonic setting of the study area within the Bengal Basin clearly suggest that the area is tectonically active. Therefore, the high value of V_f possibly related to the soft sediments exposed in the area. In soft sediments, the signatures of the tectonic activities are eroded by the weathering processes. This is clearly implies that the calculation of V_f values may not be suitable for interpreting active tectonics in an area where soft sediments are subjected to intense weathering.

References

ALAM, M., ALAM, M.M., CURRAY, J.R., CHOWDHURY, M.L.R. & GANI, M.R., 2003, An overview of the sedimentary geology of the Bengal Basin in relation to the regional tectonic framework and basin-fill history; *Sedimentary Geology*, **155**, 179–208.

AITCHISON, J.C., AO, A., BHOWMIK, S., CLARKE, G.L., IRELAND,T.R., KACHOVICH, S., LOKHO, K., STOJANOVIC. D., ROEDER, T., TRUSCOTT, N., ZHEN, Y. & ZHOU, R., 2019. Tectonic evolution of the western margin of the Burma microplate based on new fossil and radiometric age constraints. *Tectonics*. Accepted. doi: 10.1029/2018TC005049

BILHAM, R. & ENGLAND, P.C., 2001, Plateau "pop-up" in the great 1897 Assam earth-quake. *Nature,* **410**, 806–809.

BISWAS, S. & GRASEMANN, B., 2005, Quantitative morphotectonics of the southern Shillong Plateau (Bangladesh/India); *Aust. J. Earth Sci*., **97**, 82 – 93.

BRAMMER, H., 2012, *The Physical Geography of Bangladesh*, University Press Ltd, Dhaka, 547 p.

BRAMMER, H., 1996, *The geography of the soils of Bangladesh*, University Press Ltd, Dhaka, 287 p.

BULL, W.B., 2007, *Tectonic geomorphology of mountains: a new approach to paleoseismology*, Blackwell Publishing, 316p.

BULL, W.B. & MCFADDEN, L.D., 1977, Tectonic Geomorphology North and South of the Garlock Fault, California; In: DOEHRING, D.O., Ed., Geomorphology in Arid Regions: A Proceedings Volume of the 8th Annual Geomorphology Symposium, State University of New York, Binghamton, 115-138.

Curray, J.R., 1991, Possible green schist metamorphism at the base of a 22 km sedimentary section, Bay of Bengal; *Geology*, **19**, 1097–1100. https://dx.doi.org/10.1130/0091-7613(1991)019<1097:pgmatb>2.3.co;2

Curray, J.R. & Munasinghe, T., 1991, Origin of the rajmahal traps and the 85˚ E Ridge: preliminary reconstructions of the trace of the crozet hotspot; *Geology*, **19**(12), 1237-1240. doi:10.1130/0091-7613(1991)019<1237:OOTRTA>2.3.CO;2

Gani, M.R. & Alam, M.M. 2003, Sedimentation and basin-fill history of the Neogene clastic succession exposed in the southeastern fold belt of the Bengal Basin, Bangladesh: a high-resolution sequence stratigraphic approach. *Sedimentary Geology* **155**, 227–270.

Hiller, K. & Elahi, M., 1984, Structural development and hydrocarbon entrapment in the Surma Basin. In: Bangladesh (northwest Indo-Burman fold belt): Fifth Offshore Southwest Conference, Singapore, 656–663.

Hiller, K. & Elahi, M., 1988, Structural growth and hydrocarbon entrapment in the Surma basin, Bangladesh. In: Wagner, H.C., Wagner, L.C., Wang, F.F.H., Wong, F.L. (Eds.), Petroleum Resources of China and Subjects, Houston, Texas, Circum-Pacific Council for Energy and Mineral Resources, Earth Sci. Ser., **10**, 657-669.

Hirschmiller, J., Grujic, D., BOokhagen, B., Coutand, I., Huyghe, P., Mugnier, J.-L. & Ojha, T., 2014, What controls the growth of the Himalayan foreland fold-and-thrust belt? *Geology*, **42**(3), 247–250. https://doi.org/10.1130/G35057.1

Holtrop, J.F. & Keizer, J., 1970. Some aspects of the stratigraphy and correlation of the Surma Basin wells, East Pakistan. In: ECAFE mineral resources development series, United Nations, New York, **36,** 143–154.

Hossain, K.M., 1988, Earthquake Occurrences and Tectonics in Bangladesh; *Bangladesh Journal of Geology,* **7**, 1–10.

Hossain, M.S., Chowdhury, K.R., Khan, M.S.H. & Abdullah, R., 2016, Geotectonic settings of the Dauki fault—a highly potential source for a significant seismic threat; In: Kruhl, J.H. (ed.) International conference Humboldt Kolleg on living under threat of earthquake—Kathmandu, Nepal. Abstract volume, p. 25.

Hossain, M.S., Khan, M.S.H., Abdullah, R. & Chowdhury, K.R., 2020a, Tectonic Development of the Bengal Basin in Relation to Fold-thrust Belt to the East and to the North; In: Biswal, T.K., Ray, S.K. & Grasemann, B. (eds.), Structural Geology of Mobile Belts of the Indian Subcontinent: Springer Nature Switzerland AG, Cham. 91-109. doi: 10.1007/978-3-030-40593-9_4

Hossain, M.S., Khan, M.S.H., Chowdhury, K.R. & Abdullah, R., 2019, Synthesis of the Tectonic and Structural Elements of the Bengal Basin and Its Surroundings; In: Mukherjee, S. (ed.) Tectonics & Structural Geology: Indian Context: Springer International Publishing AG, Cham. 135-218. doi: 10.1007/978-3-319-99341_6

Hossain, M.S., Khan, M.S.H., Chowdhury, K.R. & Afrooz, M., 2014, Morpho-structural classification of the Indo-Burman Ranges and the adjacent regions: In: *National conference on Rock Deformation & Structures* (RDS-III), Assam, India. Abstract volume, p.31.

Hossain, M.S., Rahman, M.M, Khan, R.A., 2020b. Active Seismic Structures, Energy Infrastructures, and Earthquake Disaster Response Strategy - Bangladesh Perspective. *International Energy Journal*, **20**(3A), 509-522. http://www.rericjournal.ait.ac.th/index.php/reric/article/view/2528

Hossain, M.S., Xiao, W., Khan, M.S.H., Chowdhury, K.R. & Ao, S., 2020c, Geodynamic model and tectono-structural framework of the Bengal Basin and its surroundings; *Journal of Maps*, **16 (2)**, 445-458, doi: 10.1080/17445647.2020.1770136

Ingersoll, R.N., Graham, S.A. & Dickinson, W.R., 1995, Remnant ocean basins. In: Busby CJ, Ingersoll RV (eds.) Tectonics of sedimentary basins. Blackwell, Oxford, 363–391.

Islam, M.K., Huq, M.A. & Whitney, J.W., 1991, Tectonic Geomorphology of the Raghunandan Hill and Shahjibazar Fault, Habiganj District, Bangladesh. *Bangladesh Journal of Geology*, **10**, p. 1-10.

Islam, A.R.M. & Habib, M., 2015, Identification of gas sand horizons of the Rashidpur structure, Surma basin, Bangladesh, using 2D seismic interpretation. *International Journal of Geophysics*, 2015.

https:/doi.org/101155/2015/840168

Johnson, S.Y. & Alam, A.M.N., 1991, Sedimentation and tectonics of the Sylhet trough, Bangladesh; *Geological Society of America Bulletin*, **103**, 1513–1527. https://doi.org/10. 1130/0016-7606 (1991)103<1513:SATOTS>2.3.CO;2

Kabir, A.S.S. & Hossain, D., 2009, Geophysical Interpretation of the Rashidpur Structure Surma Basin, Bangladesh; *J. Geol .Soc. India*, **74**, 39-48. https://doi.org/10.1007/s12594-009-0102-0

Keller, E.A. & Pinter, N., 2002, Active Tectonics: *Earthquake, Uplift, and Landscape*: 2nd Ed., Prentice-Hall Inc., 359 p.

Khan, A.A., 1991, Tectonics of the Bengal Basin; *J. Himalayan Geol*., **2(1)**, 91-101.

Khan, M.S.H., Biswas,S., Singh,S. & Pati, P., 2006, OSL chronology of Dihing Formation and recent upliftment rate along the Dauki Fault, NE Bangladesh; *Bangladesh Geoscience Journal*, **12**, 1-11.

Khan, M.S.H., Haque, M.M., Pati, P., Chowdhury, K.R. & Biswas, S., 2015, OSL derived uplift rate of Dakhin Nhila anticline along the southeastern coast of the Bay of Bengal, Bangladesh; *Himalayan Geology*, **36**(2),143–152.

Khan, M.S.H., Hossain, M.S. & Chowdhury, K.R., 2017, Geomorphic Implication and Active Tectonics of the Sitapahar Anticline – CTFB Bangladesh; *Bangladesh Geoscience Journal,* **23**, 1–24.

Khan, M.S.H., Hossain, M.S. & Uddin, M.A., 2018, Geology and Active Tectonics of the Lalmai Hill Area –Overview from Chittagong Tripura Fold Belt Perspective; *Journal of Geological Society India*, **92**(6), 713–720.

Maurin, T. & Rangin, C., 2009, Structure and kinematics of the Indo-Burmese Wedge: Recent and fast growth of the outer wedge; *Tectonics*, **28**, TC2010, doi: 10.1029/2008TC002276.

Morgan, J.P. & McIntire, W.G., 1959, Quaternary geology of the Bengal Basin East Pakistan and India; *Bulletin of the Geological Society of America*, **70**, 319-341.

Mueller, J.E., 1968, An introduction to the hydraulic and topographic sinuosity indexes; *Annals of the Association of American Geographers*, **58**(2) 371-385.

Najman, Y., Bracciali, L., Parrish, R.R., Chisty, E. & Copley, A., 2016, Evolving strain partitioning in the Eastern Himalaya: The growth of the Shillong Plateau; *Earth and Planetary Science Letters*, **433**, 1-9. https://doi.org/10.1016/j.epsl.2015.10.017

Nielsen, C., Chamot-rooke, N., Rangin, C. & Cruise Team Andaman, 2004, From partial to full strain partitioning along the Indo-Burmese hyper-oblique subduction; *Marine Geology,* **209**, 303–327.

Ovi, M.M.H., Khan, M.S.H. & Haque, M.M., 2014, Geomorphic signature of active tectonics from Sylhet City and adjoining areas, Surma Basin, Bangladesh; *Bangladesh Geoscience Journal,* **20**, 19–34.

Rahman, M.J.J., 1999, Sandstone petrography of the subsurface Neogene Surma Group of the Sylhet trough, Bengal Basin. *Bangladesh Geoscience Journal*, **5**, p. 13-30.

Reimann, K.-U., 1993, *Geology of Bangladesh*; Gebrueder Borntraeger, Berlin, 160 p.

Schumm, S.A., Dumont, J.F. & Holbrook, J.M., 2002, *Active Tectonics and Alluvial Rivers*; Cambridge University Press, 292 p.

Silva, P.G., Goy, J.L., Zazo, C. & Bardajm, T., 2003, Fault-Generated Mountain Fronts in Southeast Spain: Geomorphologic Assessment of Tectonic and Earthquake Activity; *Geomorphology*, **50**, 203-225. http://dx.doi.org/10.1016/S0169-555X(02)00215-5

Sikder, A.M. & Alam, M.M., 2003, 2-D modelling of the anticlinal structures and structural development of the eastern fold belt of the Bengal Basin, Bangladesh; *Jour. Sediment. Geol.*, **155**, 209-226.https://doi.org/10.1016/S0037-0738(02)00181-1

Singh, A., Bhushan, K., Singh, C., Steckler, M.S., Akhter, S.H., Seeber, L., Kim, W.-Y., Tiwari, A.K. & Biswas, R., 2016, Crustal structure and tectonics of Bangladesh: new constraints from inversion of receiver functions; *Tectonophysics,* **680**, 99–112.

Steckler, M.S., Akhter, S.H. & Seeber, L., 2008, Collision of the Ganges-Brahmaputra Delta with the Burma Arc; *Earth Planet Sci. Lett*., **273**, 367–378. doi:10.1016/j.epsl.2008.07.009

Steckler, M.S., Mondal, D., Akhter, S.H., Seeber, L., Feng, L. & Gale, J., 2016, Locked and loading megathrust linked to active subduction beneath the Indo-Burman ranges; *Nat. Geosci*., **9**, 615–618. doi:10.1038/ngeo2760

UDDIN, A. & LUNDBERG, N., 2004, Miocene sedimentation and subsidence during continent– continent collision, Bengal basin, Bangladesh; *Sediment. Geol*., **164**, 131–146.

WANG, Y., SIEH, K., TUN, S.T., LAI, K.-Y. & MYINT, T., 2014, Active tectonics and earthquake potential of the Myanmar region; *J. Geophys. Res.*, **119**, 3767-3822.

YANG, L., XIAO, W., RAHMAN, M.J.J., WINDLEY, B.F., SCHULMANN, K., AO, S., ZHANG, J., CHEN, Z., HOSSAIN, M.S. & DONG, Y., 2020, Indo-Myanmar passive amalgamation along Kaladan Fault: insights from provenance of Chittagong-Tripura Fold Belt (Bangladesh); *Geological Society of America Bulletin*. https://doi.org/10.1130/B35429.1

YIN, A., DUBEY, C.S., WEBB, A.A.G., KELTY, T.K., GROVE, M., GEHRELS, G.E. & BURGESS, W.P., 2010, Geologic correlation of the Himalayan orogen and Indian craton: part 1. Structural geology, U-Pb zircon geochronology, and tectonic evolution of the Shillong Plateau and its neighboring regions in NE India; *Geological Society of America Bulletin,* **122**, 336–359.

Accepted 16 July, 2020

রশিদপুর গঠন, বঙ্গীয় অববাহিকা, বাংলাদেশ এর ভূপ্রাকৃতিক বৈশিষ্টাবলী, গাঠনিক নকশা এবং সক্রিয় ভূগাঠনিক প্রক্রিয়া

মোঃ শরীফ হোসেন খান, মোঃ সাখাওয়াত হোসেন ও রফিকুল ইসলাম

সারসংক্ষেপ

রশিদপুর গঠন উত্তর-দক্ষিণে প্রলম্বিত একটি মাঝারি বিস্তারসম্পন্ন অপ্রতিসম উর্ধ্বভাঁজ যা চট্টগ্রাম ত্রিপুরা ভাঁজ শ্রেণীর উত্তর পশ্চিম প্রান্তে এবং সিলেট খাদ (trough) এর দক্ষিণ প্রান্তে অবস্থিত। ভারতীয় এবং বঙ্গীয় প্লেটের তির্যক সংঘর্ষের ফলে বঙ্গীয় অববাহিকার এই গঠনটি এবং এর সংশ্লিষ্ট ভাঁজ শ্রেণীর উদ্ভব হয়। এই নিওটেকটনিক কর্মকান্ড এখনও চলমান এবং এই এলাকার ভূপ্রাকৃতিক বৈশিষ্টবলী নিয়ত পরিবর্তন করছে। ভূসংস্থান মানচিত্র, উপগ্রহচিত্র, ভূকম্পীয় রেখাচিত্র (seismic Section) এবং ভূপৃষ্ঠের ভূতাত্ত্বিক বৈশিষ্টবলী পর্যবেক্ষণ করে বর্তমান গবেষণার তথ্য, উপাত্ত সংগ্রহ ও বিশ্লেষণ করা হয়েছে। রশিদপুর গঠন এবং পার্শ্ববর্তী এলাকার ভূপ্রাকৃতিক দ্যোতনা ও সক্রিয় ভূগাঠনিক প্রক্রিয়ার পর্যায় নির্ধারণের জন্য তিন ধরনের ভূপ্রাকৃতিক নির্দেশক (আদর্শ সর্পিলতা সূচক (SSI), পর্বত সম্মুখ সর্পিলতা (S_{mf}) ও উপত্যকা তল বিস্তার-উচ্চতা অনুপাত (V_f)) পরিমাপ/ বিশ্লেষণ করা হয়েছে।

রশিদপুর গঠনের পূর্ব ও পশ্চিম পার্শ্বে দুটি নদীর সর্পিলতা সূচকের মান প্রায় ১(এক) যা হতে অনুধাবন করা যায় নদীর সর্পিলতা ভূসাংস্থানিক নিয়ামক অর্থাৎ সক্রিয় ভূগঠনিক প্রক্রিয়া দ্বারা নিয়ন্ত্রিত। রশিদপুর গঠনের পূর্ব ও পশ্চিম পার্শ্বের পর্বত সম্মুখ সর্পিলতা (S_{mf}) সূচকের মান যথাক্রমে ১.১৬ এবং ১.২৮। S_{mf} সূচকের মানও সক্রিয় ভূগাঠনিক প্রক্রিয়া নির্দেশ করে। বিবেচিত উপত্যকা তল বিস্তার-উচ্চতা অনুপাত (V_f) এর ব্যাপ্তি ০.২৮ হতে ৪। প্রাপ্ত উপত্যকা তল বিস্তার-উচ্চতা অনুপাত (V_f) এর উচ্চমান নিষ্ক্রিয় (অতীত) ভূগাঠনিক প্রক্রিয়া নির্দেশ করে। সম্ভবত: এলাকাটি নমনীয় পাললিক শিলা দিয়ে গঠিত হওয়ায় কারনে V_f সূচকের উচ্চমান নির্দেশ করছে। ভূকম্পীয় রেখাচিত্র এবং ভূপ্রাকৃতিক পর্যবেক্ষনের উপর নির্ভর করে রশিদপুর গঠনের একটি ত্রিমাত্রিক গাঠনিক নকশা প্রণীত হয়েছে। এটি নির্দেশ করছে যে রশিদপুর গঠনটির কেন্দ্রীয় অঞ্চল ঘাতচ্যুতির মাধ্যমে উত্থিত। পরিশেষে এটি বলা যায় যে, প্রবন্ধটি শুধুমাত্র রশিদপুর গঠনটির ভূপ্রাকৃতিক বিবর্তন ও সক্রিয় ভূগাঠনিক প্রক্রিয়াই ব্যাখা করছে না বরং চট্টগ্রাম-ত্রিপুরা ভাঁজ শ্রেনীর উত্তর পশ্চিমাংশের সার্বিক ভূগাঠনিক ও ভূপ্রাকৃতিক বিবর্তন সম্পর্কে ধারনা প্রদান করবে।