

Structural Style and Hydrocarbon Prospectivity of the Growth Faults Related Structures in the Bengal Basin

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Abstract

The structural and tectonic evolution of the Bengal Basin is characterized by a complex interplay of factors, including sedimentation, the rise of the Himalayan Mountains, and the movements of Jurassic syn-rift faults. This study aims to comprehend the progression of growth faults inside the basin by examining fault geometry, basin development, and structural relief patterns. We used high-quality 2D seismic lines from the PK-MY-8403, classical seismic interpretation techniques and modeling were carried out to reveal the plate tectonic conditions, stratigraphy, and sedimentation history of the basin. The break-up unconformity, Paleocene and Eocene submerged conditions, and crucial geological formations including the Sylhet Limestone, Barail Group, and Surma Group were among the notable features recognized in seismic section. With an emphasis on growth strata and pre-growth strata, significant variations in layer thickness and relief were remarked in different stratigraphic levels. Basin development events like the evolution of the Miocene remnant ocean basin, sedimentation in Oligocene, Eocene Himalayan collision, and the Pliocene reverse fault development are analyzed. In the early the Pliocene compressional forces outpaced sedimentation rates and syn-depositional normal faults of Oligocene time began to move in opposite direction. Syn-depositional growth faults may have formed in the Bengal Basin as a result of this reversal. This research provides a detailed comprehensive knowledge of growth fault development in the Bengal Basin following the seismic interpretation, modeling, and thickness/relief analysis. The outcomes point to a substantial hydrocarbon potential, especially in regions like the Eocene Hinge Zone, where the prospectivity of the area is enhanced by carbonate reefs and Jalangi shale. However, the existence of petroleum four-way closure in the investigated region requires further investigation.

Keywords

Plate Tectonic, Subsidence History, Structural Relief, Syn-Depositional Model, Growth Fault, Petroleum System

1. Introduction

The term “growth fault” is often used for syn-kinematic fault developed in sedimentary basins and rift zones, where the Earth’s crust is being stretched and thinned. As the crust is extended, it accommodates the strain through the development of faults. Generally, any fault that shows a syn-kinematic expansion of the hanging-wall block is known as growth fault, however, the original definition refers to basement detachment, gravity-driven normal faults that die out into detachment zone within sedimentary succession (Mauduit & Burn, 1998; Luthans et al., 2001; Back & Morely, 2016). Growth faults can affect the sedimentary layers, causing them to subside and create an additional space for accommodation (Twiss & Moores, 1992). The growth fault commonly demonstrates a basin ward dipping where the thickness of hanging wall block is higher compared to footwall block. The structural style of a growth fault involves examining various geological and structural factors to understand the nature and characteristics of the fault including the geometry of the fault, throw and displacement, fault zone characteristics, stratigraphy and sedimentary response, structural setting, fluid flow and hydrocarbon migration (Twiss & Moores, 1992; Allen & Allen, 2013; Boggs, 2012). The formation of growth faults can indeed exhibit both syn-depositional and post-depositional characteristics (Cazes, 2004). High sedimentation rates, rapid basin subsidence, compaction of sediments leading to subsidence and faulting are the prime regulators of syn-depositional nature (Jackson & Vendeville, 1994; Huang et al., 2009; Zang et al., 2016). Conversely, the post-depositional nature is controlled by overpressure due to compaction, tectonic forces induce faulting after sedimentation as well as changes in stress regime post-sedimentation (Childs et al., 2009). However, understanding the interplay between tectonic processes associated with subduction zones and the sedimentary dynamics in a basin is crucial for comprehending the formation and nature of growth faults. The nature of growth faults near a subduction zone and within the hinge zone (forearc region) can be influenced by the complex interactions between regional tectonic processes, sedimentation, and subsurface conditions (Von Huene & Scholl, 1991; Letouzey et al., 1995; Willett & Brandon, 2002).

The development of growth faults is quite common in sedimentary basins, especially the deltaic systems around the world. In deltaic successions, the differential loading of the rapid syn-kinematic deltaic sediment accumulations is thought to activate or reactivate growth faults (Corredor et al., 2005; Back & Morley, 2016). The Niger Delta is known for a network of growth faults that in-

fluence sedimentation patterns, basin subsidence, and hydrocarbon accumulation (Avbovbo, 1978). Growth faults in the Gulf of Mexico are critical in creating structural traps for hydrocarbons, contributing to its status as a major oil and gas province (Ewing & Galloway, 2019). The Santos Basin is characterized by growth faults that influence the trapping and distribution of hydrocarbons, especially in pre-salt and post-salt plays (Thompson et al., 2015; Gordon et al., 2023). Growth faults in the North Sea Basin contribute to structural complexity, influencing the distribution of oil and gas fields (Mosso & Shetsen, 1994). These examples highlight the global significance of growth faults in various deltaic sedimentary basins, affecting their geological evolution and hydrocarbon potential.

On the Ganges-Brahmaputra delta of Bangladesh part, no growth fault has been reported yet. The rising of the Himalayan Mountains along the subduction zone between the Indian and Eurasian plates led to the formation of a depression in the SE of the subduction belt, which finally culminated in the formation of the largest fluvio-deltaic Bengal Basin (Hossain et al., 2019). Sediment from the Ganges, Brahmaputra, and Meghna (GBM) river systems piles in the basin valley and is scattered into the Bay of Bengal, generating the world's biggest undersea fan (Hossain et al., 2019). It is split into two parts: a stable shelf and a foredeep, which are separated by a profound seismic hinge zone (Mukherjee et al., 2009). Basin sediments appear at the top of the Gondwana bedrock and extend in thickness, a few kilometers on the stable shelf and cover about 16 kilometers in the foredeep area (Mukherjee et al., 2009). This huge pile of sediment thickness was generated when the sedimentation rate was considerably high. No growth fault has been reported so far in the Bangladesh part of the Bengal Basin, despite having all the factors necessary for growth fault formation. However, this might merely be a little amount of exploration activity. There are indications that growth faults exist, although they have yet to be definitively discovered.

The objective of this study is to investigate the development and cessation of growing fault in the Bangladesh part of the Bengal Basin. A model has been constructed to evaluate the evolution process of the growth faults by utilizing the seismic reflection data to recognize major seismic horizons, fault and fault-related structures. Hence, this study aims to offer a novel viewpoint on the historical evaluation of the basin by analyzing its structure and geometry in the broader context of the northwestern region of Bangladesh. The study conducted an analysis of the growing fault-related structures found in the northern region of the basin, perhaps providing novel insights into the exploration process.

2. Tectonic Setting

The emergence of the Bengal Basin is characterized by multiple distinct periods, each marked by significant changes in source areas, basin geometry, means of transport, depositional environment, and rock thickness (Reimann & Hiller, 1993). During the Late Jurassic to Early Cretaceous, the Indian continent sepa-

rated from Gondwana, resulting in the formation of a new seafloor, a portion of which is today known as the Bay of Bengal, and the devoured sea floor underneath the Sunda Arc (Reimann & Hiller, 1993; Curray & Moore, 1974). The rising of the Himalayan mountains along the subduction zone between the Indian and Eurasian plates led to the formation of a depression in the SE of the subduction belt, which finally culminated in the formation of a massive sedimentary basin, the Bengal Basin. The basin was nourished by sediments carried by the mighty Ganges, Brahmaputra, and Meghna rivers as a result of erosion of the uplifted Himalayas (Imam, 2013) and later by sediments derived from the Indo-Burman range. The Bengal Basin has been the depo-center from the Cretaceous to the recent period, and the depo-center has been prograding towards the southeast since the Oligocene to the recent period (Salt et al., 1986). The dynamic character of the Bengal Basin may be linked to the interplay of the Indian, Eurasian, and Burmese plates from a regional viewpoint. After splitting from Gondwanaland in the Jurassic to early Cretaceous, the Indian plate began its voyage northward, eventually heading east or northeast (Curray & Moore, 1974; Alam et al., 2003). South Tibet, Burma, and SIBUMASU Blocks had already drifted off northward and landed against Asia before India's withdrawal from Australia and Antarctica in the Jurassic to Early Cretaceous (Acharyya, 1988).

The three huge continental masses were connected tightly (Figure 1(a)) with "Greater India" stretching into the Tethys Sea to an unknown extent. An uninterrupted zone of subduction was developed along the southern boundary of the Asian and Tibetan Plates because of the breakup (Dewey et al., 1988; Li et al., 2019). A mild collision in between northwestern corner of the Indian and the Eurasian plate occurred in the Mid-Paleocene, at 59 Ma, at which time the suture was entirely closed. Ever since, India has moved across Asia diagonally and/or under it. The northward or NNE drift of India proceeded during the "soft collision," ag 59 - 44 Ma, and was delayed presumably by the closure of previously squeezed sutures Shield and South Tibet (Figure 1(b)) (Lee & Lawver, 1995). From 60 - 55 million years ago, India rotated anticlockwise. Intense continent-continent collision connected to the Himalayan orogeny began in the Early Eocene, around 44 Ma (Figure 1(c)) (Lee & Lawver, 1995). Due to the obvious continued oblique subduction of India under and southeast extrusion of Burma, the Bengal Basin became a residual ocean basin (Figure 1(d)) at the beginning of the Miocene (West Burma Block) (Ingersoll, 1990). The Bengal Basin comprises three unique geo-tectonic provinces as a residual ocean basin: 1) the Stable Shelf Province, 2) the Central Deep Basin Province or remnant ocean, and 3) the subduction-related orogen in the east, the Chittagong-Tripura Fold Belt (CTFB) Province (Alam et al., 2003). The study area Bogra shelf is situated under the Stable Shelf Province (Figure 2). The Bogra shelf or Hinze, and Bengal foredeep regions are split along NE-SW trending lines in the northwestern section of the Bengal Basin (Salt et al., 1986). The Indian craton extends eastward on the Bogra shelf. Numerous basements controlled tensional faults grouped in

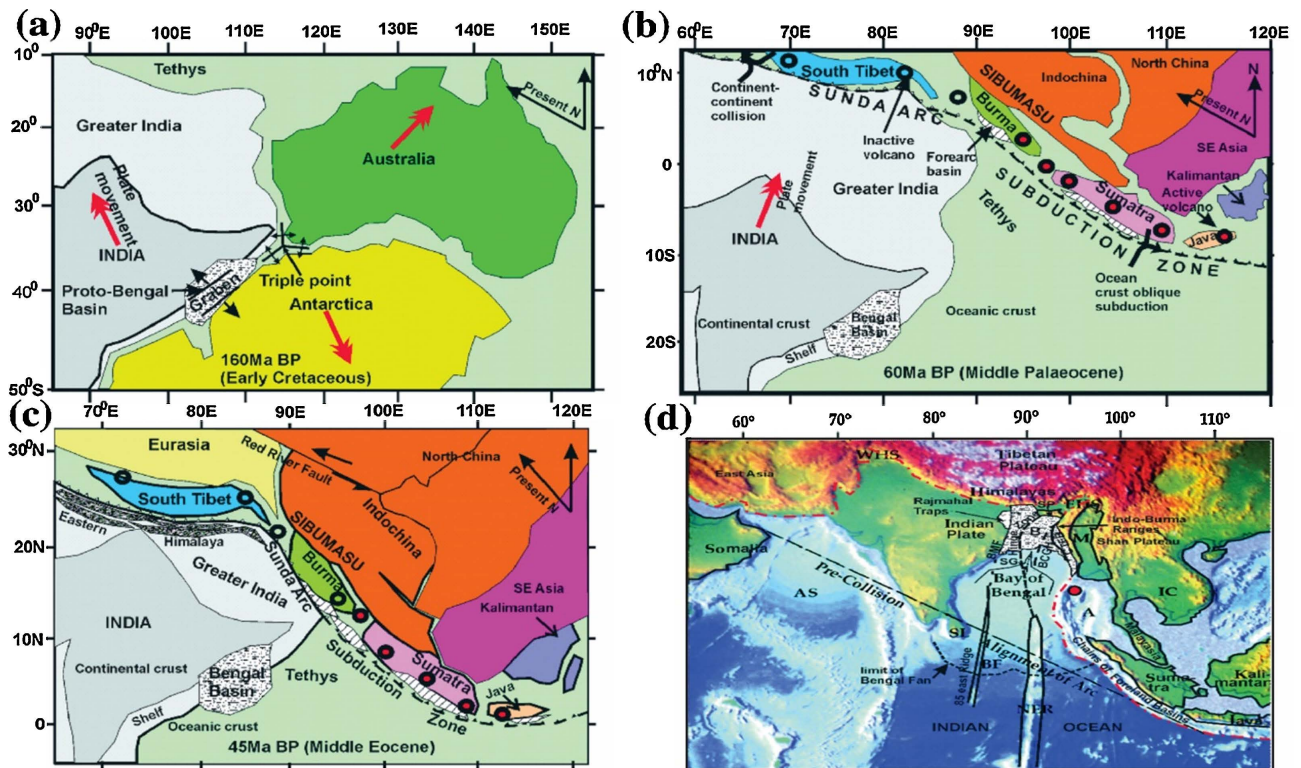


Figure 1. A series of paleogeographic maps reconstruction of Bengal Basin. (a) Jurassic—Early Cretaceous time when Eastern Gondwana fit of the margins of Australia and Antarctica (Greater India); (b) Mid Paleocene—soft collision between India and southeast Asia; (c) Middle Eocene—hard collision between India and southeast Asia; (d) Early Miocene—major tectonic collision between India and South Tibet in the north and India and Burma in the east (modified after Alam et al., 2003; Lee & Lawver, 1995).

an enechelon pattern cut through this region. Along these faults, south-eastward down-thrown blocks are coupled with half-graben type topography, forming several tiny basins for Permo-Carboniferous coal deposition (Hossain et al., 2019). The Bogra Fault, which has been active at various periods in the geologic past, is one of the area's primary structural features. In the graben produced by the Bogra fault, the thicker growth of Sylhet Limestone indicates vertical movement along the fault (Salt et al., 1986; Reimann & Hiller, 1993). The entire Bengal Basin is devoid of substantial trace fossils and representative marker horizons which makes the stratigraphy of the basin ambiguous despite of considerable endeavors (Reimann & Hiller, 1993; Bhattacharya et al., 2021). **Figure 3** displays the primary stratigraphic sequence of the Bogra shelf area in northwest Bangladesh where the Gondwana basins are found in the Precambrian basement (Islam & Eickhoff, 2001; Rabbani et al., 2000).

The basement dips generally to the southeast and is composed of tonalite, diorite, gneiss, schist, and granodiorite (Alam et al., 2003). The basement rocks were faulted, and half-grabens formed during rifting. These remnants of transoceanic grabens include the Lower Gondwana formation, which was dominated by Upper Carboniferous and Permian terrestrial organic compounds (coal), and even the Upper Gondwana formation, which was led by the invasion of Triassic

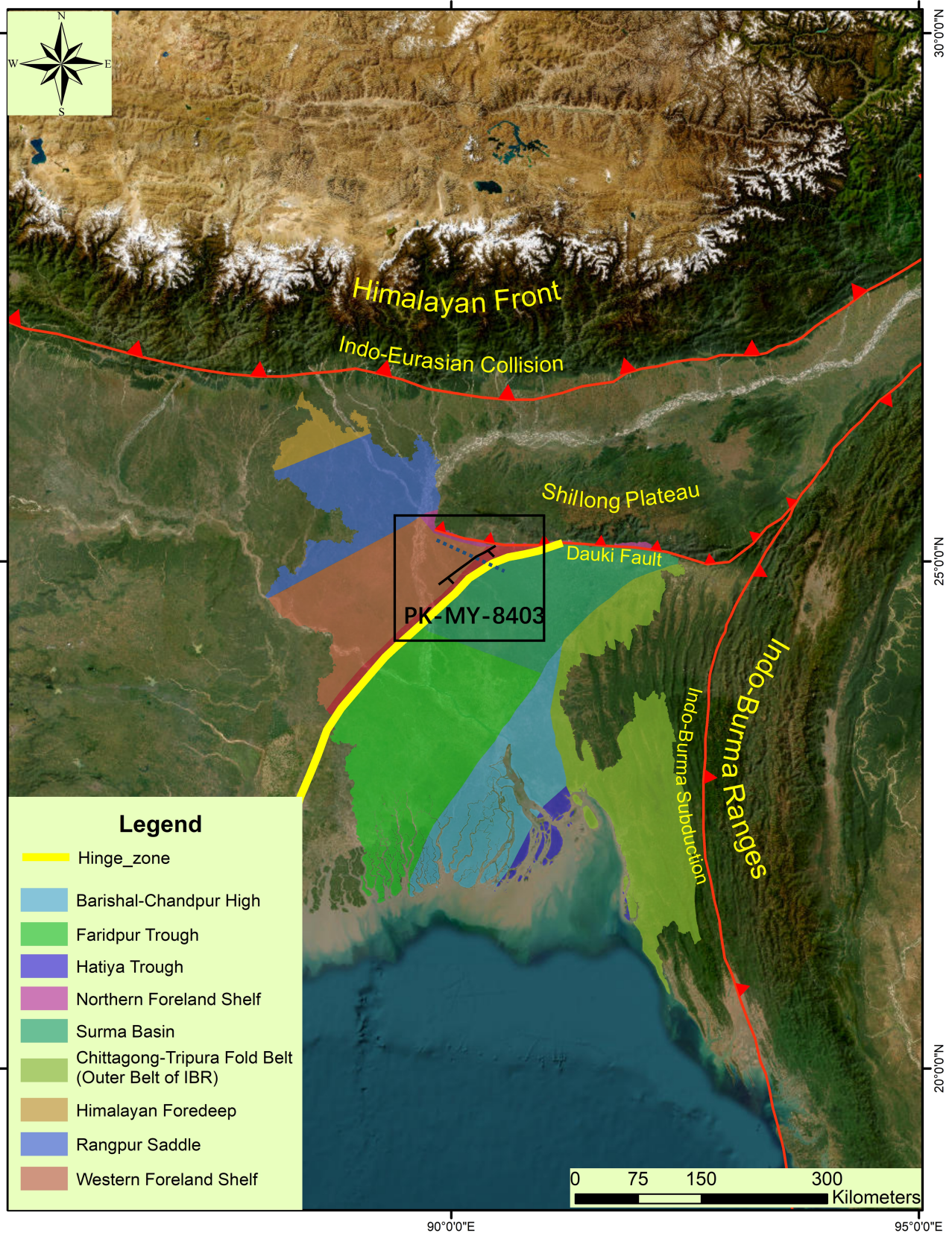


Figure 2. Location of the study area in the context of Indian and Eurasian plates; Map is also displaying the location of interpreted regional seismic line PK-MY-8403 along with tectonic province (Hinge zone) of Bangladesh.

Era	System	Series	Age (Ma)	Group	Formation	Tectonic Events	Phases
Cenozoic	Quaternary	Holocene Pleistocene		Dupi Tila	Alluvium Dupi Tila	Late Collision	Himalayan uplift
	Neogene	Pleistocene	1.81	Tipam	Girujan Clay Tipam Sst. Upper Marine Shale		
		Miocene	5.33	Surma	Boka Bil Bhuban		
	Paleogene	Oligocene	23	Barail	Renji Jenum Laisong	Early Collision	Tethys Closing
		Eocene	34	Jaintia	Kopili Shale Sylhet Limestone Chera Sst.		
		Paleocene	56				
Mesozoic	Cretaceous	Late	65		Erosion	Drift	Main Break up
		Early	99.6		Rajmahal		
	Jurassic	Upper	144.5		Erosion	Synrift	
		Middle	161		Upper Gondwana		
		Lower	175.6				
	Triassic		199.6				
Paleozoic	Permian		251		Lower Gondwana	Prerift	Graben Formation
	Carboniferous		299				

Figure 3. Schematic stratigraphic scheme, tectonic event phases, of northwest Bangladesh (modified after Chakrabarti and Mukherjee, 1997; Shamsuddin et al., 2002)

to Lower Jurassic clastic sediments (Upper Gondwana) throughout expanding lateral crustal stretching (Chakrabarti and Mukherjee, 1997). Deposition of Gondwana sediments occurred in low-sinuosity braided fluvial systems and swampy flood plain areas within cool climate settings (Ray & Chakraborty, 2002). Upper Jurassic and Lower Cretaceous sediments are largely absent in the broader part of Bogra Shelf area, reflecting the period of degradation during the Gondwana continent's breakup. This was continued by the burial of Raajmahal ash layers, which represented a period of volcanism in the surrounding region throughout the Upper Cretaceous. The Cenozoic period is characterized by the deposition of fluvial to shallow marine slope and deltaic sediments. Sylhet Limestone was deposited under high stand sea level conditions representing the marker horizon of the Eocene period. It is abundant in foraminifera, and a favorable locale for carbonate build-up and reef growth along the paleo-shelf edge (Moore & Lennengerger, 1994).

Following the limestone deposition, the marine environment transformed in-

to a southward prograding deltaic sedimentary system. Tertiary shaly formations, despite containing terrigenous organic matter, exhibit poor source rock potential due to consistently lower total organic carbon (TOC) content. The Kopili Shale and Jenum Shale are recognizable hydrocarbon-prone source rocks in the Tertiary sequence (Shamsuddin et al., 2002; Curiale et al., 2002). Simultaneously, these shale-rich formations act as seals for gas migration and caprocks for hydrocarbon accumulations in the basin.

3. Data and Methods

The investigated seismic section PK-MY-8403 was obtained and processed in 1985 by Prakla Seismos GmbH under the directive of the former German Geological Advisory Group. The survey also provided an interpreted stacked line, providing a subsurface coverage of 12-fold having a recording duration of 6 s and sampling rate of 4 milliseconds. However, understanding the seismic profile beneath the break-up unconformity is intricate and accompanied by countless diffractions. As a result, discerning pre-breakup structures is only an approximate task, and this investigation is confined to a schematic interpretation. The studied seismic line follows a northwest to southeast orientation, predominantly spanning the northwestern region of the country (The Hydrocarbon Unit, 2001; Davy et al., 1995). Subsequently, it traverses through the hinge zone area and extends into small sections of the Sylhet trough region (The Hydrocarbon Unit, 2001; Davy et al., 1995).

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3.1. Methodology

To achieve precise and extensive knowledge in analyzing the fault geometry and basin development, efforts have been exerted to pinpoint the growth fault and fault-related structures. In pursuing the research objective, secondary data was obtained from different organizations, articles, and administrative maps (Lindsay et al., 1991; Frielingsdorf et al., 2008; Imam & Hussain, 2002; German Geological Advisory Group, 1983-1985; The Hydrocarbon Unit, 2001; Eickhoff & Islam, 2001; Islam & Eickhoff, 2004). A good understanding of the tectonic evolution history of the Bengal Basin, a study on regional stratigraphy and basin geometry of the investigated area have been carried out via literature review (Hossain et al., 2019; Mukherjee et al., 2009; Reimann & Hiller, 1993; Curray & Moore, 1974; Salt et al., 1986; Alam et al., 2003; Hossain et al., 2019; Rabbani et al., 2000; Uddin & Lundberg, 1998). High-quality 2D seismic lines from the PK

survey were selected for this study. This was followed by the interpretation of 2D seismic lines from the PK survey provided by Bangladesh Petroleum Exploration and Production Company Limited (BAPEX), nomenclatures of the interpreted horizons also adopted from relevant interpretation reports (German Geological Advisory Group, 1983-1985; The Hydrocarbon Unit, 2001; Eickhoff & Islam, 2001; Islam & Eickhoff, 2004). A program used for seismic interpretation was the PC-based Schlumberger program called Petrel™ 2017 and in the end conceptual modelling results are interpreted by using a drawing software.

3.2. Stratigraphic Zonation of the Studied Seismic Section

Interpretation of the regional seismic section PK-MY-8403 unravels the style of deformation and kinematics of the major structure at depth. The stratigraphic differentiation of the studied seismic section into subsurface major formations has been done based on well log interpretations and correlations of burial histories of the wells Kuchma-1, Singra 1X and Hazipur-1 carried out by Geologists of the German Geological Advisory Group and Petrobangla in 1984 (Frielingsdorf et al., 2008; German Geological Advisory Group, 1983-1985; The Hydrocarbon Unit, 2001). The regional seismic section PK-MY-8403 reveals a notable unconformity separating Lower Cretaceous rift deposits from Tertiary sediments (Frielingsdorf et al., 2008; Abdullah et al., 2022). Additionally, the Cenozoic sediment layer thickens in a southeastward direction. The eastern edge of the faulted continental crust delineates the extent of Gondwana source rock potential (Frielingsdorf et al., 2008; Abdullah et al., 2022).

3.3. Defining Pattern of Structural Relief

The Based on the stratigraphy developed from well logs (lithologs) and interpreted seismic lines encompassing the study region (Frielingsdorf et al., 2008; Abdullah et al., 2022) two zones within the studied seismic section designated as “Zone-01” and “Zone-02” have been distinguished for thickness analysis (Figure 4(c)). Zone-02 is the forward part of the basin with a huge sedimentary thickness (Mukherjee et al., 2009; Alam et al., 2003). Conversely, Zone-01 is toward the shelf part of the basin section where the thickness is slightly less (Mukherjee et al., 2009; Alam et al., 2003).

3.4. Determining Layer Thickness Ratio

The thickness variations in each major stratigraphic interval across the folding have been measured to determine which units reflect growth characteristics. Likewise, the thickness variance ratio of each individual unit at each of the two sites (zone-01, and zone-02) has been calculated separately (Figure 4). As these two sites have large thickness variation, it has been assumed that regional stratigraphic thickness changes have a considerable impact on them. This number will be proportionally increased for pre-growth layers, representing large changes in stratigraphic thickness. On the other hand, growth layers, have non-zero thickness

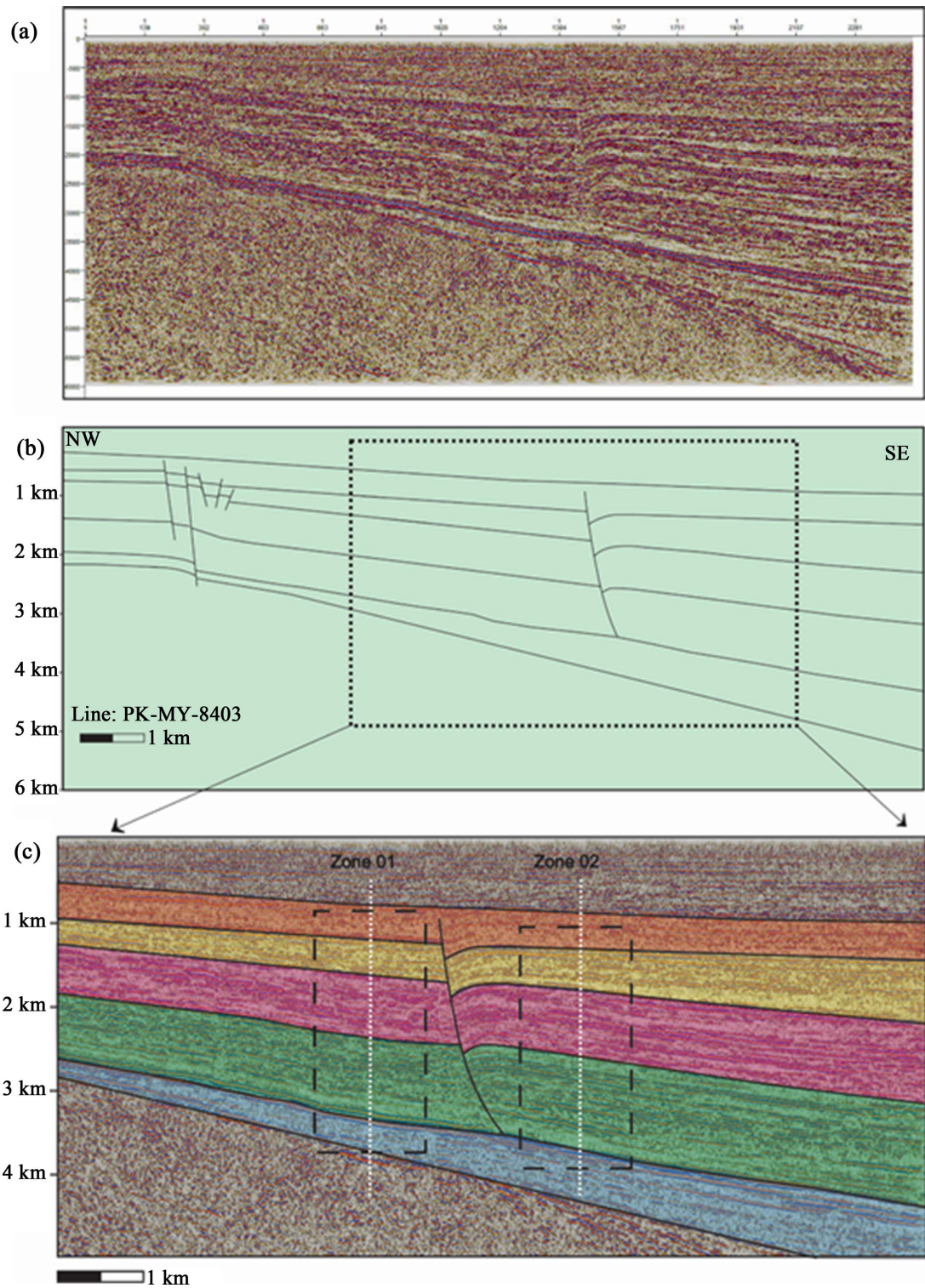


Figure 4. (a) Uninterpreted seismic section of investigated profile PK-MY-8403, shot-point number are in the x axis and travel time in millisecond (ms) in the y axis; (b) Interpreted Seismic Line PK-MY-8403 with probable fault location; (c) Zonation of Seismic Section PK-MY-8403 for thickness analysis.

ratios (Davy et al., 1995; Jadoon et al., 2015; Sibson, 1977; Zhang et al., 2016; Layfield et al., 2022). Depending on the thickness variation ratio, it might be ris-

ing or decreasing (Davy et al., 1995; Jadoon et al., 2015; Sibson, 1977; Layfield et al., 2022).

4. Results

4.1. Seismic Interpretation

The interpreted regional seismic profile PK-MY-8403 defines the plate tectonic condition and the stratigraphic section and is thus significant to tectonostratigraphic history. The prominent reflector on the seismic line represents the break-up unconformity, an erosional surface, which is clearly sloped towards east. This erosional surface overlies the chaotic reflectors of the Precambrian basement complex. Early Cretaceous and Paleocene successions were probably deposited on the erosional surface at the bottom righthand part which is not shown in the interpreted seismic section. Another prominent reflector started at 2000 ms on seismic section which dips towards east is defined as the top of the marine carbonate deposits, the Sylhet Limestone Formation (Figure 5). The Sylhet Limestone Formation is the most extensively developed unit in the subsurface of northwestern Bangladesh and is a marker horizon in the seismic section. Based on the seismic facies patterns the younger deposits: Oligocene Barail, Miocene Surma (Bhuban and BokaBil formations), and Pliocene Tipam group successions are identified (Figure 5). There is a marked difference in thickness of all the successions. The successions are tapered towards west of the seismic section, opposite to the dip of the basin. A number of extensional normal faults are identified based on the reflection termination pattern in the western part of the seismic section near the shot point (SP) 302. No marked thickness variations of successions are observed across these faults in the paleocontinental slope area. A large fault identified further east of the seismic section between SP 1384 and 1567 (Figure 5). The thickness variations of successions across the fault suggest the syndepositional growth nature of the fault. The growth-related rollover anticline also identified in the hanging wall block of the normal fault. Middle Eocene limestone units have an average thickness of 250 meters. The Barail group, consisting of sandstone, shale and siltstone with occasional carbonaceous layers, represents the deposition under deltaic settings in Oligocene eras. Over this, there lies the Surma group, which consists of deltaic sandstone, shale, and siltstone. When compared to their thickness in the geosynclinal basin portion, the Barail and Surma groups are much thinner on the stable platform.

4.2. Thickness Analysis

Following the interpretation of the seismic line PK-MY-8403, a modeling zone was chosen where the thickness rose from NNW to SSE. A normal defect has been discovered on a regional basis. If the fault is due to lateral separation, the fault's a hanging wall will slip, causing the hanging wall units to be structurally lower than the footwall units. Because of the growing thickness induced by heavy sedimentation, Zone-2 reveals higher thickness compare to Zone-1 (Table 1). These constructions have a constant growing value in the pre-growth layer

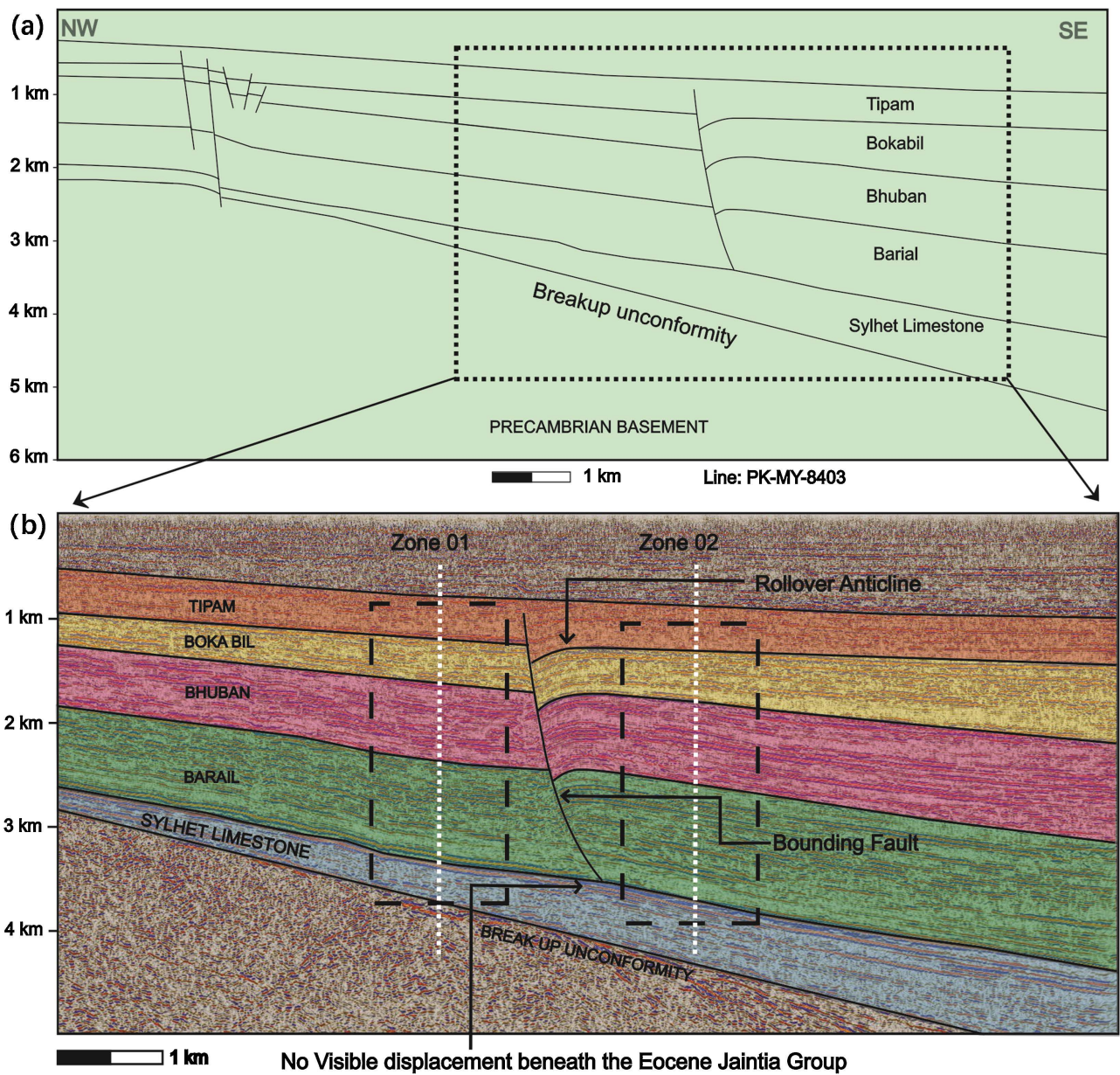


Figure 5. (a) Schematic representations of stratigraphic formations from interpreted seismic section of investigated seismic line PK-MY-8403, shot-point number are in the x axis and travel time in millisecond (ms) in the y axis; (b) The zoomed in section represents color coded stratigraphic successions, fault and various zones.

Table 1. Thickness analysis of defined schematic stratigraphic formations within the studied seismic section.

Formation	Zone 01 (m)	Zone 02 (m)	Variance (m)
Barail	973.34	1107.72	134.38
Bhuban	750.81	799.23	48.42
BokaBil	423.28	502.72	79.44
Tipam	416.21	444.50	28.29

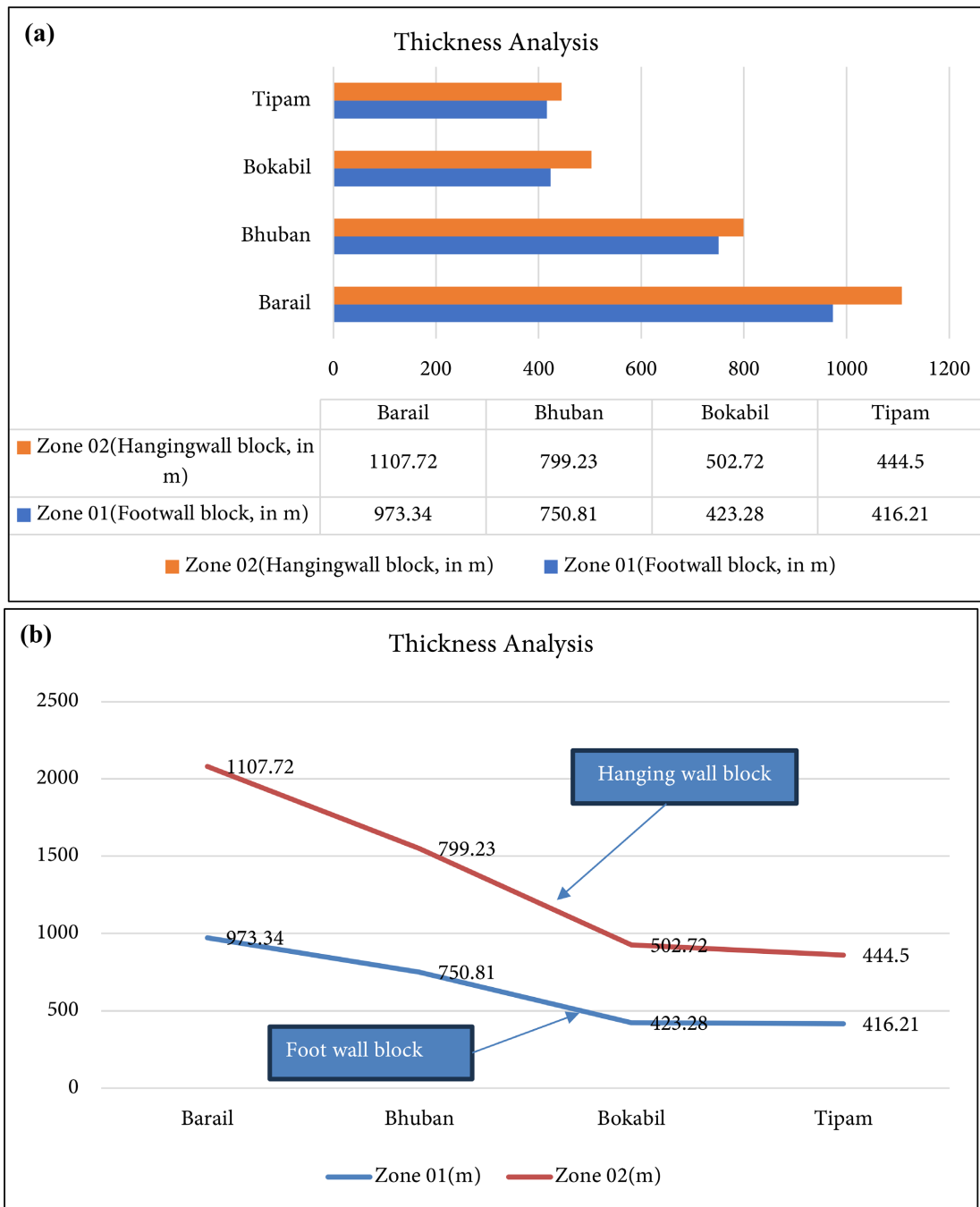


Figure 6. Thickness Analysis of Schematic Syn-Depositional fault model reveal thickness of growth strata steadily augmenting in the hanging wall block and exhibit a positive relationship between pre-growth strata and in the growth strata.

(foot wall block) and a steadily increasing value in the growth strata (hanging wall block) as shown in **Figure 6**.

5. Discussion

Several key conclusions have been drawn from the studied seismic section and the associated results, suggesting the hypothesis of syn-depositional growth fault

development during the deposition of the rock mass. Eastward dipping breakup unconformity, the Sylhet Limestone Formation as a marker horizon has been delineated from the seismic section. The seismic section has precisely delineated an Eastward dipping breakup unconformity along with the Sylhet Limestone Formation as a marker horizon. While the seismic facies patterns reveal the younger formations encompassing Oligocene Barail, Miocene Surma (Bhuban and Bokabil formations), and Pliocene Tipam group successions. Evidence of extensional normal faults in the west and a large-scale normal fault is discovered in the further east within the seismic section. The predefined modeling zone exhibit a progressive rise in thickness between NNW to SSE direction which implies a normal fault on regional basis. Due to lateral separation, the hanging-wall units are structurally lower than the footwall units, causing the fault. In line with the findings of (Bramham et al., 2021; Tek et al., 2020; Lu et al., 2024), who also reported syn-depositional fault development in similar tectonic settings, within the modelling zone, the depicted stratigraphic formations (Barail, Bhuban, Bokabil, Tipam) exhibits variations in thickness where Zone-2, representing the hanging wall block, shows higher thickness compared to Zone-1 (footwall block). This finding aligns with the work of (Frielingsdorf et al., 2008; Uddin & Lundberg, 1998; Abdullah et al., 2022) who identified similar structural trends (tectonic subsidence and tectonostratigraphic evolution) and opined the hypothesis of growth fault development adjacent parts of the study region within the Bengal Basin. The thickness variations of stratigraphic successions across the fault between SP 1384 and 1567 suggest that the fault has grown synchronously with sediment deposition. This is one of the striking features of syn-depositional fault development. The thickness of the geological formations is gradually tapering toward the west opposite to the dip direction indicating that sedimentation within the basin is structurally driven. Overall, the thickness variations, presence of extensional normal faults in the seismic section, as well as growth-related features support the hypothesis that faults developed syn-depositionally. Moreover, integrating the findings derived from our seismic section analysis with the tectonic history of the Bengal Basin yields a detailed insight into the possible occurrence of syn-depositional growth fault development. A mild collision between the northwest corner of the Indian Shield and South Tibet happened in the Mid-Paleocene, at 59 Ma. From around 60 - 55 Ma, India experienced some CCW rotation, (Klootwijk et al., 1992) at which time the suture was entirely closed. Since then, India has moved through Asia obliquely and/or beneath it. The northward or NNE drift of India persisted throughout the soft collision, about 59 - 44 Mya, and was slowed probably by the sealing up of formerly comparatively under compacted sutures between the other accreted terranes of South Asia (Chen et al., 1993). During stage A, hard continent-continent collision connected to the Himalayan orogeny began in the Early Eocene, around 44 Ma (Figure 7).

The older sutures had become totally squeezed by this point. The tectonic extrusion of the Burma and SIBUMASU Blocks, as well as Indo-China, began at

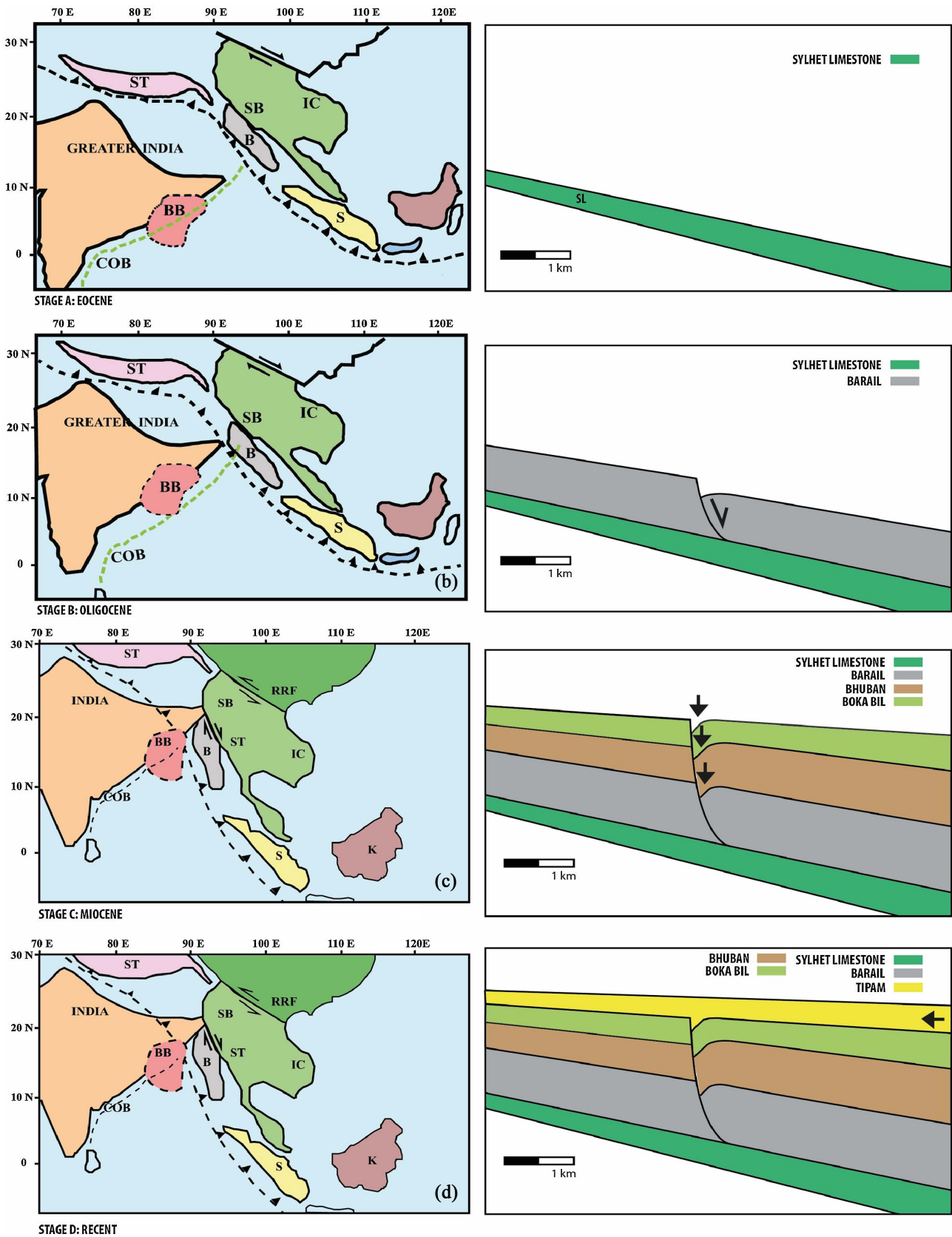


Figure 7. Paleo Tectonic Map with Syn-Depositional Fault Model. It exhibits how continent-continent collision related oblique subduction and sedimentation over time might give rise to Syn-Depositional Fault.

this time (Tapponnier et al., 1982; Tapponnier et al., 1986). Most of Bangladesh was under open sea conditions throughout the early Tertiary period (Paleocene and Eocene epochs), resulting in the creation of fossiliferous limestone and shale, as well as some sandstone. At stage B, the Oligocene is a Paleogene geologic period that lasted approximately 33.9 million to 23 million years before the present. The rock beds that characterize the epoch, as with other previous geologic periods, are well identified, although the exact dates of the epoch's start and finish are relatively uncertain. Due to hard collisions in the Himalaya, huge sediment started to come off. High sedimentation rate of deposition causes syn-depositional fault (Figure 7). Barail Group successions were deposited at this time. In the hanging wall the thickness of the Barail sediment is more than the footwall which suggests the syn-depositional movement of the fault. During stage C, the continued oblique subduction of India beneath and southeast extrusion of Burma caused the Bengal Basin became a remnant ocean basin (Ingersoll, 1990) at the beginning of the Miocene (West Burma Block). Still the sedimentation rate is high enough and the syn-depositional fault is expanding. The Surma group (Bhuban and BokaBil) deposited at this time. Syn-depositional fault continued. Stage D, describes the Pliocene Epoch, that spans 5.33 million to 2.58 million years ago. It is the Neogene Period's second and most recent period. Tipam was deposited at this period. For a long time, a normal movement of the fault was traced. This means that the collisional or compressional force is greater than the rate of sedimentation. Faulting on the normal move out has ceased. The deposition is dominated by compressional force. As a result, the roll over folding tightens (Figure 5(b)). The reversal fault occurs when the extensional force stops, and the compressional force takes control of the fault. The roll-over anticlines formed in the hanging wall block (Figure 5(b)) close to the fault plane may trap hydrocarbons as the study area reported as mature petroleum systems.

Most of Bangladesh was under open sea conditions throughout the early Tertiary era (Paleocene and Eocene epochs), resulting in the creation of fossiliferous limestone and shale, as well as some sandstone. Massive sediment began to fall as the Himalaya rose as a result of the severe collision. As a result, syn-depositional faults resulted from high rate of sedimentation. The hanging wall's thickness of the Barail sediment is larger than the Footwall. The deposition of high sediments filled till the early Pliocene. In this instance, the collisional or compressional force is greater than the rate of sedimentation. The deposition is dominated by compressional force. As a result, the roll over folding tightens. The reversal fault occurs when the extensional force stops, and the fault is taken over by the compressional force. The resulted roll-over anticlines might host hydrocarbons. Within the Bengal Basin, the Eocene shelf edge and the continental slope is depicted by the Eocene Hinge Zone (Reimann & Hiller, 1993). It indicates the shift in structure and deposition from the Stable Shelf to the Foredeep in the southeast. The hydrocarbon prospectivity of this area is not precisely defined due to lack of drilling operations. However, seismic data has revealed that the hinge zone may have potential hydrocarbon accumulation in terms of unconventional

traps such as stratigraphic traps (Salt et al., 1986). The shelf edge is a favorable locale for carbonate reef development, a favorable site for reservoir quality reefal growth presumably existing toward the east of the hinge zone (Wilson, 1997). In West Bengal, DHI (“dim” and “flat” spots) provide hydrocarbon potential within the Eocene sequence (Moore & Lenengerger, 1994; Srivastava et al., 1985). Drilled section of Eocene Sylhet Limestone is reported to be composed of biomicrite, packstone, and wackestone indicating low energy depositional condition (Moore & Lenengerger, 1994). Such coarse facies may have reservoir properties for both primary porosity and secondary porosity due to subaerial exposure of Sylhet Limestone (during Lowland). Within the hinge zone and surrounding shelfal area the Jalangi shale extends deeper into the basin. It has a TOC content of 4.7% up to 6% and it’s supposed to be within oil windows (Moore & Lenengerger, 1994). Mature Jalangi shale is supposed to be the underlying and basinward of the Hinge Zone (Moore & Lenengerger, 1994) which make it a potential candidate for petroleum source rock. The reservoir quality reef and carbonate shoals of the Sylhet limestone may trap hydrocarbons and Kopili Shale acts as a cap rock forming the regional seal all over the area. Migration of hydrocarbons may occur through faults. As, it is evident that the four-way closure required for the formulation of a Hydrocarbon system is present in this area, thereby the hydrocarbon potentiality of the investigated region can’t be denied. However, on the Indian part of the Stable Shelf exploratory wells drilled to date discovered only gas-shows and residual oil shows (Hajra et al., 1997).

6. Conclusion

The complex structural and tectonic history to the Bengal Basin, modified by Jurassic syn-rift faults, Himalayan Mountain rise and the subsequent sedimentation over the course of geologic time. The structural style of the basin has altered in response to sediment thickening and fault movement due to subsidence and syn-deposition. The interpretation of the PK-MY-8403 seismic line reveals variations in thickness and relief in different stratigraphic zones with particular attention on growth strata (post-collision sedimentation) and pre-growth strata. Distinct layer thicknesses have noticed in two modeled zones of the studied seismic section: the footwall block preceding the hypothetical fault location and the hanging wall block right after it. This is consistent with the conditions conducive to the formation of a growth fault that layers in the hanging wall block gradually thicken. Integrating the findings derived from thickness and relief analysis of the seismic section with the geological evolution of the Bengal Basin highlighting events like the Eocene Himalayan collision, Oligocene sedimentation, Miocene remnant ocean basin formation, and Pliocene reversal fault development yields a detailed insight into the possible occurrence of syn-depositional growth fault development. Based on seismic analysis and fault related modeling, this study indicates that normal faults developed during the Oligocene and continued to move in reverse until early Pliocene when compressional forces exceeded sedimentation rates. As a result of this reversal, syn-depositional growth faults de-

veloped within the investigated region. Hydrocarbons have been discovered in syn-depositional fault and associated roll over anticlines of various sedimentary basins around the world. Thereby, it can be assumed that the hypothetical syn-depositional faults and roll over anticlines in the investigated region encompassing the Eocene Hinge Zone area have HC potential where carbonate reefs and Jalangi shale contribute to the prospectivity of the region. However, the existence of petroleum system in the region requires further investigation. The outcome of this study provides greater insight and may play a crucial role in understanding the concept of growth fault development in the context of the Bengal Basin.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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