Structure and kinematics of the Indo-Burmese Wedge: Recent and fast growth of the outer wedge

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[1] The northern Sunda subduction zone, offshore Burma, and the associated Indo-Burmese Wedge mark the active eastern boundary of the Burma Platelet jammed between the India Plate and the Sunda Plate. The aim of this paper is to provide a structural and kinematics analysis of the Indo-Burmese Wedge based on seismic reflection, geodetic, and geological field data. We found out that the Indo-Burmese Wedge is the place of diffuse strain partitioning: right-lateral shearing in the innermost part and E-W shortening in the outermost part. In the outer wedge, thick-skinned deformation overprints thin-skinned deformation. It can be explained by the required preservation of the critical taper after the fast westward propagation of the outer wedge above a very efficient clayey décollement layer. The thick-skinned deformation is here characterized by major right-lateral strike-slip faults (the Kaladan Fault and the Chittagong Coastal Fault) and yet a typical internal deformation of the Indo-Burmese Wedge. We suggest that the westward migration of internal right-lateral shear deformation allows preservation of the strain-partitioning ratios between internal N-S trending right-lateral shearing and external E-W shortening. Some seismic lines show that the outer wedge deformation is not older than 2 Ma. Its propagation could have been enhanced by the large amount of sediments filling up the Sylhet flexural basin formed after the Pliocene tectonic uplift of the Shillong Plateau. **Citation:** Maurin, T., and C. Rangin (2009), Structure and kinematics of the Indo-Burmese Wedge: Recent and fast growth of the outer wedge, *Tectonics*, *28*, TC2010, doi:10.1029/2008TC002276.

1. Introduction

[2] The Indo-Burmese Wedge results from the India/Sunda plate's oblique convergence (Figure 1). Within this geodynamic framework, strain partitioning is responsible for the individualization of a sliver plate [*Jarrard*, 1986; *McCaffrey*, 1992], the Burma Plate. The Indo-Burmese Wedge marks the western margin of this sliver plate. The Sagaing right-lateral strike-slip fault marks its eastern boundary and accommodates two thirds of the parallel-to-the-trench strain component [*Vigny et al.*, 2003]. The deformation within the Indo-Burmese Wedge accommodates the remnant amount of oblique stress [*Nielsen et al.*, 2004]. Consequently, the main process responsible for the Indo-Burmese Wedge growth is N-S dextral shearing as it is confirmed by various geological observations and seismotectonic analysis [*Le Dain et al.*, 1984; *Ni et al.*, 1989; *Guzman-Speziale and Ni*, 1996; *Rao and Kumar*, 1999]. This wedge has grown and migrated rapidly westward along the southern edge of the Shillong Plateau [*Lohmann*, 1995] (Figure 1).

[3] *Curray et al.* [1979] and *Curray* [2005] have proposed that the subduction of the Bengal crust beneath the Burma Plate is active since the closure of the Neo-Tethys in Late Mesozoic [*Curray et al.*, 1979; *Curray*, 2005]. According to Curray et al., the major changes in tectonic deformation within this microplate are related to the indentation of the Eurasia by the India Plate and to the inferred clockwise rotation of Indochina. *Acharya* [2006], on the basis of a detailed analysis of the structural emplacement setting of the ophiolite belts in Burma and in Andaman Islands (Figure 1), proposes that the microplate has been constructed by the amalgamation of various microcontinents with the progressive westward jump of the subduction zone. According to Acharya, the present configuration is in place since the late Oligocene, the timing of collision of the Indo-Burma-Andaman microplate with Sunda.

[4] In this paper we provide a new structural and kinematic interpretation of the Indo-Burmese Wedge that allows a more detailed analysis of this subduction history. We propose that the Indo-Burmese Wedge was mainly built during the late Neogene by fast accretion of the Bengal Basin sediments. We also claim that the internal part of the wedge is controlled by dextral submeridian strike-slip faulting, this wedge as a whole absorbing a large part of partitioned India/Sunda oblique motion.

2. Tectonic Setting

[5] The Indo-Burmese Wedge has been recognized as a wedge resulting from the oblique subduction of the Bengal crust beneath the Burma sliver plate [*Nandy*, 1986; *Acharya et al.*, 1990; *Vanek et al.*, 1990; *Nielsen et al.*, 2004]. It presently propagates westward along the Shillong Plateau [*Lohmann*, 1995]. The tectonic units implied in this geodynamic setting are as follows:

[6] 1. The Bay of Bengal is characterized by two sets of oceanic fracture zones [*Desa et al.*, 2006] (Figure 1). The oldest fabric (transform faults) is considered to be Early

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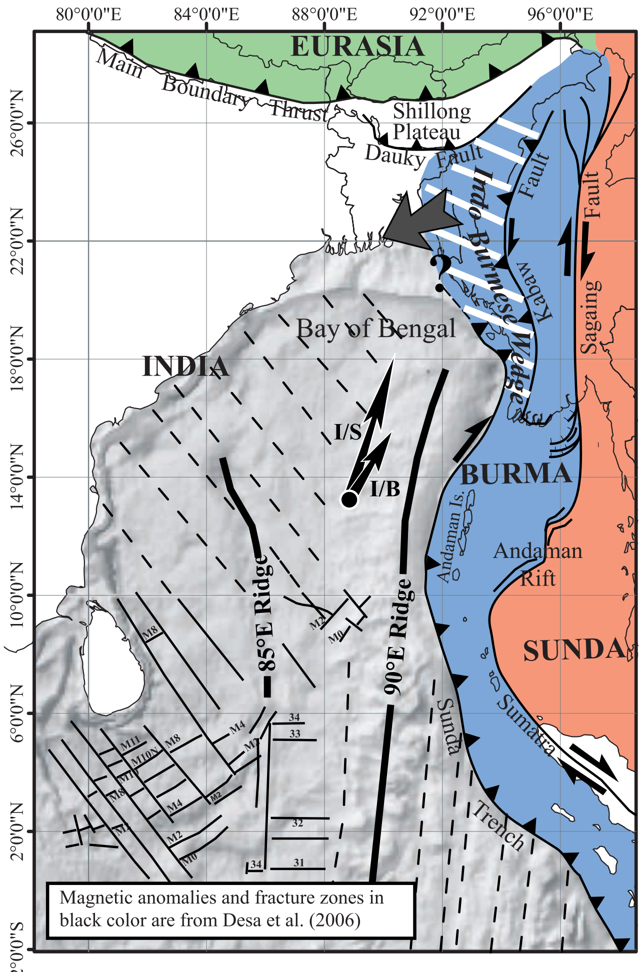

Figure 1. Structural fabric of the Bay of Bengal with its present kinematic setting. Shaded background is the gravity map from *Sandwell and Smith* [1997]. Fractures and magnetic anomalies in black color are from *Desa et al.* [2006]. Dashed black lines are inferred oceanic fracture zones which directions are deduced from Desa et al. in the Bay of Bengal and from the gravity map east of the 90°E Ridge. We have flagged particularly the 90°E and the 85°E ridges (thick black lines). Gray arrow shows the Indo-Burmese Wedge (indicated as a white and blue hatched area) growth direction discussed in this paper. For kinematics, black arrows show the motion of the India Plate with respect to the Burma Plate and to the Sunda Plate (I/B and I/S, respectively). The Eurasia, Burma, and Sunda plates are represented in green, blue, and red, respectively.

Cretaceous in age, acquired during an early spreading episode, and with strike N140°E to N150°E. It is associated with N50°E trending magnetic anomalies. The youngest fabric is submeridian and results from the northward drift of the India Plate since the end of the Mesozoic. It is associated with E-W trending magnetic anomalies initiated at An34 during the middle part of the Cretaceous [*Royer and Chang*, 1991]. These fabrics interfere into the middle part of the Bengal Basin. The 85°E and the 90°E ridges are the traces of the hot spots related to the northward drift of India. In the northern part of the Bengal Basin, and below the Bengal Fan, *Brune and Singh* [1986], *Kaila et al.* [1992]. and *Mitra et al.* [2005] propose that the continental crust has been more or less attenuated and thinned. This is still a matter of debate due to the lack of data.

[7] 2. The Burma sliver plate is bounded eastward from the Sunda Plate, by the right-lateral strike-slip Sagaing Fault [*Curray et al.*, 1979; *Le Dain et al.*, 1984; *Guzman Speziale and Ni*, 1996] (Figure 1). A 23 ± 3 mm/a rate of recent right-lateral strike-slip finite motion along this fault has been obtained by neotectonic studies [*Bertrand et al.*, 1998]. *Vigny et al.* [2003], in the GPS study in central Burma, have proposed an instantaneous 18 mm/a rate along this fault. In northern Burma, this fault connects to the Main Boundary Thrust. Southward the Sagaing Fault connects to the Andaman rift by the way of an extensive horsetail structure. Rifting in the Andaman Basin initiated some 9 Ma ago, and ocean spreading only started at 4.5 Ma [*Chamot-Rooke et al.*, 2001]. That is consequently the best estimate for the age of the Sagaing Fault.

[8] 3. Immediately west of the Sagaing Fault, the Myanmar central basins (Figure 2) consist of a series of Cenozoic basins C. Rangin et al., Cenozoic pull apart basins in central Burma; the trace of the path of India along the western margin of Sundaland, paper presented at European Union of Geosciences Conferences EUG10, Strasbourg, France, 28 March to 1 April 1999) filled up with up to 15 km of Eocene to Pliocene sediments. These basins are generally interpreted as fore-arc basins related to the Cenozoic subduction of the Bengal crust beneath the Burma Plate [*Win Swe*, 1981]. These submeridian Cenozoic basins were tectonically inverted and deformed along a dextral transpressive shear zone during the late Neogene [*Pivnik et al.*, 1998; C. Rangin et al., presented paper, 1999]. On the basis of fission track data, *Trevena et al.* [1991] proposed that the basin inversion started at 10 Ma and accelerated with a major uplift event during Plio-Pleistocene. The basement of the Myanmar central basins acts as a buttress for the growing Indo-Burmese Wedge.

[9] 4. The Shillong Plateau, bounding the Indo-Burmese Wedge to the north (Figure 2), is underlain by a Proterozoic basement [*Acharya and Mitra*, 1986]. Mesozoic to Miocene sediments drapes this basement [*Evans*, 1964]. Just south of this high, the Sylhet Trough (Figure 2) is a ~150 km wide flexural basin clearly marked by a strong negative Bouguer gravity anomaly. Sediments within this basin are 12 to 16 km thick [*Johnson and Alam*, 1991]. On the basis of seismic and well log detailed study with field validations, *Johnson and Alam* [1991] proposed that the Shillong Plateau was rapidly uplifted since the Pliocene. On the basis of new apatite (U-Th-[Sm])/He and AFT data, *Biswas et al.* [2007] show that exhumation of the Shillong Plateau started at 9–15 Ma and the tectonic uplift started some time

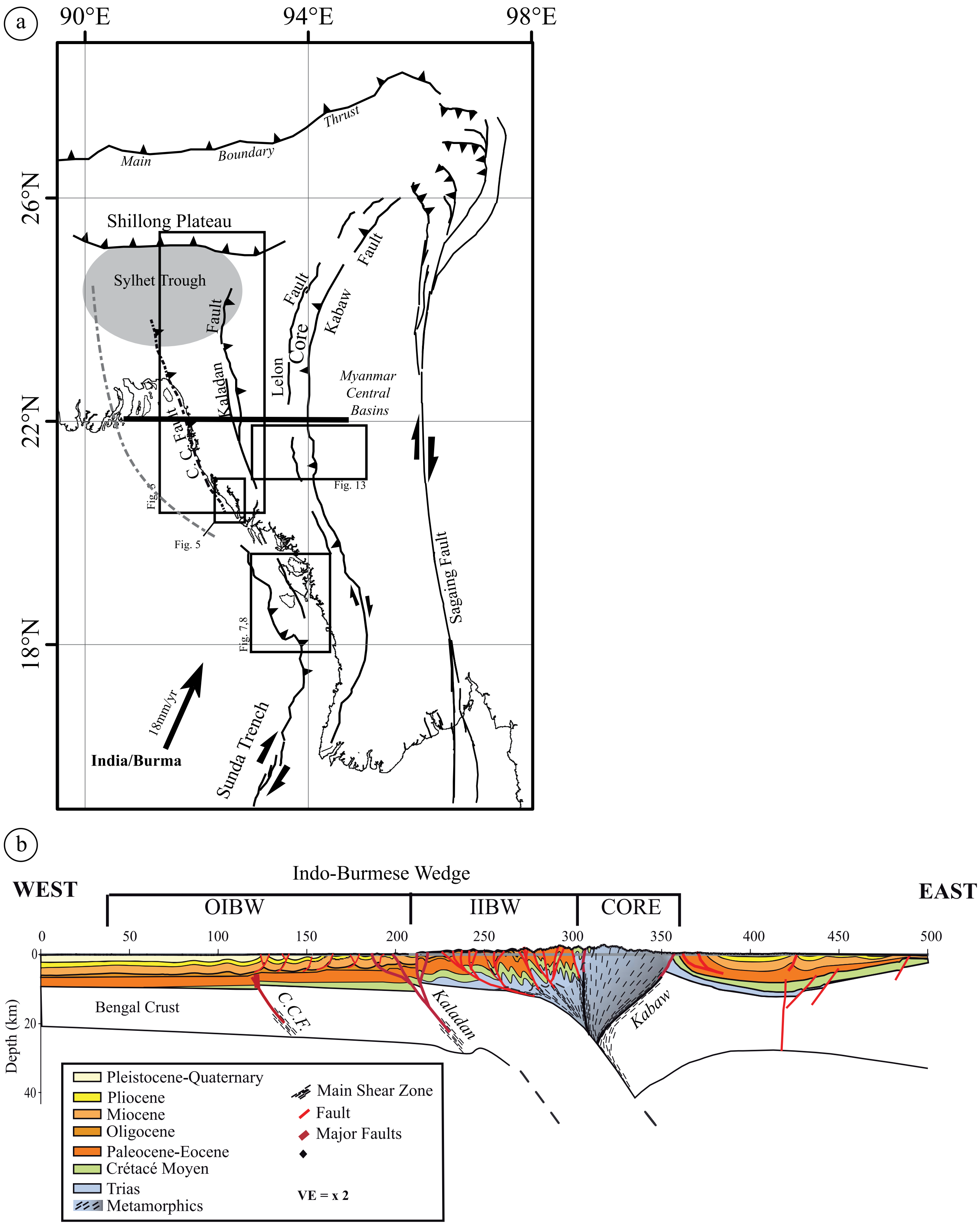
a
90°E
94°E
98°E
26°N
22°N
18°N
Main
Boundary
Thrust
Shillong Plateau
Sylhet Trough
Fault
Kaladan
C. C. Fault
Lelon
Core
Fault
Kabaw
Fault
Myanmar
Central
Basins
Fig. 13
Fig. 6
Fig. 5
Fig. 7,8
Sagaing Fault
18mm/yr
India/Burma
Sunda Trench
b
Indo-Burmese Wedge
WEST
EAST
OIBW
IIBW
CORE
0
50
100
150
200
250
300
350
400
450
500
Depth (km)
0
20
40
Bengal Crust
C.C.F.
Kaladan
Kabaw
Pleistocene-Quaternary
Pliocene
Miocene
Oligocene
Paleocene-Eocene
Crétacé Moyen
Trias
Metamorphics
Main Shear Zone
Fault
Major Faults
VE = x 2

Figure 2

later at 3–4 Ma which support the conclusions of *Johnson and Alam* [1991].

[10] In this tectonic framework, when did the Indo-Burmese Wedge form? This issue is widely debated by various studies:

[11] 1. On the basis of stratigraphic correlations on both side of this range, *Mitchell* [1993] proposed that it was continuously uplifted since early Oligocene.

[12] 2. *Acharya* [2006] proposed that a continuous eastward subduction beneath Burma since Mid-Cretaceous brought the India-Burma-Andaman microcontinent in tectonic contact and collision with Sunda, during latest Oligocene. This exotic microcontinent crops out presently in the inner part of the Indo-Burmese Wedge forming the present buttress for the outer wedge.

[13] 3. Hot spot based plate kinematics [*Lee et al.*, 2003] and ocean magnetic anomalies based plate kinematics [*Gordon et al.*, 1998] recorded a change in the rate and angle of India/Eurasia convergence in early Miocene (at ~21 Ma) which might be related to the initiation of the Indo-Burmese subduction.

[14] The age of the Indo-Burmese Wedge formation is not yet well constrained. We will show in this paper that its outer part is not older than early Pliocene.

[15] Concerning its structure, the Indo-Burmese Wedge is affected by three major transpressive strike-slip faults (Figure 2): the Kabaw Fault between the Indo-Burmese Wedge and the Myanmar central basins, the Lelon Fault between the metamorphic core of the range and the accretionary wedge, and the Kaladan Fault, described by *Sikder and Alam* [2003] as a west verging thrust extending from the Andaman Trench in the south to the northern most part of the Indo-Burmese Wedge in India. These faults delimitates three distinct tectonic units (Figure 2):

[16] 1. The core of the wedge is made of undated high-grade metamorphic rocks, tectonically imbricated with Mesozoic ophiolites and sedimentary sequences ranging from Late Triassic to Late Cretaceous [*Bender*, 1983].

[17] 2. The inner Indo-Burmese Wedge is composed of Eocene flyschs affected by N-S trending strike-slip right faults.

[18] 3. The outer Indo-Burmese Wedge is made of Neogene clastic sequences affected by folds and thrusts striking N160°E–N170°E. Sediments in the outer wedge range from lower Miocene submarine deposits, upper Miocene shelfal deposits to Plio-Pleistocene fluvial deposits.

[19] We will now focus on the outer wedge. On the basis of the well's data and seismic reflection data, supported by some field observations, we will discuss its structure and propose a tectonic model for its growth mechanism.

3. Outer Indo-Burmese Wedge

3.1. Structural Outline

[20] South of 20°N, the outer wedge is progressively narrowing, reaching only a few tens of kilometers width south of Ramree Island (Figure 2). According to *Nielsen et al.* [2004] the Indo-Burmese Wedge is here characterized by dextral transpressive tectonic with en echelon folds. In this paper we will focus on the outer wedge structure north of Ramree Island (Figure 3). From 20°N to 24°N the whole belt trends N170°E. Between 24°N and 25°N the Neogene's sediments are dragged right laterally along the southern border of the Shillong Plateau. Folds axes in the Sylhet Trough are bent from N170°E to N80°E (Figure 3).

[21] There are two main tectonic units.

[22] 1. The western offshore unit bounded eastward by the coastline is characterized by long-wavelength décollement folds, locally west verging, and subparallel to the coastline (Figure 3 and section AB in Figure 4). Their amplitude decreases westward in accordance with the westward propagation of the wedge (Figure 4, section AB).

[23] 2. The eastern unit is characterized by N160°E to N150°E trending asymmetric folds, locally faulted, box folds, and pop up observed en echelon along the Kaladan Fault (Figure 3 and section CD-EF-GH in Figure 4). Within the onshore part of the outer wedge, conjugated minor strike-slip faults striking N55°E and N114°E, respectively (Figure 3), indicate an E-W maximum compression axis σ_1 (N85°E) for this part of the wedge. Toward the north, in the Sylhet Trough, folds are dragged along the southern boundary of the Shillong Plateau (Figure 3). This pattern could be interpreted as significant dextral strike-slip motion present between the Shillong Plateau exposed basement in the north and the deformed Sylhet Trough sediments as mapped by *Srinivasan* [2005]. The fault located at the southern edge of the Shillong Plateau (the Dauky fault, Figure 3) act most probably as a lateral dextral ramp combining thrusting and dextral strike-slip faulting.

[24] The outer wedge is bounded to the east, from its inner counterpart, by the N170°E striking Kaladan Fault (Figure 2).

3.2. Kaladan Fault

[25] This fault is a noticeable morphological step between the 1300 m average elevated inner wedge to the east and the

Figure 2. (a) General structural map of the Indo-Burmese ranges. The arrow shows the motion of the India Plate with respect to the Burma Plate [*Socquet et al.*, 2006]. Figures 3, 5, 7, 8, and 13 are located with black boxes. The black dashed line is the trace of the buried incipient Chittagong Coastal Fault (C. C. Fault) discussed in this paper. The gray dashed line is the approximate position of the deformation front above the décollement, in the western boundary of the outer wedge (see text for details). The gray area shows the position of the strong negative Bouguer gravity anomaly produced by the Sylhet Trough. (b) E-W synthetic cross section based on field observations and industrial multichannel seismic data discussed in this paper. The cross section is located as a thick black line in the map. Ages and thicknesses are based on unpublished well records and previously published sedimentological studies (see text for details). OIBW, outer Indo-Burmese Wedge; IIBW, inner Indo-Burmese Wedge.

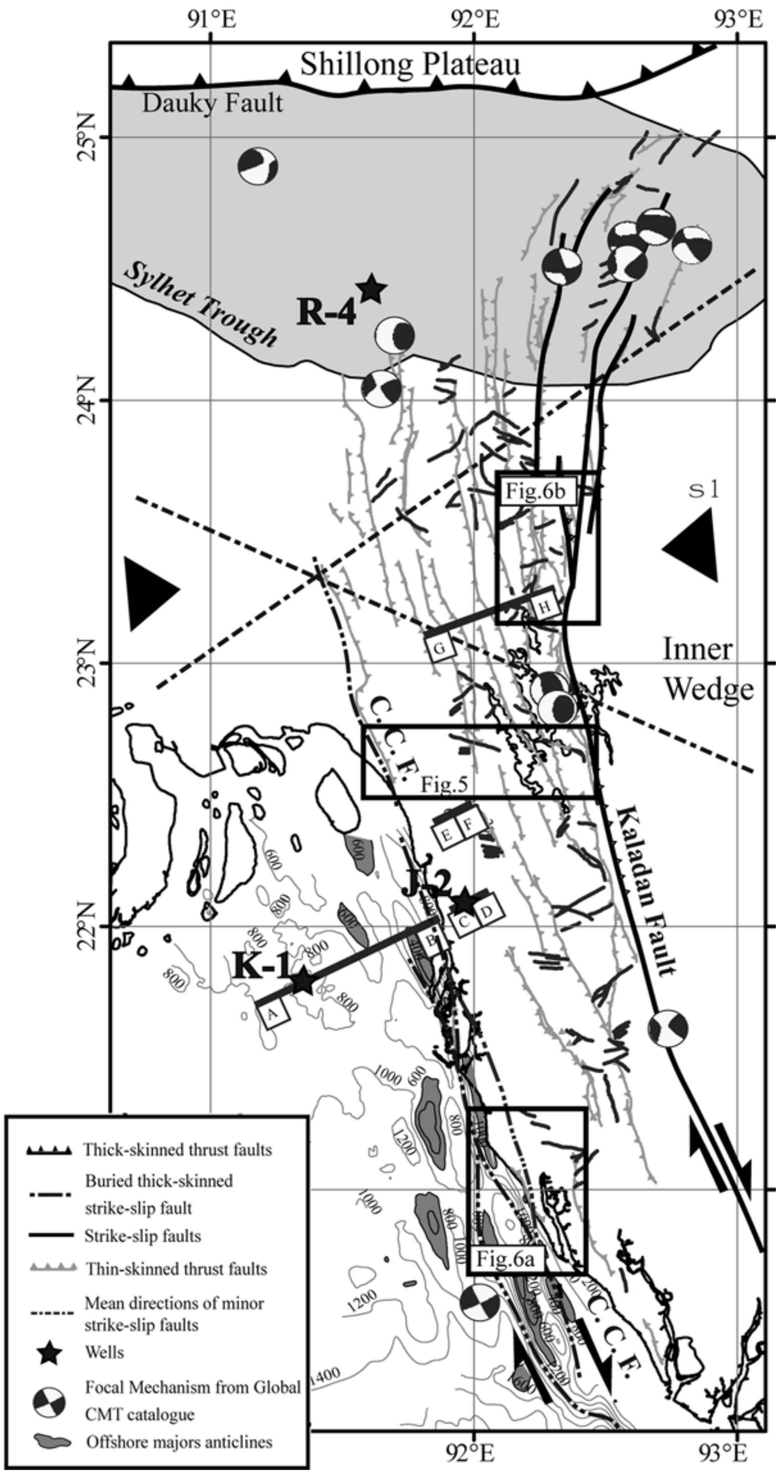

Figure 3. Structural map of the northern outer wedge. Dashed lines are the two mean directions of conjugated minor faults affecting the outer wedge. Dark gray faults are thin-skinned tectonic structures. The dash-dotted line is the buried incipient Chittagong Coastal Fault (CCF). Offshore contours are time contours (200 ms) of a latest Pliocene horizon interpreted on industrial multichannel seismic lines. Major anticlines are filled in gray. Focal mechanisms are from the global CMT catalog (http://www.globalcmt.org/CMTsearch.html). Seismic lines AB, CD, EF, and GH interpreted in Figure 4 are located as thick black lines. Black stars show the location of wells Kutubdia-1 (K-1), Rashdpur-4 (R-4), and Jaldi-2 (J-2) used for seismic interpretation.

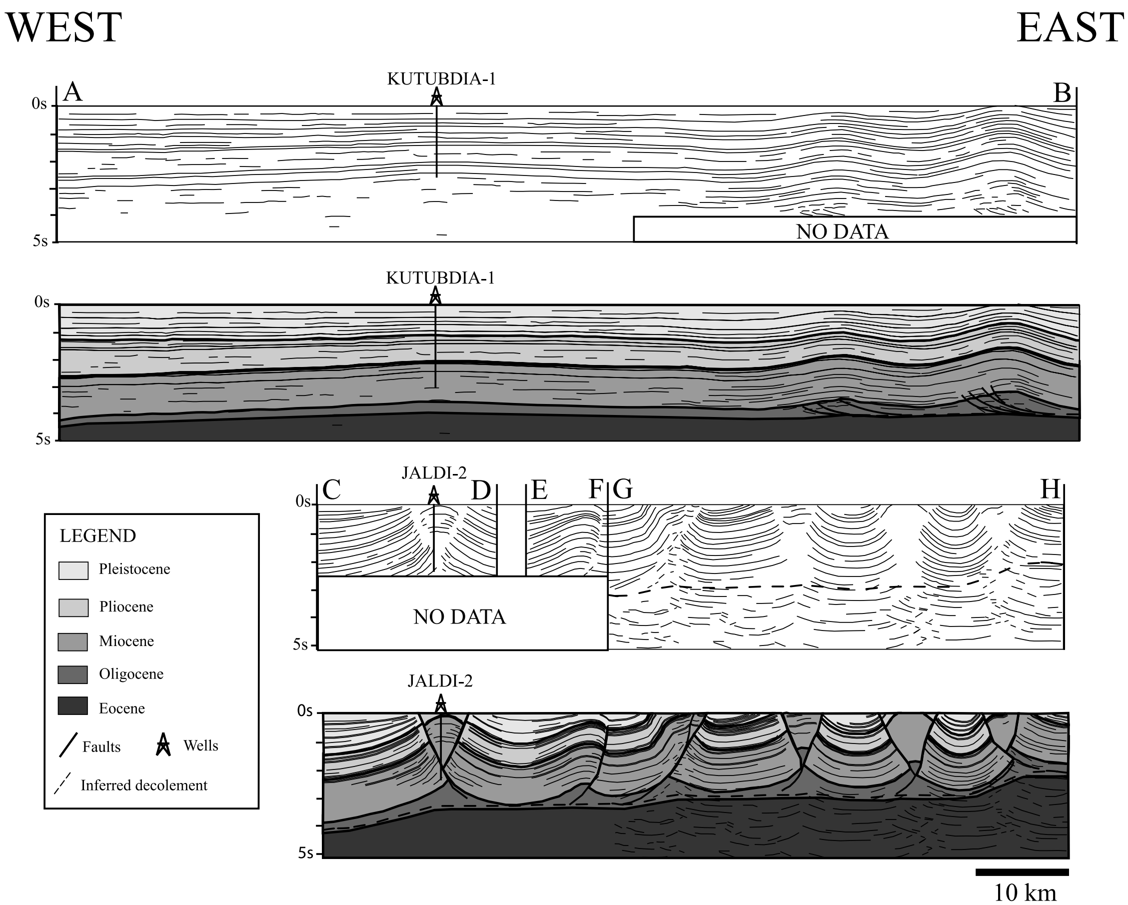

Figure 4. Line drawing and interpretation of seismic lines in the outer Indo-Burmese Wedge supported by two wells. Localization of these lines and wells are represented in Figure 3.

250 m average elevated outer wedge. Widely open en echelon folds are observed west of that fault (Figure 3). At 22°N, this boundary is geographically outlined by the N-S trending Kaladan River. Southward, between 20°N and 19°30′N, its morphological trace bends eastward as well as the general trend of the fold and thrust belt.

[26] Field data were acquired in 2004 along the Kaladan main fault in Burma at 20°30′N. A clear right-lateral offset was observed along this N160°E trending fault. The dip of the fault plane is 70°E with an 8° to 10°S pitch. In the same area, microstructural analysis indicates a N80°E to N60°E directed maximum compression axis σ_1. Unfortunately, because of bad exposures, we have not been able to collect enough microstructural data to determine with precision the stress tensor all along the fault.

[27] Seismically, the Kaladan Fault is poorly active. Several focal mechanisms show a right-lateral strike-slip motion along its northern termination (Figure 3). Immediately south of 23°N, some pure E-W or WSW-ENE thrusting focal mechanisms are known along the trace of the Kaladan Fault Zone (Figure 3), suggesting that active motion is partitioned on very short distances between N10°W dextral strike-slip and west verging thrusting. This kind of partitioning within a narrow fault system has been described along the Marlborough fault zone in New Zealand [*Van Dissen and Yeats*, 1991].

[28] As stated above, the outer wedge is composed of two main tectonic units bounded by the coastline where a major fault could be located: the Chittagong Coastal Fault.

3.3. An Incipient Chittagong Coastal Fault

[29] *Sikder and Alam* [2003] proposed that a major structure exists along the Chittagong coastline in Bangladesh but with no more details. Sikder and Alam claim that wrenched fold structures underlined this Chittagong Coastal Fault. Wrench tectonic is particularly clear in the southern Chittagong district along the coast (Mirinja and Olhatong folds Figure 6). These double verging folds can be interpreted as formed above a buried strike-slip fault. Offshore mapping of the late Pliocene seismic horizon on multichannel industrial seismic lines shows that the main folds are aligned, over a few hundreds of kilometers, along the coastline that is subparallel to the Kaladan Fault (Figure 3). This coastline could outline a tectonic structure. Finally, as illustrated by the interpreted seismic lines (Figure 4), the décollement level is deeper offshore than onshore (~4 s and ~3 s, respectively). The above observations suggest the existence of a crustal dextral strike-slip fault at depth, with a

noticeable thrusting component, along the coastline, from 19°40′N to 23°30′N: the Chittagong Coastal Fault.

[30] This Chittagong Coastal Fault is seismically poorly active. At 21°30′N, a focal mechanism (from Global CMT catalog) could be interpreted as a N10°W dextral strike-slip motion (Figure 3). North of 22°N, the fault splays in various branches before disappearing in the Sylhet Trough. There, focal mechanisms show either strike slip or thrusting. Motion could be partitioned within the different branches at the northern end of the Chittagong Coastal Fault as it is suspected for the Kaladan Fault. We think that the Chittagong Coastal Fault described above is similar to the Kaladan Fault but is more deeply buried because displacement is still very small and the fault is probably more recent and not affected by sufficient erosion. We propose that the Chittagong Coastal Fault is also a new major fault that onset after the Kaladan Fault as the wedge was progressing westward.

[31] These two major faults (Kaladan and Chittagong coastal faults) can be interpreted as the boundaries of a 100 km wide shear band embracing the whole onshore part of the outer wedge. This shear zone is framed by en echelon folds and thrusts. We will now discuss the deep internal fabric of this deformed sedimentary mass.

3.4. Deep Structure of the Outer Wedge, a Thin-Skinned Tectonic Model

3.4.1. A Décollement Level

[32] Although many observations tend to demonstrate the presence of a décollement level within this belt, its existence is still a matter of debate. *Sikder and Alam* [2003] have shown a clear décollement level at about 4 s two-way time (TWT) along two seismic lines located at the northern tip of the outer wedge. *Lohmann* [1995] has also discussed, on a 1993 seismic line from Petro-Bangla, located eastward of the previous ones, such décollement at the same depth. In both localities, this structure is inferred to be an overpressured shale horizon also described in three boreholes by *Sikder and Alam* [2003]. Southward, at 22°30′N, *Zahid and Uddin* [2005] have identified an overpressured shale horizon on the basis of a decreasing sonic velocity signal at 3 to 4 km depth. Zahid and Uddin interpret these data as a potential décollement level located within the upper Oligocene sequence.

3.4.2. A Thin-Skinned Tectonic Model

[33] We have performed an interpretation of various industrial seismic lines in the Bengal Bay and within the outer wedge. This interpretation is supported by some well data and surface geology observations. In Figure 4 we present four multichannel seismic line interpretations from the offshore and onshore part of the outer wedge. Interpretation is constrained by data from well Kutubdia-1 and Jaldi-2. Biostratigraphic analyses provide few significant markers of late Miocene to Pleistocene age: a late Pliocene nannofossil marker (NN18) is reported at 1300 ms and a Pleistocene nannofossil marker is reported at 930 ms (NN19) A. C. Salt et al., The Petroleum Geology and Hydrocarbon Potential of Bangladesh, 2 vols., BAPEX Core Lab unpublished report, 1996). Miocene series are inferred to be about 3100 m thick in the stable shelf province [*Alam et al.*, 2003].

[34] In section AB, the imaged detachment folds have amplitudes that increase eastward (Figure 4). Considering fold geometry, décollement level must be around 4.5 s. From décollement level to the latest Pliocene marker, sediment beds are parallel. From latest Pliocene to present, growth on the limbs of the anticlines allows dating of folding as young as latest Pliocene (~2 Ma).

[35] In section GH (Figure 4), the late Miocene is exposed into the core of all the anticlines, as it was observed on the field during a close by geological traverse (Figure 5 and Table 1). The thickness of the units in the synclines is constrained following *Gani and Alam* [2003]. Velocity law used is from the Rashidpur-4 well [*Zahid and Uddin*, 2005] (located in Figure 3 as "R-4"). At the latitude of the cross section, the décollement is at about 4000 m depth [*Zahid and Uddin*, 2005; *Sikder and Alam*, 2003], thus nearly 3 s depth in two-way time. Although we do not clearly see the décollement level on the seismic line which has a bad resolution at depth, the fold geometry is coherent with such a décollement at about 3 s (Figure 4). The GH section ends to the east in the vicinity of the Kaladan Fault and images pop up structures or fault propagation folds mainly east verging. Below the easternmost fold, a triangular zone is inferred as deduced from detailed mapping along the Kaladan Fault, on the basis of SRTM's interpretation (Figure 6b). Neither piggyback basins nor synfolding deposits were observed along this section, neither on the field nor on the seismic lines, indicating a very recent deformation.

[36] *Uddin and Lundberg* [1999] proposed that a paleo-Brahmaputra Delta was previously channeled through the present Chittagong Province during early to middle Miocene time. It is obvious that uncompacted sediments from this paleo-Brahmaputra could have acted as a strongly decoupled décollement level.

[37] The outer wedge is affected by thin-skinned tectonics on a décollement level probably located within lower Miocene overpressured shales at a depth of 3 to 4 km east of the Chittagong Coastal Fault and 4 to 5 km west of the Chittagong Coastal Fault. Both the base of synclines and the décollement level were uplifted east of the Chittagong Coastal Fault. This uplift could have been triggered by the active crustal Chittagong Coastal Fault thrusting component of motion implying an overprinted thick skin tectonics. Our main result is that the outer wedge was formed by a combined thin-skinned and thick-skinned tectonic during the last 2 Ma.

[38] Southward the outer wedge is narrowing down to the Ramree Island area which we discuss in detail in section 4.

4. Preliminary Observations on the Ramree Area: Virgation of the Main Faults

[39] Along the Andaman Islands and the southern part of Burma, India/Burma plate movement is parallel to the trench (Figure 1). It implies a clear dextral strike-slip motion along that trench which strikes NNE [*Nielsen et al.*, 2004].

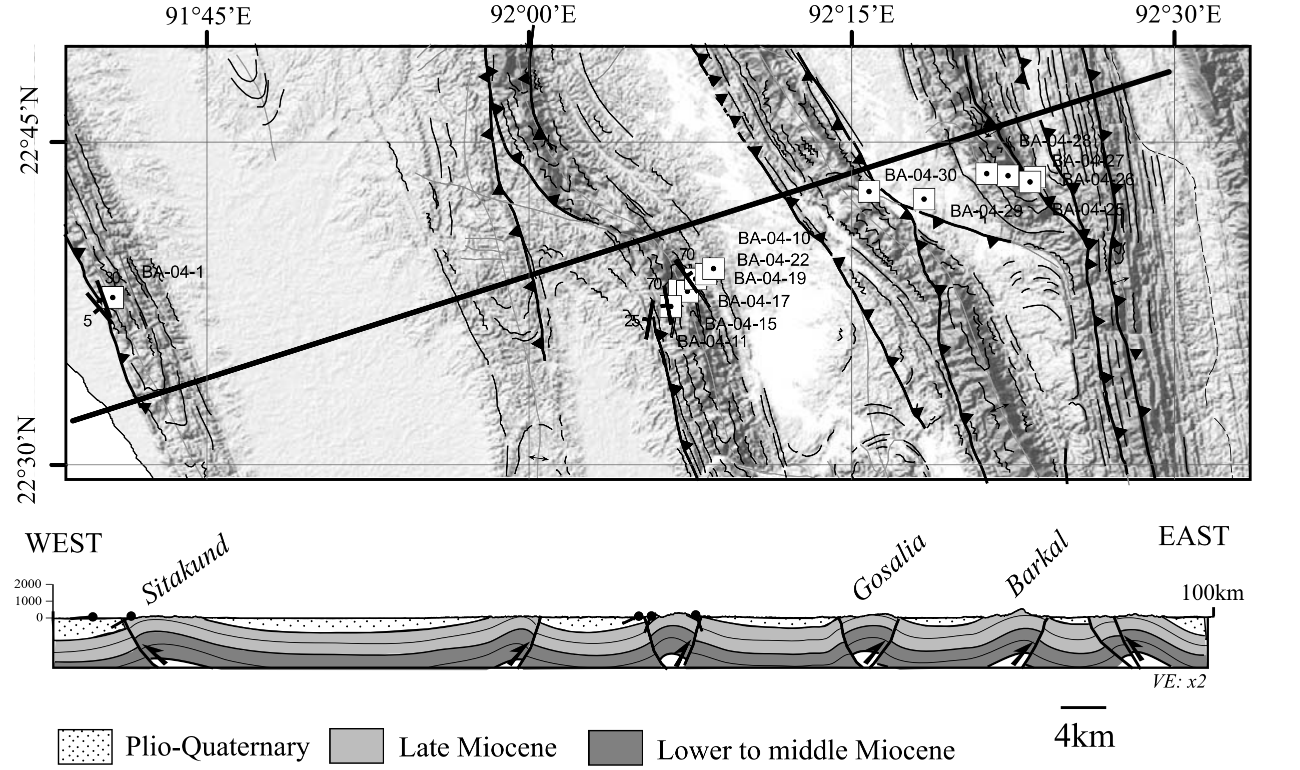

Figure 5. Synthetic field cross section through the outer Indo-Burmese Wedge. The sample list is provided in Table 1.

In the Cheduba and Ramree islands area (Figures 7 to 9), at 20°N, both the trench and the Arakan Range bend from a NNE to NNW direction (Figure 2). This area of quick change in the trend of the India/Burma plate boundary is characterized by a flat shallow coastal plain and large islands (Cheduba and Ramree) with a different stratigraphy (dominated by the Eocene melange) and structural style.

4.1. Stratigraphy of Ramree Area

[40] On Ramree Island two formations are exposed: turbidites in perched circular synclines (Figures 7 and 8a) overlooking a peneplain more or less at sea level where a melange is cropping out. The turbidites in the synclines are dated Oligocene–early Miocene on foraminifera (sample MY06/97 (N9°11.810′N; 93°49.583′E) that contains Oligocene or early Miocene planktons). The formation cropping out in the peneplain, along the sea in Ramree, and to the south in Sandoway, is a melange made of a black shaly matrix in which most of the rocks forming the core of the Arakan Range are observed as olistoliths: pillow lava (Figure 8g), polymictic conglomerates with quartz and cherts (Figure 8f), turbidites that could be lateral equivalent

Table 1. Samples Collected Within the Outer Indo-Burmese Wedge

Sample	Latitude	Longitude	Anticline	Lithology	Palynological Dating
BA-04-1	22°37′47″	91°40′37″	Sittakund	sand plus mud drapes	Miocene
BA-04-10	22°39′07″	92°08′33″	Sittakund	mud	early Miocene or younger
BA-04-11	22°37′22″	92°06′34″	Sitapahar	mud	late Miocene
BA-04-15	22°38′09″	92°06′58″	Sitapahar	mud	late Miocene
BA-04-17	22°38′04″	92°07′21″	Sitapahar	silt/shale	late Miocene
BA-04-19	22°38′39″	92°07′44″	Sitapahar	mud	-
BA-04-22	22°38′52″	92°08′13″	Sitapahar	silty shale	late Miocene
BA-04-25	22°43′24″	92°23′30″	Barkal	mud	late Miocene
BA-04-26	22°43′10″	92°23′17″	Barkal	sand/shale	-
BA-04-27	22°43′27″	92°22′15″	Barkal	sand/shale	-
BA-04-28	22°43′33″	92°21′16″	Barkal	sand/shale	-
BA-04-29	22°42′22″	92°18′22″	–	mud	-
BA-04-30	22°42′42″	92°15′47″	–	mud/silt	late Miocene

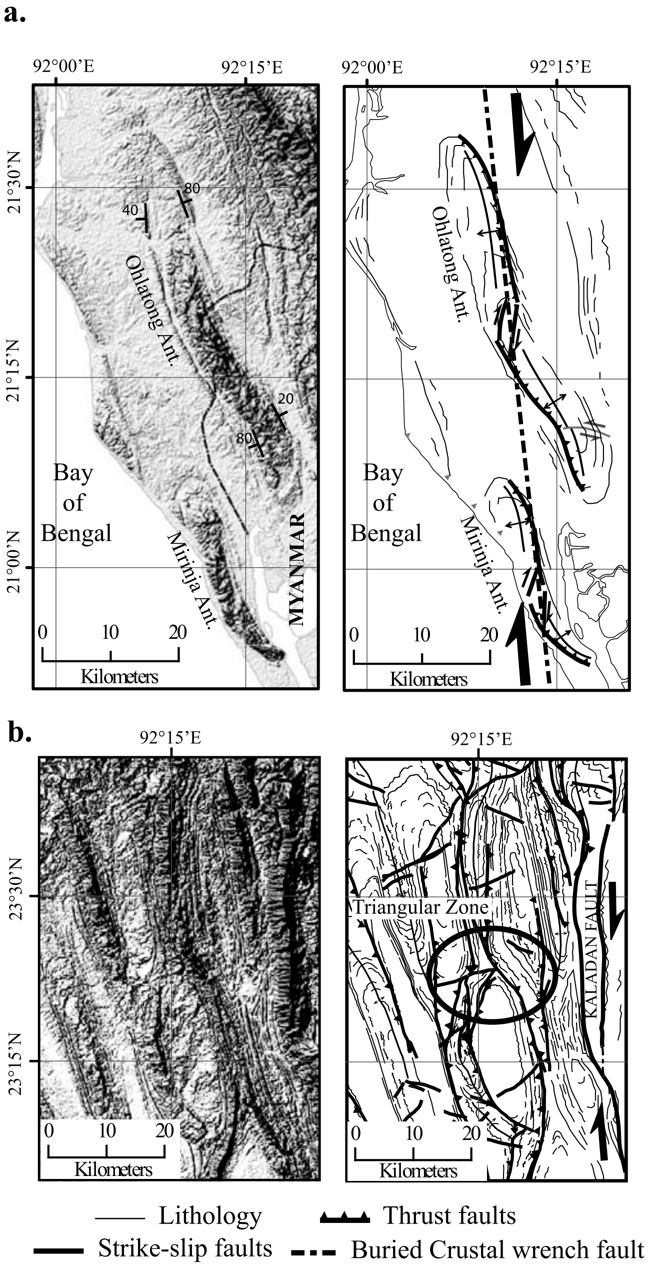

Figure 6. (a) Structural map of Olhatong and Mirinja anticlines (Ant.), based on SRTM image's interpretation. These two anticlines are interpreted as two right laterally wrenched folds along the Chittagong coast. (b) Structural map in the vicinity of the Kaladan Fault, based on SRTM image's interpretation, showing typical triangular zones.

of the black shaly matrix (Figure 8d), sandstone and shale possibly belonging to the Triassic Halobia sandstone (Figure 8e). The matrix of the melange was dated Lutetian to Chattian on foraminifera (sample MY06/112 (19°05.25′N; 94°11.247′E) that contains *Reticulofenestra bisecta* and *Cyclicargolithus floridanus*).

[41] A large block (over 100 m) of nummulite-rich bioclastic limestone (Figure 8b) has been observed as a sliver in the N130°E thrust zone between the Eocene and Miocene along the northwestern shore of Ramree Island (Figure 9). This large block can either be part of the melange or another formation accreted in the belt. This kind of nummulite-rich calcarenite could originate from the lower plate, e.g., deposited on volcanic highs like the 90°E Ridge.

4.2. Tectonic Interpretation of Ramree Area

[42] The most common features observed in Ramree Island are the circular synclines (Figure 7). Below and between them, in the melange, common veins with no preferential orientations and hydrofractured boulders (Figure 8c) are observed, suggesting that the shales have been overpressured. The geometry recalling that of the minibasins on salt known in the Gulf of Mexico M. G. Rowan et al., Evolution of autochthonous salt and primary diapirs, southeastern Mississippi Canyon: Lessons for the subsalt environment of the northern Gulf of Mexico, paper presented at AAPG Annual Convention, New Orleans, Louisiana, 2000; B. C. Vendeville and M. G. Rowan, 3-D kinematics of minibasins and salt ridges remobilized by late contraction: Physical models and seismic examples (SE Mississippi Canyon, Gulf of Mexico), paper presented at AAPG Annual Meeting, Houston, Texas, 2002) and evidence for overpressure in the shales both lead us to interpret Ramree's structures as minibasins on mobile clay. In these assumptions, their formation occurred at the time of deposition of the turbidites in the circular syncline. We dated these turbidites Oligocene–early Miocene on foraminifera (sample MY06/97 (19°11.810′N; 93°49.583′E) that contains Oligocene or early Miocene planktons). The paleogeography of this large clayey deposit is still poorly understood.

[43] Following this Oligocene–early Miocene gravity tectonic episode, recent deformation of the wedge involved three main NW–SE thrusts (Figure 9). The inner thrust, the Ramree thrust, was observed on the northwestern shore of Ramree Island as a N130°E striking thrust. Considering its alignment with the Kaladan Fault observed more to the north (Figure 2a), the Ramree thrust is a good candidate for the southward continuation of the Kaladan Fault. West of it, the structure of the thrust sheet is complex due to the early gravity tectonics. The style differs from the one observed in the north, where closely spaced elongated folds are observed between the Kaladan Fault and the Chittagong Coastal Fault, probably due to less competent rheology of the sedimentary pile.

[44] Offshore Cheduba Island, on the western side, a map of the top Pliocene horizon traced on industrial multichannel seismic lines reveals two N130°E trending west verging fold (Figure 9a). On the basis of seismic data (Figure 9b), we interpreted these folds as a fault propagation folds that growth on deep rooted west verging thrust faults. Both faults situated west of the inferred Kaladan Fault (Figure 9a) are good candidates for the southward continuation of the Chittagong Coastal Fault.

[45] Overprinted gravity sliding occurred on the limb of the escarpment (Figure 9). The resulting detachment faults are observed on both the high-resolution bathymetric map

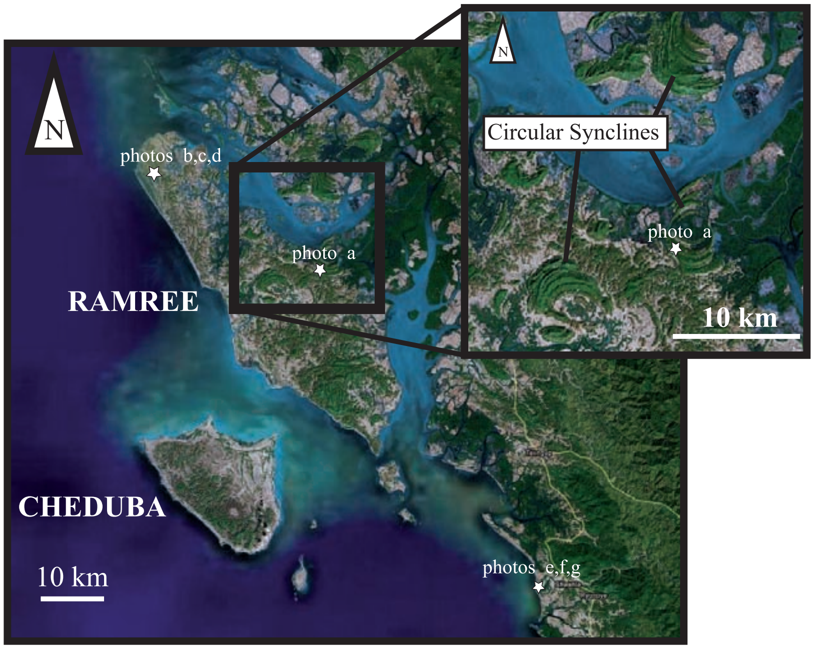

Figure 7. Landsat image of the Ramree and Cheduba islands. The area is located in the larger-scaled Figure 2. The locations of photos from Figure 8 are flagged as white stars. Insert at top right shows a close-up on the typical circular synclines.

and the seismic line (Figures 9a and 9b). On the seafloor, traces of a recent sliding event have been observed (Figure 9a). The area covered by this gravity sliding is more than 750 km^2.

[46] Both the gravity sliding and the thrusts and folds discussed above, offshore Cheduba, form the ‘‘Ramree lobe’’ first described by *Nielsen et al.* [2004] The lobe is framed by N120–140°E trending fold and thrust combined with N10°–20°E strike-slip right faults. A conjugated N55°E sinistral lateral ramp fault (already reported by *Nielsen et al.* [2004]) guides the outward growth of the lobe. This fault geometry suggests a ~N30°E maximum compression axis σ_1 which is coaxial with the India/Burma plate convergence vector (~N27°E). Also the folds and the thrust axis are perpendicular to that direction. The seismic data suggest that this compressive tectonic episode started during late Pliocene–early Pleistocene (Figure 9). As stated above, it follows an Oligo-Miocene gravity tectonic episode during which the circular synclines were formed (Figure 9c).

[47] The Ramree area is a peculiar area where the Chittagong Coastal Fault and the Kaladan Fault swing from N130°E–N160°E in the north to N10°E–N30°E in the south, inducing this apparently complex tectonic geometry (Figure 9a).

5. Recent Shortening Across the Outer Indo-Burmese Wedge

5.1. Recent Onset of Deformation

[48] On land, the folded sediments on top of most of the anticlines have been dated late Miocene (Figure 5 and Table 1). No piggyback basin was observed between anticlines in the outer wedge, indicating a recent coeval deformation all across the belt. Synfolding deposits observed on the various interpreted seismic lines show that the deformation took place in the outer wedge since latest Pliocene time. This age is coeval with the major Pliocene unconformity observed in the Bengal Bay [*Shwenk*, 2003] and with the Pliocene uplift of the Shillong Plateau [*Johnson and Alam*, 1991]. The onset of the Shillong Plateau uplift and thrusting is a major event that is recorded far inside in the Bengal Bay. The India Plate is flexured in front of this plateau, creating the 150 to 200 km wide Sylhet Trough with a typical width (Figure 3). The deepening and infilling of this basin could be responsible for the fast westward growth of the outer Indo-Burmese Wedge since 2 Ma. The outer wedge alone represents two thirds of the total wedge thickness at 22°N. It has propagated westward at nearly 10 cm/a (the outer wedge deformation extends over 200 km wide and is not older than 2 Ma).

5.2. Amount of Shortening Since 2 Ma

[49] A 200 km long N70°E striking composite balanced cross section through the outer wedge (Figure 10) is used to estimate the shortening across the belt. The geometry at depth is constrained by four N70°E trending multichannel seismic lines (lines AB, CD, EF, GH located in Figure 10b). Lithology and ages (Figure 10c) are constrained by two wells located within this area and by previously published sedimentary works in the area [*Evans*, 1932; *Johnson and Alam*, 1991; *Uddin and Lundberg*, 1999; *Gani and Alam*, 2003; *Alam et al.*, 2003; *Sikder and Alam*, 2003]. Depth to

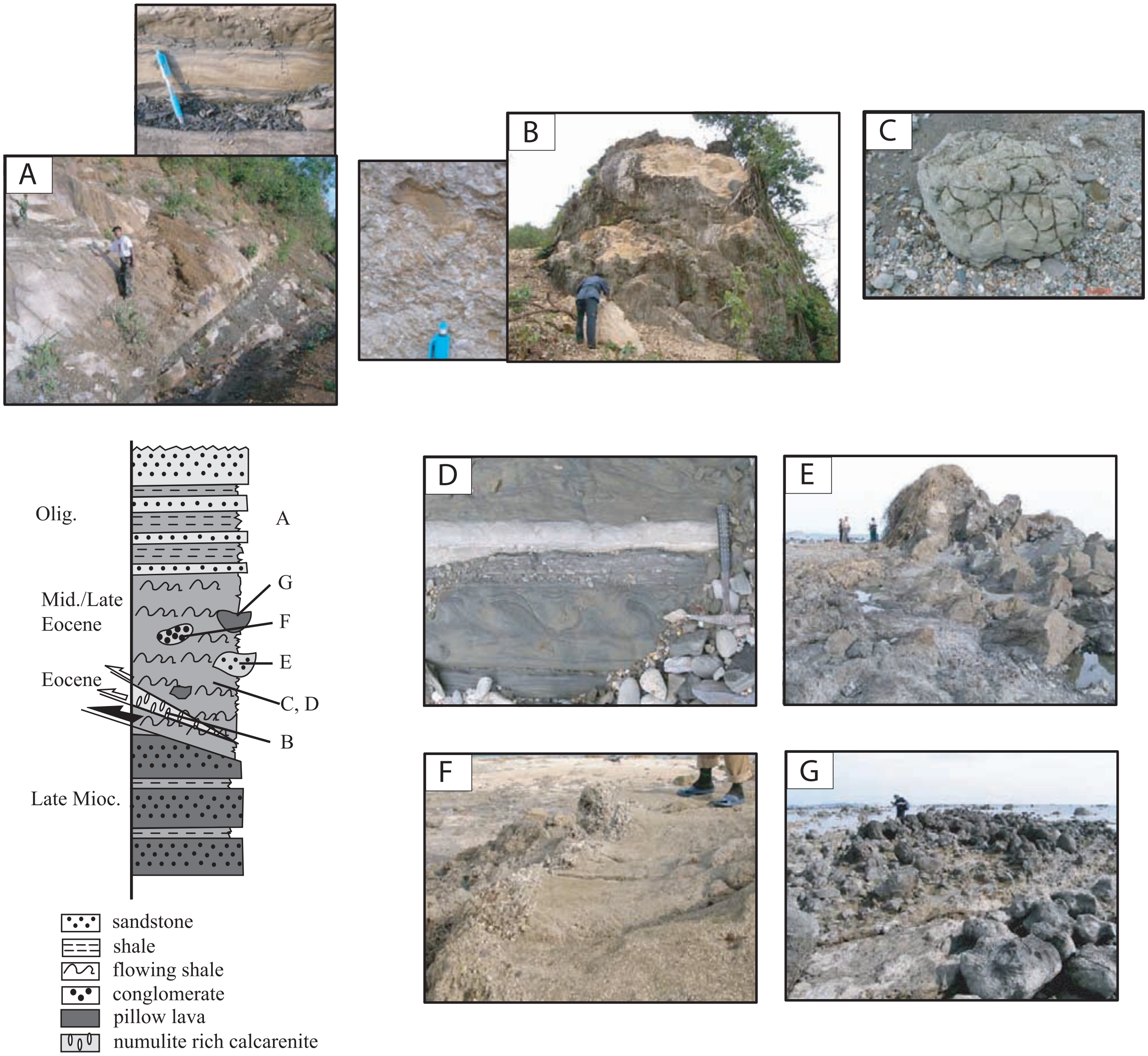

Figure 8. Approximate stratigraphic column of Ramree area and pictures illustrating these various stratigraphic units (see text for a detailed description of the units).

basement is constrained by deep seismic sounding investigations to be about 12 km [*Kaila et al.*, 1992].

[50] In the Myanmar central basins, *Pivnik et al.* [1998] show that pre-Oligocene strata are lying unconformably on top of a Mesozoic basement. On the basis of the assumption that the Indo-Burmese Wedge was uplifted since latest Eocene [*Mitchell*, 1993], we constrained the geometry of pre Oligocene strata to be similar to those of the Myanmar central basins, i.e., lying unconformably on top of a Mesozoic basement. We have restored the synthetic cross section using the Paradigm software GeoSec 2D. Considering that the deformation is very recent and that section azimuth is very close to the maximum compression axis azimuth obtained from structural data (60–80°E; this study), we postulate that out-of-section transport is negligible.

[51] The Kaladan Fault and the Chittagong Coastal Fault were first considered as thin-skinned faults. The restoration of the compressive component of the deformation yields ~10 km of shortening including the two crustal faults. The Kaladan Fault and the Chittagong Coastal Fault are interpreted as deep-seated basement strike-slip reverse fault below the décollement. Geometrical constraints during the restoration process revealed that the crustal faults must have been activated after the thin-skinned tectonic deformation. This kind of latter thick-skinned tectonic has been interpreted in Zagros as a step toward the reestablishment of the critical taper by *Molinaro et al.* [2005]. Décollement folding produced one additional kilometer of shortening. Total restoration of the synthetic cross section yields 11 km of shortening.

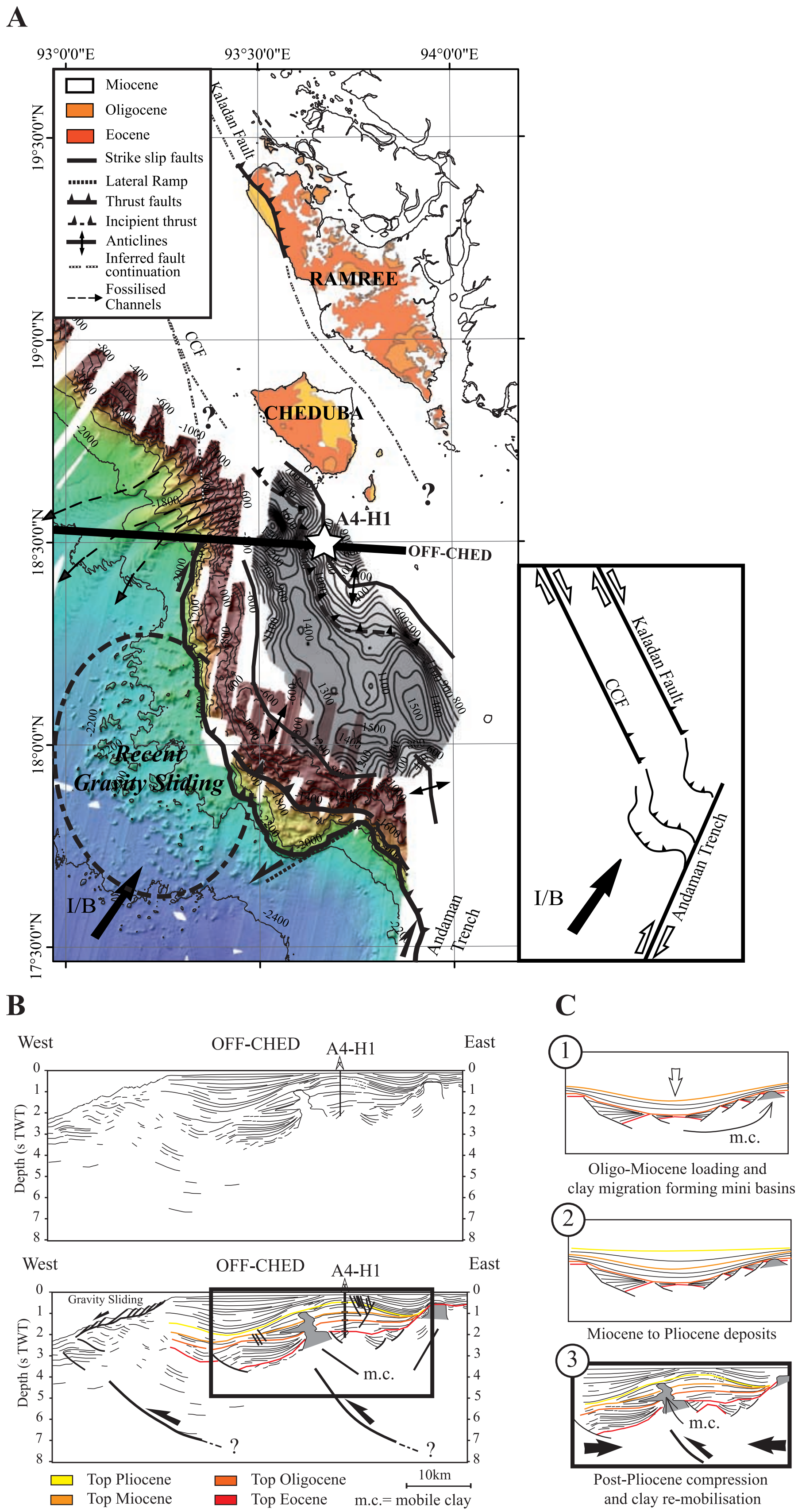
A
93°0'0"E
93°30'0"E
94°0'0"E
19°30'0"N
19°0'0"N
18°30'0"N
18°0'0"N
17°30'0"N
Miocene
Oligocene
Eocene
Strike slip faults
Lateral Ramp
Thrust faults
Incipient thrust
Anticlines
Inferred fault continuation
Fossilised Channels
Kaladan Fault
RAMREE
CCF
CHEDUBA
A4-H1
OFF-CHED
Recent Gravity Sliding
I/B
Andaman Trench
Kaladan Fault
CCF
I/B
Andaman Trench
B
West
OFF-CHED
A4-H1
East
Depth (s TWT)
Gravity Sliding
m.c.
Top Pliocene
Top Miocene
Top Oligocene
Top Eocene
10km
m.c.= mobile clay
C
1
m.c.
Oligo-Miocene loading and clay migration forming mini basins
2
Miocene to Pliocene deposits
3
m.c.
Post-Pliocene compression and clay re-mobilisation

Figure 9

[52] To complete our restoration process, a forward modeling has been completed to test this section (Figure 11). The same constraints as above have been used for the initial model geometry. Visually, our forward modeling yields a satisfactory fit to the data used for the restoration. Nevertheless, one should note that décollement folding west of the Chittagong Coastal Fault has not been modeled. Eleven kilometers of shortening are necessary to fit the data. Considering that the deformation has been active since 2 Ma, we obtain a shortening rate of about 5.5 mm/a along the section.

5.3. Kinematics Outcomes

[53] The shortening rate calculated above (5.5 mm/a) is the projected India/Burma plate motion along azimuth of the section from point H (Burma Plate) to point A (that belongs to India). The section azimuth is very close to the finite motion azimuth. We thus can simply calculate the eastward motion of point H with respect to India and compare it to what is expected from plate kinematics.

[54] The India plate motion is proposed to be 35 mm/a in a N11°E azimuth with respect to the Sunda Plate at latitude 22°N [*Socquet et al.*, 2006]. Considering the 18 mm/a N5°W motion of the Burma Plate with respect to Sunda Plate along the Sagaing Fault [*Vigny et al.*, 2003; *Nielsen et al.*, 2004], we expect a westward motion of Burma with respect to India of 8.3 mm/a.

[55] The east component of the calculated shortening rate across the whole outer wedge is 5.1 mm/a. It is less than the E-W plate convergence rate (8.3 mm/a). Since 2 Ma, about two thirds of the total amount of E-W shortening is accommodated in the outer wedge. The remnant shortening can be accommodated within the inner wedge, along the west verging Kabaw Fault or within the inverted Myanmar central basins. Hereafter, the oblique subduction is probably partly decoupled.

[56] GPS data in Burma from *Vigny et al.* [2003] provide additional data between the Indo-Burmese Wedge and the Sagaing Fault. Considering that the estimated finite deformation within the outer wedge is recent (not older than 2 Ma) and coeval, we assume that the comparison with GPS instantaneous measurements is valid. Figure 12 shows the east component of motion at stations belonging to the Burma sliver plate from *Vigny et al.* [2003] with respect to India (white diamonds) and E-W shortening data in the outer wedge calculated from restored cross sections (black diamonds), all plotted on an E-W section located at ~22°N.

[57] The Mindat GPS station (MIND) moves eastward with respect to India at the same rate (4.3 ± 0.5 mm/a) as point H (5.1 ± 1 mm/a for point H). It means that MIND station is not moving with respect to the outer wedge. As a first result, the inner wedge, between MIND and point H, is locked or is only affected by N-S strike-slip deformation.

5.4. Inner Wedge: From Deep-Seated Ductile Shear Zone to Brittle Wrenching

[58] On the basis of teleseismic data interpretation, *Ni et al.* [1989], *Guzman-Speziale and Ni* [1996], and *Rao and Kumar* [1999] have postulated active dextral shear deformation at India-Burma Plate boundary within the Indo-Burmese Wedge.

[59] The easternmost major fault of the Indo-Burmese Wedge is the Kabaw Fault (Figure 2). It is an east verging reverse-dextral fault zone between the ophiolite and metamorphics to the west and the clastic Late Cretaceous Kabaw Formation to the east (Figure 13). In the fault zone a melange similar to the one observed in Ramree, made up of a black shaly matrix with various olistoliths and clasts (conglomerates with peridotite, metamorphics and calcareous clasts; microconglomerates with cherts; recrystallized and pelagic Limestone; radiolarian and pillow basalts), was observed. The wide extension of this melange and the association with the ophiolite suggest that it may be related to the mid-Eocene ophiolite obduction [*Acharya*, 2006]. In the assumption that the Arakan Range is an oblique wedge, the Kabaw Fault can be interpreted as the back thrust between the wedge and its back stop (the Myanmar central basins).

[60] The core of the Indo-Burmese Wedge, between the Kabaw and Lelon faults, is made of undated high-grade metamorphic rocks (Kampetlet schist) (Figure 13). Along some river sections, the progressive evolution from unmetamorphosed Triassic Halobia sandstone (Figure 14a) to micaschists affected by N165°E mullions (Figure 14b) was studied. Associated shear criterions of the quartz exolutions demonstrate a top-to-the-south deformation resulting from a deep northward transport (Figure 14c). The brittle deformation associated to the progressive exhumation of the mullion involves right-lateral slickensides on N-S fold limbs and E-W normal faults in the overlying Triassic sandstones (Figure 14d).

[61] Although more field data would be necessary for confirmation, the Kampetlet schists are interpreted as the uplifted deepest part (brittle-ductile transition) of a right-lateral shear zone. It affects the inner wedge at the expenses of the Triassic, the ophiolite, and younger sediments and was exhumed by continuous deformation. Analyses of P-T path demonstrate a 25–30 km slow exhumation that can be related to a shear zone [*Socquet et al.*, 2002].

[62] To the west, the Lelon Fault Zone is a 5 km dextral reverse shear zone, where slivers of micashists (Kampetlet) and sandstones (Chin Flysch) affected by N-S to N170°E,

Figure 9. (a) Geological and structural map of the Ramree and Cheduba islands area (Myanmar). The blue to red shaded grid is a high-resolution bathymetric map contoured every 200 m. Dark to bright gray grid is obtained from top Pliocene horizon mapping based on industrial seismic lines and contoured every 100 ms TWT. The thick black line and the white star show the localization of the interpreted seismic line and the well A4-H1, respectively. A black arrow indicates the Indian plate motion with respect to the Burma Plate. Enclosed is the schematic restraining bend interpretation of Ramree area. (b) Line drawing of (top) a seismic line through Ramree area and (bottom) its interpretation. (c) Tectonic episodes 1–3 affecting the Ramree area since Oligocene illustrates the formation of circular minibasins on mobile clay.

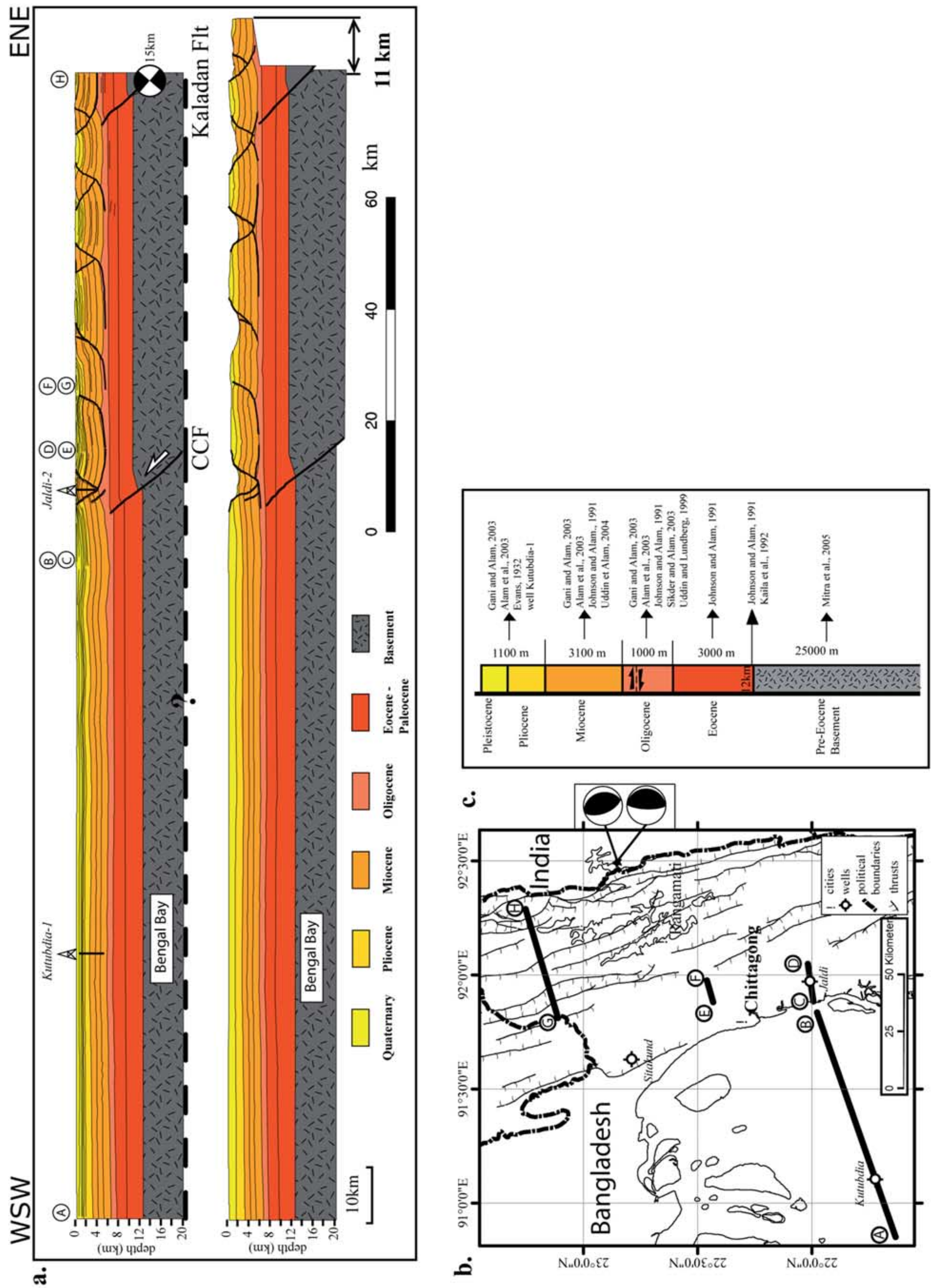
a.
WSW
ENE
depth (km)
Kutubdia-1
Jaldi-2
Bengal Bay
CCF
Kaladan Flt
15km
11 km
10km
km
Quaternary
Pliocene
Miocene
Oligocene
Eocene - Paleocene
Basement
b.
Bangladesh
India
Chittagong
Rangamati
Sitakund
Jaldi
Kutubdia
cities
wells
political boundaries
thrusts
50 Kilometers
c.
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Pre-Eocene Basement
1100 m
3100 m
1000 m
3000 m
25000 m
Gani and Alam, 2003
Alam et al., 2003
Evans, 1932
well Kutubdia-1
Johnson and Alam, 1991
Uddin et Alam, 2004
Sikder and Alam, 2003
Uddin and Lundberg, 1999
Kaila et al., 1992
Mitra et al., 2005

Figure 10

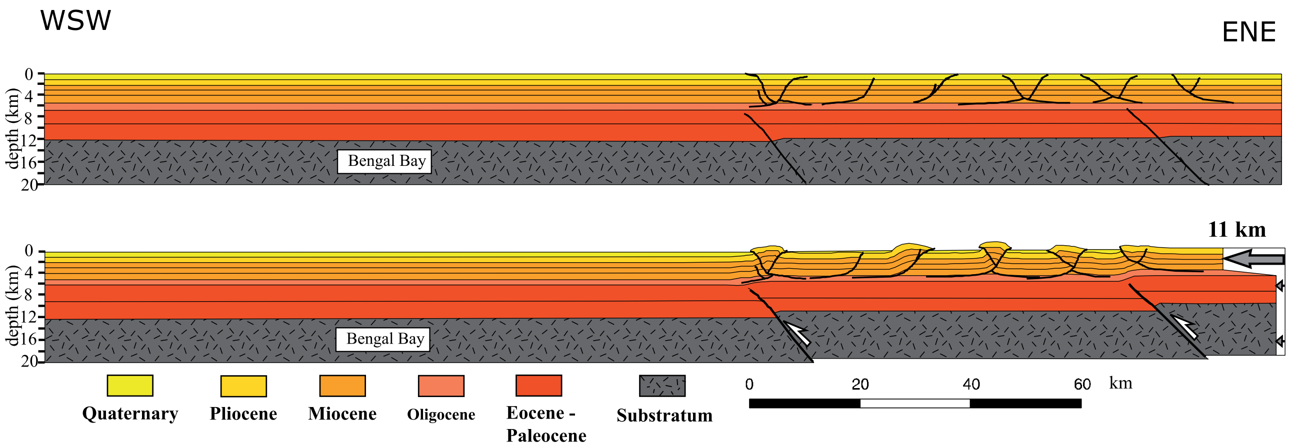

Figure 11. Forward modeling constructed with the Paradigm software GeoSec 2D. Best fit is controlled visually with the cross section presented in Figure 8a. Only fault-related deformation is modeled. See text for initial model constrains.

50°E schistosity with serpentinite phacoides intercalated, were observed.

[63] West of the Lelon Fault Zone, the inner wedge is made of parallel-to-the-range long narrow tight folds (Figure 14e) in the Eocene Chin Flysch with a brittle schistosity that decreases westward. Structural observations including schistosity, fracturation, and bed/bed slickensides on fold limbs are compatible with a N50°–70°E striking shortening axis, slightly oblique to the N165°E strike of the folds. The numerous N160°–N170°E long narrow valleys parallel to fold axis are the place of right-lateral reverse shear bands that have been observed on the road from Mindat to Matupi (Figures 13 and 14f).

[64] The observed structural features are not consistent with a simple N-S folding related to E-W compression during India Plate eastward subduction. The core of the wedge is clearly affected by N-S dextral shear deformation. The inner wedge is affected by both long narrow N-S folds related to a close-to-perpendicular shortening axis and N-S dextral shear bands. The folds could be interpreted as pressure ridges parallel to the right-lateral strike-slip faults. Alternatively, on the basis of satellite imagery and seismotectonic analysis, *Le Dain et al.* [1984] propose that previous N-S trending folds are affected by subsequent active dextral strike-slip faults.

6. Discussion: Structure and Kinematics of the Indo-Burmese Wedge

6.1. Structure of the Indo-Burmese Wedge

6.1.1. Strain Partitioning at the Scale of the Wedge

[65] As stated by previous geodetic studies [*Nielsen et al.*, 2004; *Vigny et al.*, 2003; *Socquet et al.*, 2006], the India-Sunda plate convergence is partially partitioned: two thirds of the parallel-to-the-trench component is presently accommodated along the Sagaing Fault, while the remnant oblique strain component is distributed through the Indo-Burmese Wedge.

[66] On the basis of analog modeling, *Martinez et al.* [2002] show that in such an oblique convergence setting, the core of the accretionary wedge is the locus for shear deformation above the velocity discontinuity, which means at the top of the subduction hinge, whereas the most external parts are the locus of shortening nearly perpendicular to the plate boundary. They conclude that the accretionary wedge, in an oblique convergence setting, can be the place for strain partitioning.

[67] The results of our study allow us to assess the various deformation styles that affect the Indo-Burmese Wedge: the core of the wedge is interpreted as the metamorphosed exhumed ductile part of an intense dextral shear zone originated at depth. It is located on top of the subduction hinge (Figure 15). The inner wedge is affected by strike-slip brittle deformation (Figure 15). The easternmost unit of the outer wedge can be interpreted as a 100 km shear band, framed by detachment folds and thrusts and bounded by two major crustal strike-slip faults, the Kaladan Fault and the Chittagong Costal Fault (Figure 15). This eastern unit is affected by both E-W shortening and N-S strike-slip deformation. Finally, the western unit of the outer wedge is affected only by E-W shortening and is framed by simple detachment folds (Figure 15). Similar to *Martinez et al.* [2002], we conclude that strain is partitioned at the scale of the wedge.

[68] However, in the outer wedge, some major strike-slip faults (the Kaladan Fault and the Chittagong Coastal Fault) are superimposed to the thrusts and folds, and in the inner

Figure 10. (a) Deformed and restored synthetic cross section through the outer wedge. The restoration has been performed with the Paradigm software GeoSec 2D. A to H show the projected location of the seismic lines used to constrain the geometry at depth. The focal mechanism shows the location of two events from Harvard catalog (depth of events is appended). (b) Localization of the seismic lines, boreholes, and focal mechanism used to constrain the synthetic cross section. (c) Stratigraphic column used with references for beds tops.

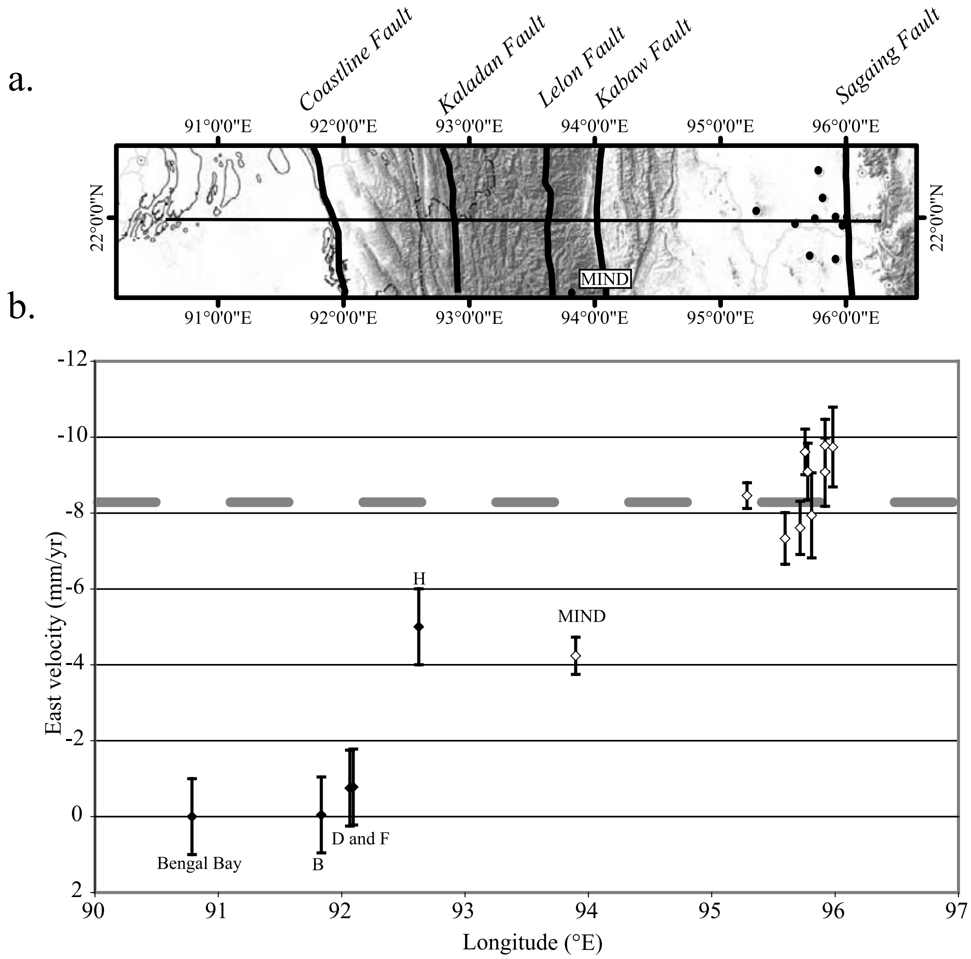

Figure 12. (a) Shaded SRTM image along the cross section at 22°N. Black lines represent the major faults. Black dots are the GPS sites within the Burma Plate. (b) Graphic representation of the E-W shortening rate with respect to India as a function of longitude, around 22°N. White diamonds are from geodetic measurements within the Burma Plate [*Vigny et al.*, 2003], and black diamonds are obtained from the four restored cross sections (this study) and have been projected parallel to the folds azimuth on an E-W cross section at 22°N. MIND is the Mindat GPS station. B, D, F, and H are the end points of cross sections CS-AB, CS-CD, CS-EF, and CS-GH, respectively. The thick dashed line shows the India/Burma E-W shortening rate (8.3 mm/a) calculated from *Socquet et al.* [2006] and *Nielsen et al.* [2004].

wedge, the strike-slip faults have a significant reverse component. Consequently, we argue that strain is not fully partitioned sensu stricto but more likely is diffusively partitioned through the wedge. Transition between the two deformation styles is progressive from east to west across the wedge.

6.1.2. From Thin-Skinned to Thick-Skinned Deformation

[69] A crustal N-S strike-slip deformation overprints the thin-skinned E-W shortening deformation. We propose various interpretations for this thin-skinned to thick-skinned transition:

[70] 1. In term of wedge dynamics, *McClay et al.* [2004] showed that for a double verging wedge, with a 45° to 15° oblique convergence, the back thrust (which could correspond in that case to the Kabaw Fault) passively transport prowedge structures toward the core of the wedge where these former prothrusts are cut by strike-slip faults. These strike-slip faults are rooted at the plate interface. This model may explain the inner wedge geometry because it is close enough to the plate interface but not the outer wedge located farther west.

[71] 2. In term of critical taper, *Molinaro et al.* [2005] proposed that the transition from thin-skinned tectonics to thick-skinned tectonics in Zagros could have occurred when the wedge was propagating over a large distance, in order to preserve the critical taper. The décollement level would then have jumped from a salt layer down to an intracrustal ductile layer. This model is pertinent but does not explain why the crustal structures, within the outer wedge are strike-slip faults where we expect E-W shortening, in this strain-partitioning hypothesis.

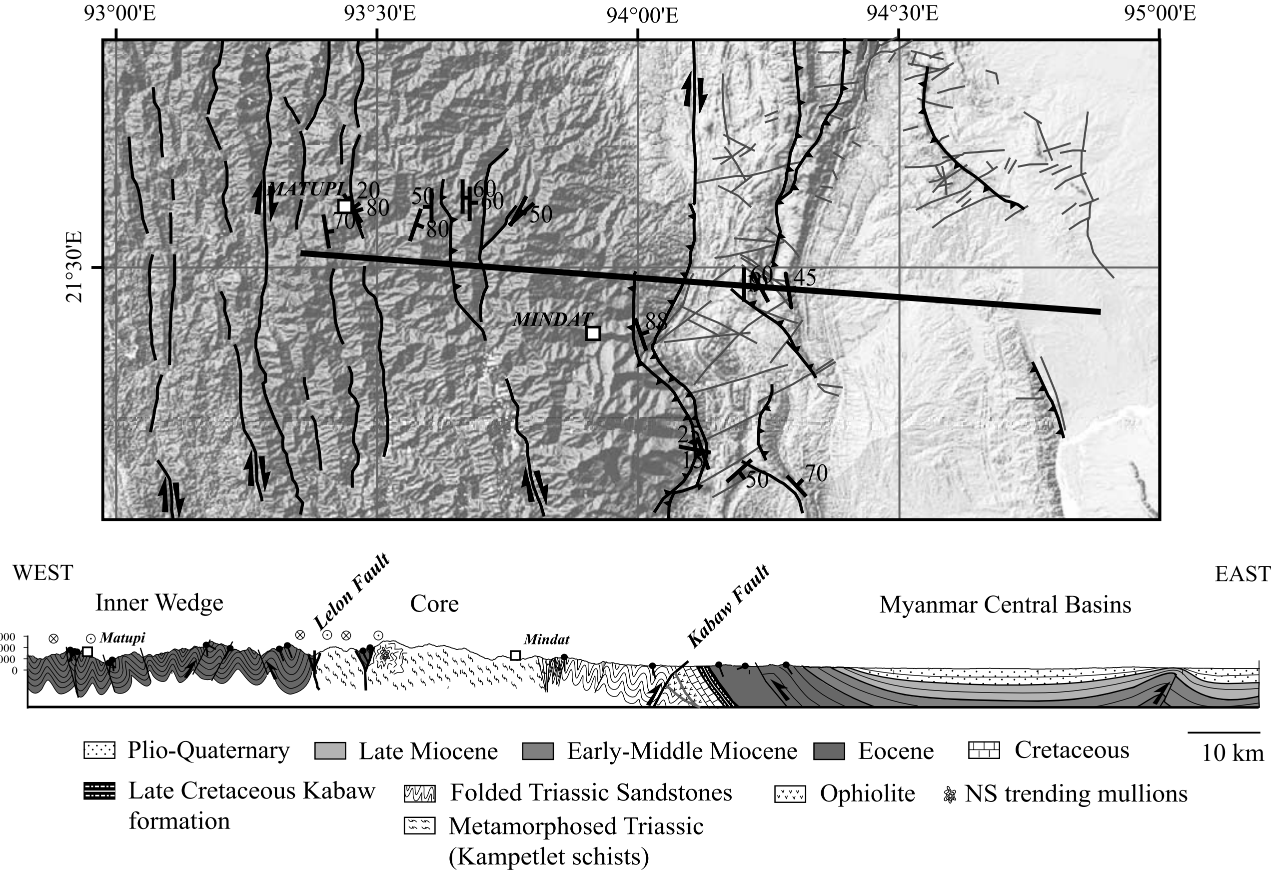

Figure 13. Synthetic field cross section through the inner Indo-Burmese Wedge (location in Figure 2).

[72] 3. In term of strain partitioning, as the most external part, characterized by E-W shortening, is rapidly propagating westward, the N-S strike-slip deformation may affect the wedge more and more westward in order to keep the strain-partitioning ratios between the external and internal parts of the Indo-Burmese Wedge.

[73] The Indo-Burmese Wedge growth mechanism, described here, can be interpreted as the progressive incorporation of the most internal part of the outer wedge, formerly framed by thin-skinned folding and thrusting, to the inner wedge framed by thick-skinned shear deformation, most probably rooted at the plate interface. We suggest that at a given time, the wedge was propagating westward faster than the subduction hinge and the plate interface were able to migrate. Consequently, in order to preserve the critical taper, and in order to preserve the strain-partitioning ratios between external shortening and internal shearing, some of the outer wedge had to be affected by thick-skinned shear deformation (Figure 16). As a result, the plate interface jumped to the west, and part of the downgoing plate was incorporated to the upper plate. The previous Bengal crust subduction might have ceased (as suggested by the lack of significant seismicity at the subducted plate hinge). The subducted Bengal crust is now delaminated below 90 km depth and right-laterally sheared between the Indian lithosphere and the Burmese lithosphere as proposed by *Rao and Kumar* [1999] (Figure 15).

6.1.3. A Characteristic S Shape

[74] The last point that we will discussed is the peculiar S shape of the Indo-Burmese Wedge. We propose that this peculiar shape could originate from two distinct sources:

[75] First, the bending of the outer wedge could have been enhanced by the onset of the Sylhet Trough as a result of the Shillong tectonic uplift during early Pliocene [*Johnson and Alam*, 1991; *Biswas et al.*, 2007]. The large amount of sediments that fill the Sylhet Trough allows the very rapid westward growth of the outer wedge. Consequently, the wedge is wider above the Sylhet through than south of it, producing this characteristic S shape.

[76] Second, the bending of the outer wedge could have been guided by the underlying oceanic fabric directions. The interaction of the Indian oceanic crust fabrics with the subduction zone geometry has been documented on the basis of seismic reflection and bathymetric data in Sumatra area [*Sibuet et al.*, 2007; *Rangin et al.*, 2009]. In the southern part of the Indo-Burmese Wedge, the underlying Bengal oceanic plate is characterized by N10°E structures such as the 90°E Ridge and so are the Andaman Trench and the Indo-Burmese Wedge. North of Ramree Island, the Bengal oceanic crust is structured by possible Early Creta-

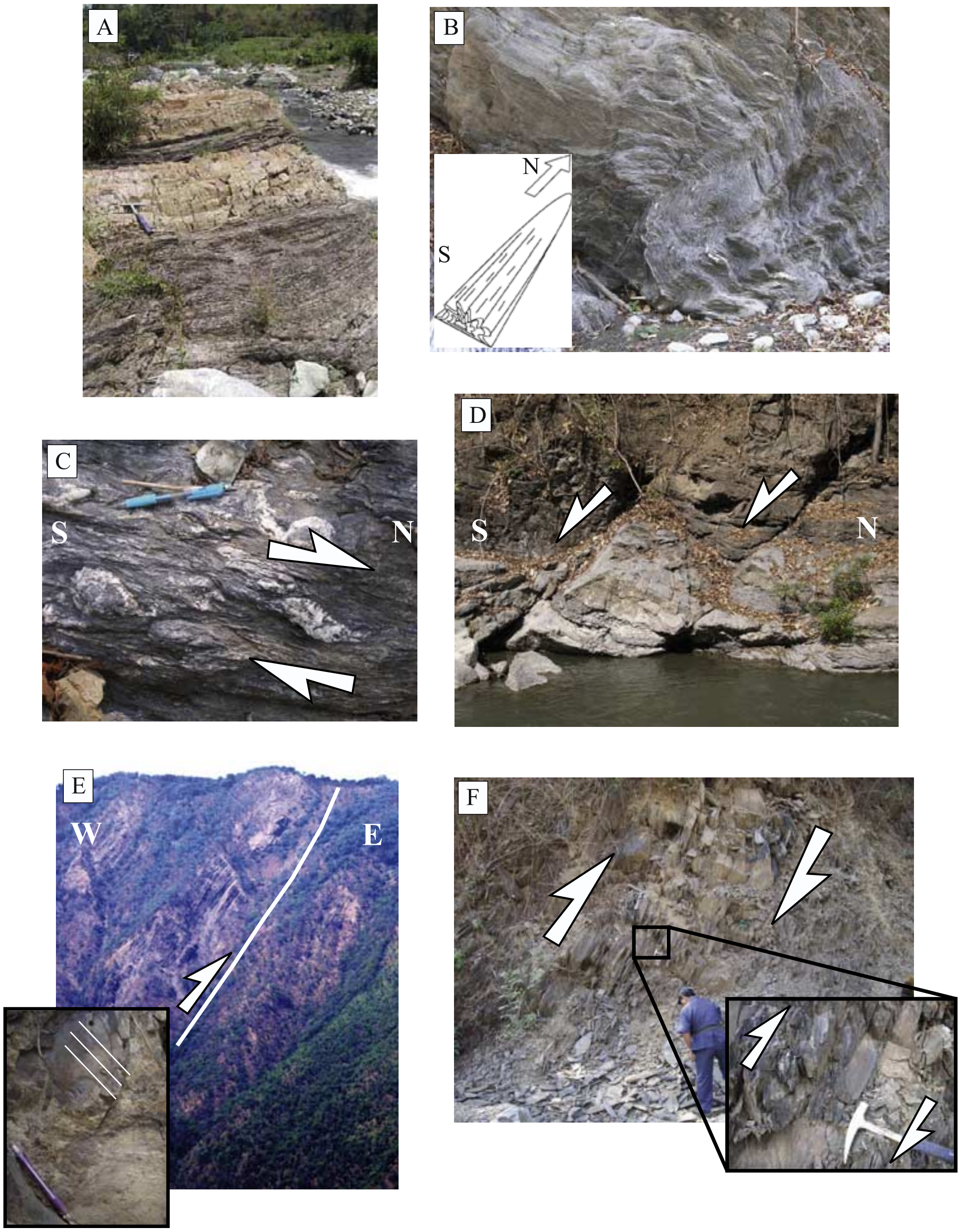

Figure 14. Pictures illustrating the structures observed on the inner most parts of the Indo-Burmese Wedge. (a) Unmetamorphosed Triassic sandstones. (b) Mica schists affected by mulion folds that indicate N-S extension. (c) Quartz exsolution that indicates top-to-the-north motion. (d) E-W striking normal faults affecting the Triassic sandstones. (e) Tight folds in the inner wedge with slickensides on S0 indicating a combined right-lateral and reverse motion. (f) Reverse right-lateral shear zone within the inner wedge.

ceous oceanic fracture zones that strike N140°E [*Desa et al.*, 2006] and so are the structures of the overriding Burma Plate such as the Kaladan Fault and the Chittagong Coastal Fault. The peculiar structural style observed in Ramree could originate from this trend change in the oceanic crust fabrics. Northward, in the Sylhet Trough, the westward growth of the wedge is guided and controlled by the E-W Dauky fault along the Shillong Plateau. Consequently, the major structures cited above bend to the north between Ramree and the Dauky fault to accommodate a fast westward growth of the wedge.

6.2. Late Neogene to Present Kinematics of the Indo-Burmese Wedge

[77] One of our main results is that the outer wedge is not older than 2 Ma. Furthermore, the Sagaing Fault is 4.5 Ma old as suggested by the spreading age in the Andaman Sea, at its southern end [*Chamot-Rooke et al.*, 2001; *Raju et al.*,

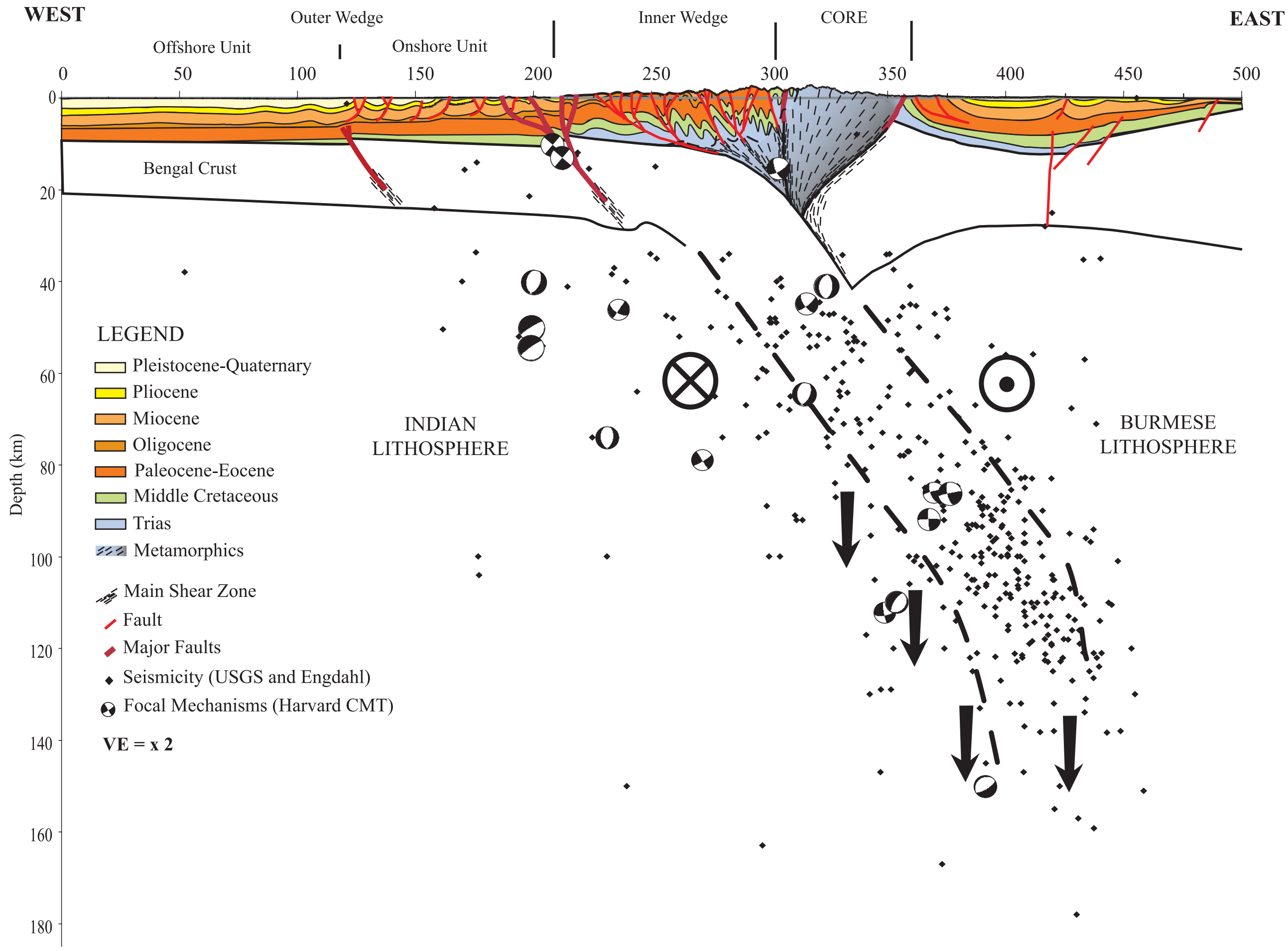

Figure 15. Present cross section based on industrial multichannel seismics and field observations. The seismicity from USGS catalog and *Engdahl* [2002] is represented as black dots. Focal mechanisms from Global CMT (http://www.globalcmt.org/CMTsearch.html) catalog are also represented.

2004]. The Myanmar central basins are inverted since late Miocene [*Pivnik et al.*, 1998; C. Rangin et al., presented paper, 1999]. During late Miocene (~8–10 Ma), a major plate reorganization is registered in the equatorial Indian Ocean [*Gordon et al.*, 1998; *Krishna et al.*, 2001]. The India/Sunda Plate convergence obliquity subsequently decreased, and the tectonic regime along the eastern margin of the Burmese microplate probably changed from transtension to transpression [*Bertrand and Rangin*, 2003]. No older deformation, related to the Cenozoic tectonic history of the Burmese microplate, has been observed. We propose that this major plate reorganization during 8–10 Ma is also a major step in the Indo-Burmese Wedge growth.

[78] We propose the following tectonic history for the Indo-Burmese Wedge evolution (Figure 16):

[79] During late Miocene, as the India/Sunda Plate convergence obliquity decreased, following the separation of Indian and Australian plate, the subduction of Bengal oceanic crust beneath the Burmese microplate accelerated. Alternatively, the subduction might have jumped westward at that time incorporating the India Burma Andaman microcontinent [from *Acharya*, 2006] into the Burmese microplate. Anyhow, following this major tectonic event, a wedge characterized by en echelon west verging folds and thrusts is built in front of a core affected by shear deformation (Figure 16). Besides, the rifting in the Andaman Sea during latest Miocene [*Curray et al.*, 1979; *Khan and Chakraborty*, 2005] and the inversion of the Myanmar central basins at ~10 Ma are probably also both related to this major tectonic event.

[80] From late Miocene to early Pliocene, the Indo-Burmese Wedge is the place of intense strain partitioning: The outer wedge is characterized by thin-skinned folds and thrusts, and the inner wedge is affected by right-lateral strike-slip reverse faulting. Finally, during Pliocene, the Shillong Plateau was tectonically uplifted, and the Sylhet Through was formed (Figure 16). The Shillong Plateau could be considered as a crustal duplex of the Main Boundary Thrust. Since 2 Ma, the large amount of sediments filling the Sylhet Through enhanced the very fast westward growth of the outer Indo-Burmese Wedge over a large distance. This induced the transition from thin-skinned

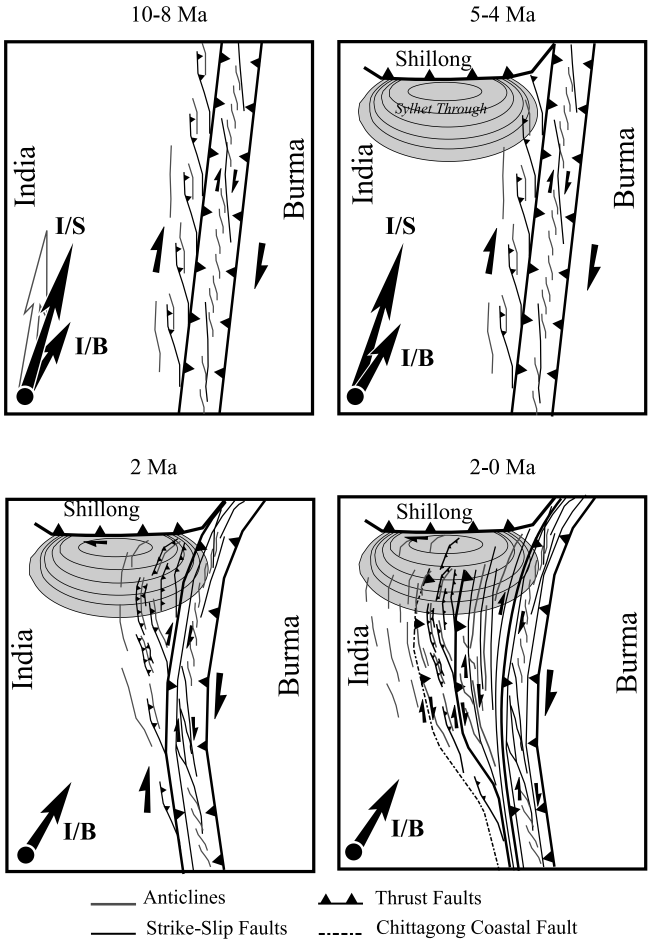

Figure 16. Cartoon showing the tectonic evolution of the Indo-Burmese Wedge from late Miocene to present.

to thick-skinned tectonics, as discussed previously. Consequently, the plate boundary probably jumped again westward and is now located along the Kaladan Fault or the Chittagong Coastal Fault.

[81] The Indo-Burmese Wedge kinematics can be summarized by two major steps:

[82] 1. The major plate kinematics reorganization between India and Australia during 8–10 Ma induced intense deformation at the India-Burma Plate interface and diffused strain partitioning through the Indo-Burmese Wedge.

[83] 2. As a consequence of the Pliocene tectonic uplift of the Shillong Plateau and the subsequent formation of the Sylhet Trough, filled with a large amount of sediments, the wedge is propagating westward very fast, keeping the strain-partitioning ratio between internal and external zones.

7. Conclusion

[84] A detailed analysis of deformation through the Indo-Burmese Wedge, based on geodetic data, field observations, and seismic reflection data, shows that the most internal part of the wedge is mainly affected by right-lateral N-S shear, whereas the most external parts are mainly affected by E-W shortening. The Indo-Burmese Wedge is the place of strain partitioning at the scale of the wedge. However, part of the shear deformation is also accommodated in the outer wedge, and part of the shortening is accommodated into the inner wedge. So the strain is not fully partitioned, in the strictest sense; it is more likely diffusively partitioned through the whole wedge.

[85] We have noticed a transition from thin-skinned to thick-skinned deformation within the outer wedge. The latter has quickly propagated westward above a very efficient décollement layer. As a result, the taper of the accretionary wedge significantly decreased. The subsequent use of a deeper detachment layer, involving the crust, allows the preservation of the critical taper. The overprinted thick-skinned deformation is characterized by N-S trending strike-slip-reverse faults. The strike-slip deformation, here, a typical internal deformation, is interpreted as migrating westward and overprinting former shortening structures of the outer wedge. So the strain-partitioning ratio between internal shearing and external shortening is preserved.

[86] The seismic lines presented in this paper strongly suggest that deformation through the outer wedge is not older than 2 Ma. The sedimentary mass filling the Sylhet Through, a flexural basin formed during early Pliocene [*Johnson and Alam*, 1991; *Biswas et al.*, 2007], can be responsible for the rapid westward propagation of the Indo-Burmese Wedge since 2 Ma. The differences in sediment thickness and the downgoing oceanic crusts fabrics might both be responsible for the typical S shape of the Indo-Burmese deformation front.

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