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Slip-partitioning above a shallow, weak décollement beneath the Indo-Burman accretionary prism

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ABSTRACT

The Indo-Burman Ranges (IBR) are an ∼375 km wide accretionary prism that accommodates oblique convergence of the ∼13–20 km thick Ganges–Brahmaputra Delta on the Indian plate with the Shan Plateau to the east and Shillong massif to the north. The IBR are entirely subaerial and adjacent to one of the most densely populated (>140 M people) regions on the planet, with the potential to generate a $M_w \geq 8.2$ megathrust earthquake. To determine the kinematic evolution, décollement geometry, and geologic deformation rates near the front of the IBR, we combined geologic field mapping, detrital thermochronology, and structural analysis of eight antiforms that define the ∼120 km wide outer belt. The antiforms are bivergent fault-propagation or detachment folds that record plane-strain and east-trending horizontal shortening perpendicular to the axial trace of the folds, indicating nearly full slip-partitioning with the fold-belt normal and parallel components of convergence dominating, respectively, the front and back of the IBR. At 24°N the antiforms have accommodated ∼38.4 ± 16 km of shortening since ∼8 Ma above a ∼3–4 km deep, weak, subhorizontal décollement. Results indicate a shortening rate of ≥4.8 mm/yr, at least 28–37% of the arc-normal geodetic rate, and thrust front propagation rate of ≥15 km/Myr. The shallow décollement is laterally continuous with a regional detachment previously imaged by industry seismic reflection profiles to the west, north and south of the study area. We interpret this décollement to be the up-dip part of the megathrust that has the potential to accommodate large coseismic slip during a great earthquake.

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1. Introduction

The Indo-Burman Ranges (IBR, Fig. 1) are a west-directed fold-thrust belt located at the northern end of the Sunda subduction zone where it joins the Himalayan collisional orogen. Plate convergence between India and southeast Asia at the IBR trends north–northeast, highly oblique (∼70°; 46 mm/yr) to the northerly trend of the plate margin (Nielsen et al., 2004; Rangin et al., 2013; Steckler et al., 2016). Where the subduction zone encounters the ∼13–20 km thick Ganges–Brahmaputra Delta (GBD), the IBR widens to >300 km to accommodate the thickly sedimented margin. Oblique convergent margins commonly result in partitioning of the orogen-parallel and orogen-normal components of the plate motion (McCaffrey et al., 2000). Even in highly oblique settings, such as Sumatra, megathrust earthquakes occur and record slip that is oblique to the overall plate convergence vector, reflecting full to partial slip partitioning of the upper plate (Bradley et al., 2017 and references therein).

The degree of slip-partitioning and nature of the highly oblique India–Asia convergence at the IBR is controversial. One view proposes active subduction is highly partitioned between the frontal fold-thrust belt and dextral strike-slip faults in the internal part of the IBR (Satyabala, 1998; Nielson et al., 2004; Steckler et al., 2016). Another posits that the IBR is undergoing purely dextral strike-slip deformation with no active subduction (Rao and Kumar, 1999). Part of this controversy reflects the fact that structural geometry and kinematics of deformation across the frontal part of the IBR continue to be debated. For example, Maurin and Rangin (2009) consider the outer belt as a thin-skinned fold-belt that is overprinted by thick-skinned dextral transpressional deformation associated with an inferred, basement-involved fault that they call the Chittagong Coastal fault. Similarly, Rangin et al. (2013) in-

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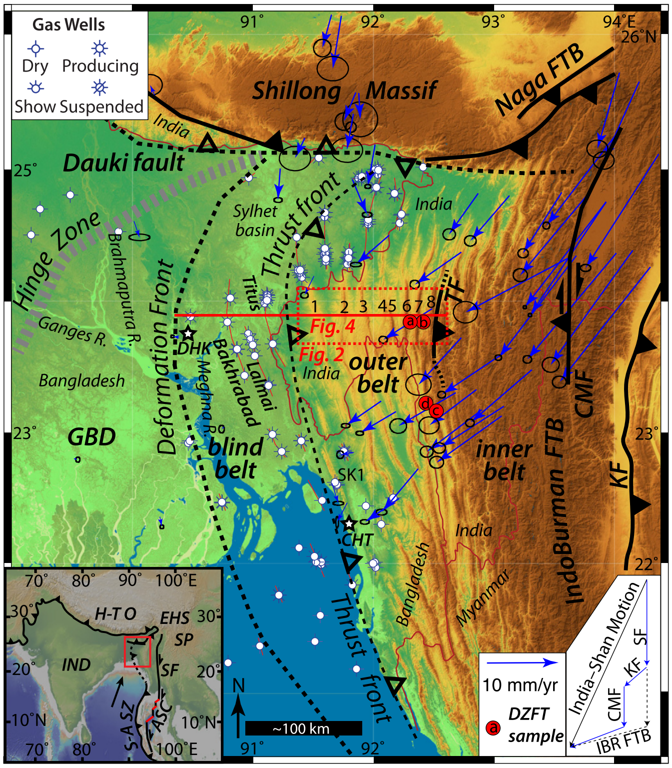

Fig. 1. Shaded relief map of the IBR showing GPS velocities in an Indian frame of reference and major structures (black lines, dashed where blind). The inset in lower right shows velocity triangles (inset vectors not to scale, dashed arrows show an alternative single fault model; Steckler et al., 2016). The deformation front (dashed black curve) marks the western limit of gentle, buried anticlines, based on exploration wells and industry seismic data (e.g., Imam and Hussain, 2002). The study area and location of Fig. 2 is shown with a red-dashed box. The solid red line shows the cross section location for Fig. 4. Black numerals 1–8 in the study area mark the location of antiforms A1–8. Red-colored circles with letters a–d show locations of dZFT samples (a) N386, (b) N357A, (c) MIZ05 and (d) MIZ06. Dark brown line shows international borders. Inset, lower left: tectonic setting of the IBR. The large black arrow gives the plate motion of India with respect to the Shan Plateau. Black and white stars labeled DHK and CHT mark the cities of Dhaka and Chittagong, respectively. Abbreviations: SK-1 – Sitakund 1 well; CMF – Churachandpur–Mao Fault; KF – Kabaw Fault; TF – Tut Fault; Inset: S–A SZ – Sumatra–Andaman subduction zone; ASC – Andaman spreading center; SF – Sagaing Fault; SP – Shan Plateau; EHS – Eastern Himalayan syntaxis; H–T O – Himalayan–Tibetan orogen; IND – Indian craton. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

terpret the inner belt as a right lateral shear zone on the basis of strike-slip centroid moment tensor solutions from intermediate depth (30–100 km) earthquakes in the lower plate (cf. Rao and Kumar, 1999). Rangin et al. (2013) and Rangin (2017) also highlight submarine landslides at the shelf break offshore of western Myanmar to argue that shortening across the outer and blind belts is driven by gravity collapse.

Recent geodetic data from the IBR confirms that there is active convergence and that the plate motion is strongly partitioned at the latitude of the GBD. Between the active deformation front in Bangladesh (90.5°E) and the Shan Plateau in Myanmar (SP, 97.5°E) dextral shear is mostly absorbed by north-striking right-lateral faults in the internal part of the forearc, including the Sagaing and Churachandpur–Mao faults (SF and CMF, Fig. 1; Steckler et al., 2016; Sloan et al., 2017). Most of the 70° of the total obliquity is taken up between the SF and CMF, leaving only ∼20° of obliquity within the frontal ∼200 km wide fold-belt (Fig. 1). Fold-belt-normal convergence of ∼13–17 mm/yr is absorbed by the frontal part of the IBR and has been modeled as elastic loading of the accretionary prism along a locked, east-dipping megathrust with the possibility of a $M_w \geq 8.2$ earthquake (Steckler et al., 2016).

Owing to an incomplete paleoseismologic record within the modern GBD, the seismogenic potential of the northern (∼22–25°N) segment of the subduction zone remains uncertain. However, an earthquake in 1762 farther south is interpreted as a M_w 8.5–8.8 subduction megathrust event that ruptured northward to 22.5°N (Wang et al., 2013). Although the down-dip end of the locked zone is constrained by GPS data, the structure of the up-dip part of the IBR is not because geodetic data record the present surface elastic deformation field which does not inform the structural geometry.

In this study, we address these uncertainties by focusing on the structure of the frontal part of the Indo-Burman forearc where it rapidly accretes the GBD and partially absorbs highly oblique convergence between India and the Shan Plateau (Steckler et al., 2016). We combine field-mapping, structural analysis, and detrital zircon thermochronology to test for strain-partitioning and determine the structure and geologic shortening rates in the frontal part of the IBR. We find that, despite the high obliquity of convergence, there is only evidence of fold-belt-perpendicular shortening in the frontal fold-belt. Our results emphasize the extent of slip-partitioning across the IBR forearc and inform the regional seismic hazard by documenting the structure of the up-dip part of the accretionary prism.

2. Geologic setting

The frontal fold-belt records ongoing deformation of Paleogene(?)–present Himalayan sourced fluvial-deltaic sedimentary rocks of the GBD (Gani and Alam, 1999; Alam et al., 2003; Najman et al., 2012). GBD sediments on the Indian plate reach to near sea level on the continental shelf and become subaerial at the delta. Teleseismic receiver functions show that the Indian plate has 16–20 km of sediment beneath Bangladesh and northeast India at the latitude of our study area (Mitra et al., 2008, 2018; Singh et al., 2016). Refraction seismic data from the Bengal Fan shows that postrift sediment thickness alone is a minimum of ∼13 km near the Bengal delta front (Sibuet et al., 2016).

The frontal ∼80 km of the fold-belt is almost entirely buried by ongoing GBD sedimentation, and thus not mapped here, but the locations of the folds are approximated from gas exploration wells and industry reflection seismic data (blind belt in Fig. 1; Sikder and Alam, 2003; Imam and Hussain, 2002; Burgi et al., 2016). Inboard of the blind belt, the outer belt is ∼120 km wide and consists of late Miocene–Quaternary fluvial and shallow marine deltaic deposits. The Surma Group within the outer belt consists of Miocene shallow marine shelfal and intertidal deposits. Overlying the Surma Group, the Tipam Group comprises Miocene–Pliocene fluvial deposits including small fluvial distributary channels and large braided river channel deposits. Above that, the Dupi Tila Group consists of Pliocene–Quaternary second-cycle smaller meandering river, floodplain, and alluvial deposits (Figs. 1–3; Alam et al., 2003). Underlying the Surma Group, but not exposed in the outer belt, is the Oligocene Barail Group which includes distal and muddy facies of a lower-shelf to slope or submarine fan depositional environment (Alam et al., 2003).

Within the outer belt, the Surma, Tipam, and Dupi Tila Groups are folded into a series of fault-cored antiforms that define ∼10 km wide north-trending ridges. The antiforms are continuous along-strike for tens to >100 km and separated by ∼10–20 km wide low relief synclinal valleys (Fig. 2). We define the thrust-front (Fig. 1) to mark the transition from anticlines of the blind-belt with low structural relief and no topographic expression to fault-cored antiforms with topographic relief in the outer belt. In the eastern part of the study area the Barail Group is exposed in the hanging wall of an out-of-sequence reverse fault (Tut Fault, discussed below), we define the boundary between the outer and inner belt at this fault (Figs. 1, 2).

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