Interseismic uplift of anticlines above the Rakhine-Bangladesh Megathrust from ALOS-2 InSAR

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Abstract

The shallow portion of a megathrust represents the zone of first contact between two colliding plates, and its rheological properties control the seismic and tsunami hazards generated by the fault. Unfortunately, underwater geodetic observations are sparse due to the high cost of obtaining geodetic data, meaning limited information is available on the interseismic behavior of this part of most megathrusts. The Rakhine-Bangladesh megathrust offers a unique opportunity to probe the behavior of the shallow megathrust as it is the only ocean-continent subduction zone where the near-trench region is fully accessible on land. Here, we use observations from ALOS-2 wide-swath imagery spanning 2015 to 2022 to conduct an InSAR timeseries analysis of the overriding plate within Bangladesh and the Indo-Myanmar Ranges. We identify a narrow pattern of alternating uplift and subsidence associated with mapped anticlines but show that it cannot be explained by plausible rates of slip on the megathrust or other fault structures. Instead, we argue that the deformation is likely caused by active aseismic folding within the wedge above a shallow decollement. We show that estimates of the decollement depth derived from a viscous folding model and the observed anticline spacing are in agreement with previous seismic observations of the decollement depth across the fold belt. We suggest that the role of ductile deformation in the overriding plate in subduction zones may be more important than previously recognized.

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15	Key Points:						
16 17 18 19 20	 First large-scale InSAR velocities across the northern Rakhine-Bangladesh Megathrust Observed patterns of uplift above outer anticlines cannot be explained by fault creep Folding of sediment above the megathrust might cause interseismic uplift on anticlines 						
21	Abstract						
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39	The shallow portion of a megathrust represents the zone of first contact between two colliding plates, and its rheological properties control the seismic and tsunami hazards generated by the fault. Unfortunately, underwater geodetic observations are sparse due to the high cost of obtaining geodetic data, meaning limited information is available on the interseismic behavior of this part of most megathrusts. The Rakhine-Bangladesh megathrust offers a unique opportunity to probe the behavior of the shallow megathrust as it is the only ocean-continent subduction zone where the near-trench region is fully accessible on land. Here, we use observations from ALOS-2 wide-swath imagery spanning 2015 to 2022 to conduct an InSAR timeseries analysis of the overriding plate within Bangladesh and the Indo-Myanmar Ranges. We identify a narrow pattern of alternating uplift and subsidence associated with mapped anticlines but show that it cannot be explained by plausible rates of slip on the megathrust or other fault structures. Instead, we argue that the deformation is likely caused by active aseismic folding within the wedge above a shallow decollement. We show that estimates of the decollement depth derived from a viscous folding model and the observed anticline spacing are in agreement with previous seismic observations of the decollement depth across the fold belt. We suggest that the role of ductile deformation in the overriding plate in subduction zones may be more important than previously recognized.						
40 41	Plain Language Summary						
42 43	The shallowest portion of a subduction zone where one plates goes below another is not well studied as these areas are usually located underwater. This provides a challenge to understand the						

- 44 properties of the faults in this area, which cause large earthquakes can generate tsunamis. In this
- 45 study, we used satellite radar imagery spanning 7 years over a subduction zone that is heavily

- 46 sediment filled from the Ganges and Brahmaputra Rivers in Bangladesh. We identified a narrow
- 47 pattern of alternating uplift and subsidence above existing folds in the overriding plate. However,
- 48 we were not able to explain these observations with a model based on fault slip. We suggest
- 49 instead that these structures are dominated by a viscous folding mechanism, analogous to
- 50 wrinkles in a sheet, during the early stages of their formation. Our findings help to shed light on
- 51 tectonic processes of the overriding plate in areas where much is unknown.
- 52

53 Keywords

- 54 L-Band InSAR, ALOS-2, Bangladesh, Myanmar, Aseismic Folding, Interseismic deformation,
- 55 Anticline uplift
- 56
- 57

58 Introduction

- 59 A megathrust fault defines the interface between two colliding plates and typically the shallowest
- 60 portion of the fault is associated with the greatest seismic and tsunami hazards (e.g., Lay et al.,
- 61 2012; Bilek and Lay, 2018; Lindsey et al., 2021). However, in ocean-continent subduction zones
- 62 this portion of the fault is typically offshore, and the high cost of obtaining geodetic data
- underwater means limited information is available on the properties and behavior of this portionof the fault (e.g., Evans et al., 2021). The northern Rakhine-Bangladesh megathrust is the only
- 65 ocean-continent subduction zone where the near-trench region is subaerial (e.g., Le Dain et al.,
- 66 1984; Ni et al., 1989; Satyabala, 1998; Steckler et al., 2016; Mallick et al., 2019; Panda et al.,
- 67 2020; Oryan et al., 2023; Lindsey et al., 2023), making it an ideal target for geodetic
- 68 investigation.
- 69
- 70 Highly complex deformation is observed throughout the Indian Plate collision with the Eurasian
- 71 Plate to the north and Sunda Plate to the east. Geodetic observations show a total convergence
- rate of 35 mm/yr to ~46 mm/yr between the obliquely subducted Indian Plate and the overriding
- 73 Burma Plate (Socquet et al., 2006; Steckler et al., 2016). The resulting deformation gives rise to
- 74 several major tectonic structures (**Figure 1**) throughout Myanmar, Bangladesh, and northeast
- 75 India, including the right-lateral Sagaing fault (Vigny et al., 2003; Maurin et al., 2010; Panda et
- al., 2018), Rakhine-Bangladesh megathrust (Steckler et al., 2008; Mallick et al., 2019), and the
- fold-and-thrust belt structures in the Indo-Myanmar Ranges (Maurin and Rangin, 2009; Betka et al., 2018).
- 78 79

80 The Rakhine-Bangladesh megathrust is located offshore western Myanmar and continues

- 81 northward into Bangladesh, with the approximate surface trace running through the capital
- 82 Dhaka (Figure 1; Steckler et al., 2016). Deep focal mechanisms suggest that the subduction zone
- is driven by a net slab pull (Le Dain et al., 1984; Maneerat et. al., 2022b), but the absence of
- 84 seismicity along the shallow megathrust interface led some authors to speculate that either the
- megathrust is inactive or is aseismically slipping (e.g., Ni et al., 1989; Rangin et al., 2013;
- 86 Kundu and Gahalut, 2012; Gahalut et al., 2013). However, historical reports and observations of
- 87 uplifted corals on the western coast of Myanmar suggest a megathrust earthquake occurred there
- in 1762 (Cummins, 2007; Wang et al., 2013), potentially with a magnitude 8.5 (Aung et al.,
- 89 2008; Wang et al., 2013; Mondal et al., 2018). Wang et al. (2013) proposed that the 1762 Arakan
- 90 earthquake could have ruptured either the megathrust or splay faults, but in either case a shallow
- 91 rupture was required to produce the observed uplift.
- 92
- 93 Recent geodetic studies suggest the northern part of the megathrust in Bangladesh most likely
- 94 accommodates around 11 to 17 mm/yr of the total convergence rate (Steckler et al., 2016; Oryan 95 at al. 2022; Lindsey et al. 2022) although verying rates have been proposed from as low on 7
- et al., 2023; Lindsey et al., 2023), although varying rates have been proposed, from as low as ~7
 mm/yr (Panda et al., 2020) to as high as 24 mm/yr (Mallick et al., 2019). Much of this
- 96 mm/yr (Panda et al., 2020) to as high as 24 mm/yr (Mallick et al., 2019). Much of this
 97 uncertainty is due to the sparsity of available geodetic observations and the short geodetic record
- 98 in the region, as well as the high obliquity of the convergence (e.g., Mallick et al., 2019).
- 99
- 100 The sparse geodetic network has made it difficult to discern whether the shallow portion of the
- 101 megathrust is frictionally locked or could be partially creeping aseismically (Panda et al., 2020).
- 102 Recent studies suggest that it is more likely to be a shallowly locked megathrust with a
- 103 potentially limited downdip locking depth (Vorobieva et al., 2021; Bürgi et al., 2021; Oryan et

104 al., 2023) and that uplift of the overriding plate occurs only during the coseismic period (Higgins

105 et al., 2014), though some observations suggest aseismic uplift of St Martin's Island (Mondal et

- 106 al., 2018). These different scenarios would have significant implications for the seismic hazard:
- 107 if the shallow part of the fault is frictionally creeping, potentially at a low rate due to the stress
- 108 shadow from deeper locking (Lindsey et al., 2021), the seismic hazard may be moderate. In
- 109 contrast, the shallow section of the megathrust could be fully frictionally locked, representing a
- 110 much more significant seismic hazard to Bangladesh and the surrounding region. More detailed
- 111 observations are therefore needed to determine the true frictional state of the shallow megathrust.
- 112
- 113 The remainder of the India-Sunda convergent motion is likely distributed onto a series of oblique
- thrust faults and anticlines within the Indo-Myanmar Range (IMR) (Wang et al., 2014) (Figure 114 1), extending as far as the Kabaw fault along the western edge of the Myanmar Central Basin 115
- (Oryan et al., 2023). Geodetic studies suggest a total convergence of 8 to 24 mm/yr and 8 to 10 116
- mm/yr of right-lateral slip across the IMR (Mallick et al., 2019; Panda et al., 2020; Oryan et al., 117
- 2023; Lindsey et al., 2023). It is suggested that active permanent uplift in the inner belt of the 118
- 119 Indo-Myanmar Range (IMR) is due to active-out-of-sequence thrusts faults (Maneerat and
- 120 Bürgmann, 2022a). Geologic studies suggested a lower minimum rate of ~5 mm/yr of shortening
- in the IMR along a weak décollement (Betka et al., 2018). It is unclear if the eastern IMR is 121
- 122 dominated by strike-slip (Mon et al., 2020) or north-south compression (Maneerat et al., 2022b).
- 123
- Despite the difference in rates, parts of the Chattogram-Myanmar fold-and-thrust-belt (CMFB) 124
- 125 could potentially host significant earthquakes, with megathrust events on the décollement, or
- 126 smaller events on the splay faults in the fold-and-thrust belt (Betka et al., 2018; Wang et al.,
- 127 2014).
- 128

129 A décollement can also undergo aseismic slip that reduces strain buildup during the interseismic

130 period if the frictional properties are conducive to stable sliding (Marone and Scholz, 1988;

Scholz, 1998; Fielding et al., 2004; Simpson, 2009; Johnson et al., 2018; Mallick et al., 2021). 131

132 Understanding the type of deformation in the Rakhine-Bangladesh megathrust is crucial for us to

133 provide accurate hazard analysis to the communities in the surrounding countries.

134

135 Because of this region's limited GNSS data, integration of the existing GNSS data with InSAR

- observations represents the only feasible approach to filling this data gap. However, the region's 136
- dense vegetation coverage results in low C-band coherence, causing difficulties obtaining 137
- reliable long-term deformation (Higgins et al., 2014; Chong and Huang, 2020). L-band InSAR is 138
- 139 a better alternative, as it performs significantly better in vegetated areas (e.g., Lindsey et al., 2015).
- 140
- 141

142 Below, we present a timeseries of InSAR line-of-sight (LOS) deformation derived from L-band ALOS-2 observations acquired between 2015-2022. Our results represent the first regional-scale 143 144 map of interseismic velocities over the region, allowing us to identify alternating patterns of

uplift and subsidence correlated with anticlines and synclines within the outer belt of the Indo-145

- Myanmar fold-and-thrust-belt. We show that this deformation pattern cannot be explained by 146
- creeping thrust faults unless the rates are unrealistically high (tens of mm/yr). Alternatively, we 147
- 148 suggest the deformation pattern can be explained by aseismic folding of the upper plate, resulting
- in permanent distributed deformation taking place across the fold-and-thrust belt. 149

- 151 2. Methods & Results
- 152 2.1 InSAR data processing

153 Most successful uses of ALOS-2 L-band InSAR in densely vegetated regions have been

154 primarily for coseismic ruptures of earthquakes where the deformation signals are large, such as

- the 2015 Mw 7.8 Gorkha, Nepal (Lindsey et al., 2015), the 2018 Mw 6 Bago-Yoma, Myanmar
- 156 (Fadil et al., 2021), and the 2018 Mw 7.5 Central Papua New Guinea (Wang et al., 2020). To
- 157 observe the much lower rates of interseismic deformation, however, ionospheric and
- tropospheric effects must be corrected to prevent them from overwhelming the signal (e.g.,
- 159 Gomba et al., 2016; Jolivet et al., 2011; Liang et al., 2018).
- 160
- 161 We acquired 50 scenes from path 44 frame 3150 spanning from 30th March 2015 to 7th February
- 162 2022 (almost seven years of interseismic deformation). The number of scenes collected varies
- 163 with the highest number of 12 scenes in 2021. We removed the topographic phase from the
- 164 interferograms using Shuttle Radar Topography Mission (SRTM-GL1) (Farr et al., 2007).
- 165
- 166 We apply corrections for variable ionospheric delays using the split-spectrum method
- implemented in the ISCE software package from JPL (Rosen et al., 2012; Liang et al., 2018) and
- use the PyAPS software to estimate and remove tropospheric delays using the ERA5 weather
- 169 model (Jolivet et al., 2011; Jolivet et al., 2014; Hersbach et al., 2020). Following the correction
- 170 of both atmospheric effects, we use the small baseline subset (SBAS) method (Berardino et al.,
- 171 2002; Schmidt and Bürgmann, 2003) as implemented in MintPy (Zhang et al., 2019) to perform
- 172 InSAR time-series analysis.
- 173

174 2.1.1 Ionospheric delay removal

The split-spectrum method estimates the sub-band interferograms at high and low center frequencies after bandpass filtering SAR images. The sub-band interferograms are then unwrapped and combined to estimate the interferometric ionospheric phase delay which is later

- 178 removed from the original interferogram (Fattahi et al., 2017). Ionosphere corrections for ALOS-
- 179 2 InSAR have shown success for coseismic events (Gomba et al., 2016), and for time-series over
 180 high-coherence areas including Los Angeles and the San Andreas Fault (Liang et al., 2018). The
- uncertainty reported for a 2-year ALOS-2 timeseries after ionospheric correction is ~4.3 mm/yr
- in southern California (Liang et al., 2018). However, we find that several parameter choices
- 183 (filtering, multilooking, temporal and spatial baselines of pairs, etc.) during the process of
- making the interferograms can affect the quality of the results and require special optimization
- for low- to moderate-coherence regions such as the Chattogram-Myanmar fold-and-thrust belt
- and the Indo-Myanmar Ranges.
- 187
- The presence of strong ionosphere variations in the Myanmar-Bangladesh region poses a
 particular challenge for the method; due to its location near the magnetic equator, the region
- experiences particularly strong ionospheric variations (Jee et al., 2004). Our study area (20°N) is
- 191 located within the highest TEC bands. We found that a majority of interferograms have very
- 192 dense ionospheric fringes resulting in phase aliasing or unwrapping errors, which cause the
- ionospheric estimation step to fail when using the default multilooking values of 80 by 32 pixels
- 194 (range and azimuth). We were able to recover most interferograms using a smaller number of
- 195 looks (40 by 16 pixels), at a cost of increased computational time. We also identified some

- 196 interferograms with low coherence or several hundreds of ionospheric fringes (several hundred
- 197 across the image; example in Figure S4) that could not be corrected successfully. These
- 198 interferograms were identified visually and removed from further analysis steps.
- 199
- 200 We were able to correct the ionospheric effects in most interferograms (Figure S1); however, the
- 201 coherence is still low over the more densely forested higher elevations of the Indo-Myanmar
- 202 Ranges. We successfully improved the coherence across this region somewhat by increasing the
- 203 Goldstein filtering patch size in ISCE to 128 pixels from a default of 64.
- 204

205 2.1.2 Time-series estimation

- All 186 interferograms were manually inspected after the removal of ionospheric effects and 206
- 207 tropospheric effects. The InSAR time-series analysis was conducted using the MintPy software
- 208 package (Zhang et al., 2019). We applied the bridging and phase closure steps to reduce
- 209 unwrapping errors, which improved stability of the timeseries especially across the Indo-
- Myanmar Ranges (Zhang et al., 2019). A total of 106 interferograms was identified to be suitable 210
- 211 for stacking based on the coherence across the interferogram, number of connected components,
- 212 and residual unwrapping error. Additionally, three ALOS-2 scenes had significant localized
- tropospheric disturbances and excluded from the analysis by removing all interferograms 213 connecting to those dates (see Figure S1).
- 214
- 215
- The InSAR timeseries reference point is chosen to be the GNSS station BAGH near the center of 216
- 217 the image (23.1617°N, 92.1919°E). To allow for a more similar comparison between regional
- GNSS and InSAR velocities, we selected 18 GNSS velocities from Oryan et al., (2023), 218
- identified from their full dataset of 78 stations by removing those not within the ALOS-2 scene 219
- 220 boundary, and removing outlier GNSS stations. Stations west of the Meghna River are not
- included because of potential InSAR unwrapping errors across the river. Lastly, we only include 221
- 222 GNSS stations that have an overlapping observation period with our InSAR data (2015-2022).
- We projected the GNSS velocities onto the radar LOS using the appropriate azimuth and 223
- 224 incidence angle values at each station location. and converted them to an Indian Plate reference
- frame using an Euler pole for ITRF2014/Indian Plate motion at 50.82°N 9.28°E with an angular 225
- rotation of 0.538 degrees/Myr (Panda et al., 2020). The final GNSS velocities and their LOS 226 227 projection are listed in Supplementary Table 1 and timeseries shown in Figure S5.
- 228
- 229 We estimated our final InSAR LOS velocity map by removing a planar trend from the InSAR
- 230 LOS velocities and adding back the trend fitted to the LOS-projected GNSS velocities. This
- allows us to place the two datasets in the same reference frame (Indian Plate) while avoiding bias 231
- caused by unmodeled effects at any station. The final velocity map is shown in Figure 2. LOS 232
- motion away from the satellite (negative values) corresponds to subsidence or westward motion 233
- 234 whereas motion towards the satellite (positive values) corresponds to uplift or eastward motion.
- 235

236 **2.2 Elastic fault modeling**

- The overall pattern of LOS velocities does not clearly show large-scale tectonic motion, which 237
- 238 may be obscured by residual ionospheric or tropospheric effects at long spatial wavelengths.
- 239 However, we identified three areas of notable localized deformation that might be caused by
- 240 fault slip, or by other deformation processes considered below. These areas are in the outer belt

of the Indo-Myanmar Ranges and are indicated by the profiles labeled Northern (A-A'), Central
(B-B') and Chattogram (C-C') in Figure 2.

243

In the northern section, we observed uplift along the Rashidpur anticline (A-A') with a

245 maximum positive LOS rate of 5 mm/yr (Figure 3). The syncline adjacent to the anticline shows

- a high negative LOS (subsidence) rate of -30 mm/yr at peak. Although the uplift pattern
- corresponds well with the location of the anticline, it is not likely to be driven by topographically
- 248 correlated tropospheric noise because the correspondence is imperfect, and the topographic
- 249 difference is very small tens of meters (**Figure 3**).
- 250

In the central section, the deformation profile crosses an area of subsidence of approximately -10 mm/yr followed by a broad uplift of 3 mm/yr that slowly decays towards the northeast (B-B')
(Figure S3). The area of subsidence follows well with the outline of a valley, however, the uplift cuts across multiple hills and valleys without any regard to the surface elevation.

255

256 In the Chattogram section, we observed a strong subsidence signal with a peak of -20 mm/yr

- 257 northeast of Chattogram east of the Sitakund anticline (C-C') (**Figure S3**). The subsidence
- 258 pinches out towards the north, and the subsidence rate reduces south of the Karnaphuli River.
- 259 We identified significant subsidence in Chattogram with the highest subsidence rate of -33
- 260 mm/yr close to the coast, likely due to groundwater extraction (Wu et al., 2022).
- 261

To investigate whether these patterns can be explained by fault slip, we constructed a series of
2D dislocation models in a homogenous elastic half-space (e.g., Okada, 1985). We compare the
models to a smoothed 2D transect of the LOS velocities, obtained by applying a median filter
with a width of 0.3 km and then downsampling by a factor of 10.

266

267 We used a Bayesian Monte Carlo optimization method called slice sampling to find the bestfitting model parameters for a set of dislocations representing a series of different possible fault 268 geometries (Neal et al., 2003; Lindsey and Fialko, 2013). The Bayesian approach provides an 269 estimate of the full probability distribution for each parameter but requires a reasonable initial 270 271 estimate for computational efficiency. Therefore, we first estimated the best-fitting parameters 272 for all dislocations (x-location, depth, dip, width, slip) using the nonlinear multivariable optimization function *fmincon* in Matlab and used the optimized parameters as the initial values 273 274 for the Bayesian sampler.

275

We constructed five primary fault model types: 1) forethrust fault only (east dipping fault), 2)

forethrust fault with a decollement and hinge fault, 3) forethrust fault and identical hinge, 4)
backthrust fault only (west dipping fault), and 5) backthrust fault and a decollement. We also
tested a duplex structure as a sixth model type for the northern cross-section. Backthrust are

faults dipping towards west. As the backthrust and hinge faults are dependent on the geometry of
the main fault (forethrust or backthrust), we can eliminate some free parameters such as x-

location (position of centroid along the x-axis) and depth. The hinge fault is not a physical fault

- but a way to represent the accommodation of slip in the form of a shear band (e.g., Mallick et al.,
- 284 2021). The dip angle of the hinge fault is calculated using (Johnson and Fletcher, 1994):
- 285 286

$$\theta_H = 90 - \frac{\theta_M}{2}$$

(Eq. 1)

288 Where θ_H is the angle of the hinge fault, θ_M is the angle of the main fault. The fault slip of the 289 hinge is calculated using (Kanda and Simons, 2010):

 $u_H = 2V_M \sin(\frac{\Delta \theta_H}{2})$

(Eq. 2)

- 290
- 291
- 292
- 293

Where u_H is the slip of the hinge fault, V_M is the slip of the main fault, θ_H is the angle of the hinge fault.

296

After finding the optimized fault parameters, we perform a series of Bayesian searches using slightly different initial parameters, with each initial parameter value varying by a random factor of up to 10% from the optimal values. We created **10** different sets of initial parameters with each set consisting of **2000** samples, after dropping the first **1000** samples. We report the mean of the free parameters from all the runs as our final optimized parameters (**Supplement Table 1**)

- and show the full posterior probability distributions in **Figure S2 & S3**.
- 303

304 2.3 Inversion results

- Although several models were successful at fitting the observed LOS velocity profiles, none of them have reasonable parameter values (**Supplementary Table 1-3**). In particular, the required slip rates are generally far above the long-term convergence rate of 11 to 17 mm/yr (e.g.,
- 308 Steckler et al., 2016; Mallick et al., 2019; Oryan et al., 2023; Lindsey et al., 2023), and some
- 309 models additionally require an implausible fault geometry compared to what is known
- geologically about the region (Betka et al., 2018; Bürgi et al., 2021; Abdullah et al., 2022).
- 311

Across the northern section (A-A') on the Rashidpur anticline a simple east dipping thrust fault can fit the observed deformation at a depth of 4.6 km, dip of ~1.7°, but with 66 mm/yr of slip on the fault (**Figure 3**). Including a decollement does not improve the modeled results. Invoking a

duplex structure to represent two anticlines in the cross-section does not fit the data well. The

- backthrust faults fitted the velocities using a steeply dipping fault that do not coincide with the
- 317 geologic structure.
- 318

For the central section (B-B'), we identified that in almost all cases, the data require at least 10

- mm/yr or more of slip on the fault. A main east dipping fault was able to fit the subsidence with a depth of 0.5 km, dip of 0.7° , and a slip of 10 mm/yr. The misfit is the lowest when we allowed
- for an exact hinge fault with the same properties as the main fault with a 0.7° dip (**Figure S3**).
- 323

However, the model was not able to fit the subsidence pattern and only fitted broad uplift pattern.
Adding a decollement to the models does not improve the results and the position of the fault is
off the region of interest. The backthrust models were not able to fully produce the subsidence
signals and only able to fit the uplift pattern slightly.

- 328
- We tested five different fault geometries for the Chattogram transect (C-C'), and some models
- produce significant uplift rates (>15 mm/yr) on the Sitakund anticline (Figure S3). We were able
 to fit the velocities using a simple thrust fault and a decollement with the best fitting fault
- parameters: depth of 1.3 and 2.1 km, dip of 3.7° and 1.8°, and a slip of ~41 and 12 mm/yr. A

- thrust fault only model could not recreate the subsidence. A simple backthrust model produces a
- very steep fault with similarly high slip rate. Similarly, the remaining models requires high slip rates to fit the observed velocities.
- 336
- We also tested models with constrained slip to a maximum of 20 mm/yr and minimum centroid
- depth greater than 2 km and found that these all the fault models do not fully fit the observed
- velocities as well as having unconstrained slip and depth (e.g., Figure 2 & Figure S2).
- 340

341 2.4 Viscous modeling

An alternate explanation for observed deformation is that the pattern of uplift and subsidence
represents ongoing permanent (inelastic) deformation, for example caused by aseismic folding or
slip along bedding planes (Figure 5). To test this hypothesis, we consider a simple analytic
model for folding of a viscous layer above a weak (low viscosity) decollement layer. This
method implies the upper layer thickness controls the spacing between anticlines (Biot, 1957):

 $H = \frac{L_d}{2\pi} \left(\frac{R}{6}\right)^{-1/3}$ (Eq. 3)

348

where L_d is the dominant wavelength (or spacing), *H* is the thickness of the upper layer, and *R* is the viscosity ratio between the layers above and below the decollement, which we take as 1 in the absence of additional information.

352

We mapped the dominant anticline spacing in a zone between the first anticlines visible at the surface and before the inner belt of the Indo-Myanmar Ranges (**Figure S7**). Using Equation 3, we calculated the decollement depth between our mapped anticlines and the averaged decollement depth along the accretionary prism (**Figure 6**).

357

Our estimated depths across latitude vary between 3 km and 9 km with an average depth of 5.4 km (**Figure 6**). Across the northern transect, we estimate decollement depth of 7-8 km, across the central transect, we estimate decollement depth of 3-4 km, and Chattogram transect to be 5-6 km depth. These depths are comparable to previous seismic and geologic studies done in the region (e.g., Betka et al., 2018; Bürgi et al., 2021; Abdullah et al., 2022), lending support to the hypothesis that the anticline spacing, and uplift is controlled by viscous folding processes above

363 hypothesis th364 this layer.

365

Additionally, we calculated the implied shortening rates accommodated by the anticlines by assuming the uplifted volume within the anticline is equivalent to the volume of material taken up by shortening (**Figure S6**). Li et al., (2018) previously used this relationship to calculate displacement of anticlines due to fixed-hinge rotation:

370

$$S_r = \frac{A}{D}, \qquad (\text{Eq. 4})$$

371

where S_r is the shortening rate, A is the uplifted cross-sectional area per year, i.e., the positive

area under the LOS velocity profile, and D is the depth to the decollement.

- 375 We calculated the shortening rates for the northern transect, which shows the most clearly
- 376 isolated uplifting anticlines, in particular the Rashidpur anticline (Figure 3). We calculated a
- 377 range of shortening rates using decollement depth estimates from previous studies and our
- 378 averaged calculated depths from **Figure 6**. We estimated horizontal shortening rates between 1.0
- 379 mm/yr (assuming an 8 km decollement depth) to 2.7 mm/yr (3 km decollement depth) for the 380
- Rashidpur anticline, which represents 5 20% of the overall convergence rate (e.g., Steckler et
- 381 al., 2016; Mallick et al., 2019; Panda et al., 2020; Oryan et al., 2023; Lindsey et al., 2023).
- 382

383 3. Discussion

- 384 We have constructed an ALOS-2 InSAR LOS velocity map that spans the central and northern Rakhine-Bangladesh megathrust, from the deformation front in the west to the fold-and-thrust-385 belts in the east. Our results are among the first to map deformation at the front of an active 386 387 megathrust and provide an important first look into potential active tectonic behavior in this 388 critical region.
- 389
- 390 The data reveal localized areas of deformation along the outer belt of the Indo-Myanmar Ranges,
- with uplift on anticlines and subsidence in synclines (Figures 2 and 3). However, none of our 391
- 392 models of a fault-cored anticline or a creeping decollement can fit the data with reasonable slip
- rates or fault geometry that agrees with geologic studies. Instead, we suggest that the uplift can 393
- 394 be driven by viscous folding of the upper plate, with important implications for our
- 395 understanding of the long-term processes that build topography within the wedge and the earthquake hazard.
- 396 397

398 **3.1 InSAR corrections**

- 399 Due to the significant amplitude of ionospheric variations near the magnetic equator (Jee et al., 400 2004) and the high sensitivity of L-band wavelengths to this layer of the atmosphere, many of 401 our interferograms have several hundred ionospheric fringes across them, resulting in a failed 402 split-spectrum correction step during processing. We found that decreasing the number of looks 403 in the ionospheric correction step (from 80x32 to 40x16) and increasing the window size of the 404 Goldstein filter (from 64 to 128) is effective in reducing the number of unwrapping errors 405 causing these corrections to fail, though more computational time is also needed. Using a smaller 406 number of looks in both azimuth and range during the ionosphere correction is likely effective because it avoids the spatial aliasing of very high ionosphere fringe rates in some images (e.g., 407
- 408 Figure S4). However, some interferograms were not improved by this method, possibly because
- 409 the unwrapping errors in these cases resulted from spatial decorrelation due to other noise
- 410 sources, rather than aliasing (e.g., Figure S4). In such cases, it may not be possible to recover the
- 411 signal without a more complex unwrapping approach.
- 412
- 413 Thus, obtaining an accurate timeseries requires a careful manual check of each individual
- interferogram. We identified several interferograms that still have residual atmospheric effects 414
- (ionosphere or troposphere) and unwrapping errors. We carefully inspected all interferograms 415
- and excluded interferograms that were too decorrelated, and fully excluded some dates for which 416
- most of the pairs were bad. Overall, our InSAR results show areas of highest coherence at lower 417
- elevations and partial decorrelation within the foothills of the Indo-Myanmar Ranges due to 418
- 419 influences from vegetation. Finally, we attempted to estimate the closure phase bias (Zheng et

- 420 al., 2022) but did not see an improvement in the results, most likely due to an insufficiently 421 redundant network of successful interferograms.
- 422

423 **3.2 Broad InSAR velocities**

In addition to the small-scale pattern of uplift and subsidence we identified above the fold and 424

425 thrust belt, we note broad east-west bands of apparent uplift and subsidence alternating along

426 strike in our LOS velocity map, with amplitude greater than 5 mm/yr (Figure 2). We consider

- 427 three hypotheses that could explain these broader signals.
- 428

429 The first hypothesis for the LOS velocity alternation is that it represents a residual uncorrected or 430 second-order ionospheric effect remaining in our final InSAR velocities. Previous studies have found that InSAR velocities perform worse at longer wavelengths due to ionosphere, orbit, and 431 432 the atmosphere (Tong et al., 2013; Xu et al., 2021). A second-order ionospheric effect has been 433 identified in GNSS observations in the case of very strong ionospheric variations (e.g., Kedar et 434 al., 2003; Hernández-Pajares et al., 2007). These effects can affect the L-band GPS signals at a 435 level of several millimeters up to the centimeters after the dual-frequency correction is applied (e.g., Hernández-Pajares et al., 2007; Liu et al., 2015). The influence of these higher order 436 ionospheric effects is strongest at lower magnetic latitudes and mainly visible in the north-south 437 direction (Liu et al., 2015). Moreover, this hypothesis could potentially explain the trend of 438 439 positive LOS velocity that is visible across the ALOS-2 scene towards the inner belt of the Indo-440 Myanmar Ranges. Quantifying the magnitude of this effect and determining whether it is 441 responsible for the observed patterns will be important for understanding the limits of the first-442 order ionosphere correction approach adopted here and by future L-band InSAR missions 443 including NISAR.

444 445 Secondly, the broad pattern of alternating subsidence and uplift could be due to north-south compression or shortening related to the hypothesized northward subduction initiation of the 446 447 Surma Basin beneath the Shillong Massif (Mallick et al., 2020). The Shillong Massif is a rigid

448 block uplifted due to the underthrusting of the Indian lithosphere, also causing the Surma Basin

- to subsequently form (Johnson and Alam, 1991; Bilham and England, 2001; Najman et al., 449 450 2016). The northernmost band of negative LOS velocities in our image may be related to the
- 451 long-term subsidence of the Surma Basin (Figure 2). South of the Surma basin, the broad pattern
- 452 of uplift along 23°N along a topographic culmination could be attributed to the flexural bulge
- from the overthrusting of Shillong over the Surma Basin (e.g., Maurin and Rangin, 2009; 453
- 454 Steckler et al., 2018). The area of uplift corresponds with the shallowest decollement depth
- 455 inferred by Bürgi et al., (2021), who also observed a general east-west directed trend in the
- 456 minimum depth, with a deepening trend to both the north and south (Figure 6). However, the
- 457 secondary bands of subsidence and uplift south of these two bands are not well explained by this 458 hypothesis, unless the overriding plate is buckling in several places.
- 459

460 The third and less likely hypothesis is related to variations in the megathrust kinematic coupling

- along strike. Freely slipping parts of the megathrust would result in westward motion of the 461
- 462 overriding plate, resulting in a negative descending-track LOS velocity, while locked parts of the
- megathrust would be moving upward or eastward, resulting in a positive LOS velocity. 463
- 464 Therefore, a variation along strike in the LOS velocity could indicate an along-strike variation in
- coupling. However, the observed magnitude of alternation would indicate a large difference in 465

fault slip rates between the bands, which has not been observed or suggested by previous studies
using InSAR (Higgins et al., 2014) or GNSS (Steckler et al., 2016; Panda et al., 2020; Oryan et

- 468 al., 2023; Lindsey et al., 2023).
- 469

470 **3.3** Applicability of fault slip models to observed deformation patterns

471 Our InSAR velocities can be fit by elastic dislocation models only with implausibly high fault

- slip rates, at greater than the regional convergence rate and unlikely geometries (**supplement**
- tables 1 to 3). This happens because the data record localized positive LOS velocities directly
 above each anticline, but the orientation of the LOS vector in our descending image is such that
- 475 slip on a decollement or east-dipping fault results in westward (negative) motion that partly
- 476 counteracts the positive vertical component. As a result, the fault model requires implausibly
- 477 high slip rates to fit the observations. This can also explain why our model prefers a shallowly
- east-dipping thrust fault, contrary to the expected geometry of moderately to steeply west-
- dipping faults (Abdullah et al., 2022; Betka et al., 2018).
- 480

481 Our observations show a faster rate of subsidence in the synclines surrounding the Rashidpur

482 anticline than the uplift rate of the anticline itself (**Figure 3**). A possible explanation is that the

483 subsidence is enhanced by sediment loading and compaction in addition to the folding processes.

484 Sediment compaction is significant in this region, especially around the delta (e.g., Higgins et al.,

485 2014; Steckler et al., 2022). It was proposed that the magnitude 7.5 Srimangal earthquake in

- 486 1918 occurred on a thrust fault within the Rashidpur anticline (Stuart, 1920; Wang et al., 2014).
- 487 However, it is unlikely that post-seismic slip from this earthquake produces the uplift and
- 488 subsidence signals here one hundred years later.
- 489

490 In the central anticline section, we fitted a shallow dipping fault at a very shallow depth (<1 km), 491 shallower than the seismic survey depths at ~6 km (Bürgi et al., 2021) (Figure S3). This model does not fully fit the secondary uplift pattern across the transect despite having fitted the general 492 493 subsidence and uplift pattern. In the Chattogram transect, we were not able to fit the velocities 494 using a reasonable slip rate despite having fitting with a steeper dipping fault comparable to 495 seismic surveys (Abdullah et al., 2015). The lack of uplift in the anticline suggests that it could 496 be inactive, and that the subsidence around the anticline can be contributed by ongoing sediment 497 compaction.

498

499 **3.4 Possible ductile folding of anticlines**

500 We estimated the northern and southern section of our study area tend to have deeper decollement than the central section using the viscous modeling (Figure 5). This pattern is 501 502 similar to the decollement depth interpreted from reflection seismic lines analyzed by Bürgi et al. 503 (2021), in which the decollement depth plunges to the north and south of a culmination in 504 Tripura, India. In our northern profile, we estimate a decollement depth of ~7-8 km under the Rashidpur anticline which is about the same as the seismic survey and structural interpretations 505 506 (Bürgi et al., 2021, Abdullah et al., 2022). It is deeper than the estimated top of overpressure (Zahid and Uddin, 2005). Results from a recent broadband seismic deployment (Carchedi, 2023; 507 Carchedi et al., 2023; Kumar et al., 2024) suggest a velocity increase at ~10 km and a change in 508 anisotropy at 8-10 km at the Rashidpur anticline, although the resolution of the passive seismic 509 510 data is limited at this depth. In Tripura, India, Betka et al., (2018) structurally interpreted depths of 3.1 km to 3.4 km for the decollement, but Bürgi et al., (2021) interpolated a ~5 km depth. 511

512 These depths are within the depth range of our central transect (south of the culmination), where

- 513 we estimate a depth of 3-4 km. Here, we expect a depth between that of the culmination and the
- 514 Chattogram transect, so a little deeper than our estimate. The southern Chattogram transect
- decollement of 5-6 km is within the depth ranges of 4.5-5.5 km estimated by the structural model
 of Abdullah et al. (2015), ~6 km estimated by Maurin and Rangin (2009), and the 7 km depth
- of Abdullah et al. (2015), ~6 km estimated by Maurin and Rangin (2009), and the 7 km depth
 estimated by Bürgi et al., (2021) and Abdullah et al., (2021). However, Sikder and Alam (2003)
- estimated by Bürgi et al., (2021) and Abdullah et al., (2021). However, Sikder and Alam (2003)
 had a shallower depth of 3-4 km. We note that our estimated depths are a minimum value
- because we assume a viscosity ratio of R = 1 (Equation 3), and we assume the observed
- 519 because we assume a viscosity ratio of X = 1 (Equation 5), and we assume the observed 520 anticline spacing is equivalent to the folding initiation wavelength. The inferred decollement
- 521 depths will be slightly deeper if we assume a lower viscosity of the upper layer (Biot, 1957), or if
- 522 significant shortening has occurred at the location where the anticlines are mapped (**Figure 6**).
- 523
- 524 The folds of the IBR transition from initial detachment folds in the blind frontal part of the fold
- belt to fault-propagation folds in the outer fold belt (Betka et al., 2018; Bürgi et al., 2021).
- 526 Although the anticlines analyzed here are all from the faulted outer fold belt (e.g., Betka et al,
- 527 2018; Bürgi et al., 2021; Abdullah et al., 2022), our best fit to the LOS deformation is suggest
- that there is ongoing viscous deformation. We note that faulting only in the outer belt only
- 529 accounts for ~40% of the total shortening of the fold belt (Betka et al., 2018; Oryan et al., 2023).
- 530 Only limited deformation is taken up by blind anticlines buried closer to the deformation front
- 531 (Islam et al., 2021). We propose that deformation here can alternate between fault-cored or
- ductile deformation at different times, possibly expressing a ductile-brittle behavior (e.g., Nabaviand Fossen, 2021).
- 533 534

535 Our estimated horizontal shortening rates ranges from 1.0 to 2.7 mm/yr for the Rashidpur

- anticline which is 5 20% of the convergence rate of 15 20 mm/yr (Steckler et al., 2016;
- 537 Mallick et al., 2019; Panda et al., 2020; Lindsey et al., 2023; Oryan et al., 2023). Our rates are
- also close to the estimated long-term uplift rate of 1 to 3 mm/yr from Wang et al., (2014). A
- 539 lower shortening rate of the anticline than the convergence rate can be explained by most of the
- 540 deformation being taken up on the splay faults and megathrust, augmented by inelastic
- 541 deformation across the fold-and-thrust belt (**Figure 7**).
- 542

543 **3.5 Implications of aseismic anticlines and its seismic hazards**

- 544 The role of creeping reverse faults or folding of anticlines in releasing strain accumulated within an upper plate has not yet been fully understood. The elastic rebound earthquake cycle yields no 545 permanent deformation of the upper plate, thus the topography and uplift of upper plates of 546 547 subduction zone indicate that there must be ongoing non-elastic deformation (Jolivet et al., 2021; 548 Malatesta et al., 2021; Mallick et al., 2021). Our study can shed more information on fold-and-549 thrust belt systems in other convergent boundaries. A possible analog to our study area is the 550 Zagros fold-and-thrust belt that exhibits either aseismic creep or ductile folding; however, in that case the low viscosity layer is composed of salt (Nissen et al., 2011). The presence of anticlines 551 552 above the Hikurangi, Alaska and Cascadia megathrusts suggests ductile deformation at trenches 553 may be common in the overriding plate (Figure 8).
- 554
- 555 The distribution of strain as permanent deformation can reduce the coseismic slip from the long-
- 556 term deformation (e.g., Meade, 2010; Jolivet et al., 2020; Malatesta et al., 2020). If 5 20% of
- 557 deformation is taken up as permanent deformation without fault creep, then only the remaining

deformation is released as earthquakes overriding plate faults or megathrust seismically. Mondal

- et al. (2018) demonstrated that St. Martin's Island in SE Bangladesh has been undergoing
- nonelastic deformation following the 1762 earthquake. Assuming the Rashidpur anticline is still

561 partially locked, Wang et al. (2014) estimated the anticline will still be able to produce a

- magnitude 7.2 earthquake with a slip rate of 1 to 3 mm/yr. Some possible explanation that
 anticlines can undergo ductile deformation is due a large and low strength decollement zone, th
- 563 anticlines can undergo ductile deformation is due a large and low strength decollement zone, the 564 upper layer has high elastic shear modulus, and the total thickness of the sequence is small
- 565 (Simpson, 2009).
- 566

The lack of historic megathrust earthquakes along the Sylhet-Tripura-Chittagong segment of the
subduction zone could also reflect the long recurrence of megathrust earthquake. Modeling by
Vorobieva et al. (2021) suggest a variable repeat time averaging over 1000 years. If some of the
strain in the upper plate is being released aseismically, the repeat time between megathrust

- earthquakes could be lengthened or earthquake magnitude reduced. Both these scenarios lessen
- the earthquake hazard for Bangladesh. This finding has implications for other subduction zones
- 573 where geodetic data are lacking close to the trench. If ductile deformation accommodates a
- 574 significant portion of the shortening above these megathrusts, it may have important implications
- for the processes leading to earthquakes with large shallow slip, and their recurrence interval.

577 Conclusion

- 578 This study presents the first InSAR interseismic velocity map over the central and northern
- 579 Rakhine-Bangladesh megathrust, spanning from the near-trench fold and thrust belt to the Indo-
- 580 Myanmar Ranges. We identified several interseismically deforming structures in the outer fold
- and thrust belt corresponding to mapped anticlines. However, the observed motion could not be
- 582 fitted by dislocation models representing a fault-cored anticline. Instead, we propose that a
- simple viscous folding process could potentially explain the deformation of these structures and
- show that the decollement depth predicted from the anticline spacing by a simple viscous folding
- 585 model is in good agreement with independent seismic and geologic observations. Ultimately, we
- 586 propose that ductile deformation in the outer wedge could take up part of the deformation in this 587 and other subduction going worldwide. The implications of this process for the sublition of
- and other subduction zones worldwide. The implications of this process for the evolution of
- 588 frictional properties along the megathrust and potential seismic or tsunami hazards will require 589 careful further study.
- 590

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- 598

599 Open Research

- 600 ALOS-2 wide-swath SAR imagery are available from G-Portal (<u>https://gportal.jaxa.jp/gpr/</u>).
- 601 GNSS RINEX data are archived at EarthScope (<u>https://www.unavco.org/data/data.html</u>).
- 602 Processed GNSS timeseries and velocities, InSAR velocities, and MATLAB scripts for the
- 603 models described in the text are available from (<u>https://digitalrepository.unm.edu/</u>).

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935 Figures



Figure 1: Map view of study area. Circles represent seismicity from 1976 to 2023 data from USGS Earthquake Search Catalog. Arrows represent GNSS velocities referenced on Indian Plate. Black box represents the area coverage of the ALOS2 scene. CMFB is the Chattogram-Myanmar fold and thrust belt, IMR is the Indo-Myanmar Ranges, SF is the Sagaing Fault, CMF is the Churachandpur-Mao Fault, KBW is the Kabaw Fault System, and SP is the Shillong Plateau. The dotted line indicates the estimated trace of the northern section of the megathrust. Faults were plotted from the Global Earthquake Model (GEM) by Styron and Pagani (2020). The inset shows the major plate boundaries.



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Figure 2: Interseismic LOS deformation of the area of interest, from ALOS-2 Path 44, Frame 3150. GNSS LOS-projected velocities are represented by colored circles. Negative values correspond to subsidence or westward motion whereas positive values correspond to uplift or eastward motion. Inset maps show the satellite imagery and elevation of the same area. Each profile is 2 km in width. The dashed line represents the Rakhine-Bangladesh megathrust from Wang et al., (2014). Inset shows the terrain over the region.



Figure 3: Cross-sections of all the transects of their respective median elevation (meters) and the

- LOS velocities (mm/yr). The same filtering and down sampling for the DEM is used for eachtransect.
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- 964 Figure 4: Left: showing the map of the Rashidpur anticline uplift, anticlines were mapped from
- 965 Wang et al., (2014). Right: Showing the fitting of the best-fitted model.
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- **Figure 5**: Examples of the LOS velocities for uplift on fault-cored anticline and aseismic
- 970 folding. Fault-cored anticlines will show asymmetrical LOS velocities whereas aseismic folding971 will show symmetrical LOS velocities.
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90.0 | 92.5 I 9 km 25.0-0 50 100 km O 5 km 6 km Rakhine-Bangladesh Megathrust 22.5-7 km 0 Decollement Depth (km) >9 8 km 3

Figure 6: Map of estimated averaged decollement depths from our viscous folding model (dots)
overlaid on the interpolated depth map from Bürgi et al., (2021).

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983 Bottom panel shows the proposed long-term deformation phases across the transect.



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Figure 8: Other subduction zones with potential viscous folding of anticlines at subduction zones.

1	Journal of Geophysical Research: Solid Earth
2	Supporting Information for
3	Interseismic uplift of anticlines above the Rakhine-Bangladesh Megathrust from ALOS-2
4	InSAR
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13 14 15 16	Introduction This supplement file contains additional figures and tables of the manuscript for the processing and analysis.
17 18	Contents of this file
19 20 21 22 23	Figures S1 to S7 Tables S1 to S4 Equation S1

Stations	Lon	Lat	GNSS LOS	InSAR LOS	InSAR LOS
			(m/yr)	ori (m/yr)	fitted (m/yr)
BAGH	92.1919	23.1617	-0.001474	0.00023333	-0.0041252
BARK	92.3753	22.7256	0.001702	-0.0015877	-0.0048232
CHNR	91.515	24.1897	-0.001749	0.00414588	-0.0033999
CHT2	91.7801	22.3665	-0.004834	0.00057248	-0.0033768
COML	91.1363	23.4197	0.001593	0.011735	0.00462758
DCPS	91.7783	24.3028	-0.000552	0.00666936	-0.0004875
DIGH	92.067	23.2501	-0.000947	0.00171826	-0.0030618
ICPS	92.0377	24.4038	-0.006077	0.0034909	-0.0032603
JURI	92.1353	24.4984	-0.000207	0.00348198	-0.0032127
KGPS	91.6186	24.1862	-0.003124	0.00601808	-0.0012934
KPTI	92.2171	22.4986	-0.001947	0.00313477	-7.04E-05
МКСН	91.8447	22.8512	-0.001334	0.00752473	0.00291628
MPR2	91.3909	23.9865	0.004479	0.00629722	-0.0011862
RPUR	90.7632	23.0365	0.003696	0.0101271	0.00283509
SSPS	91.6625	22.6148	0.00029	0.00565574	0.00103574
TEDM	91.7266	24.3093	-0.002915	0.00637526	-0.0009029
SITA	91.895	24.2819	-0.004757	0.00466376	-0.0021997
SRIM	93.6494	23.3542	-0.006429	-0.0031068	-0.0045783

Table S1: LOS velocities of collocated InSAR and GNSS. Where InSAR LOS ori is the original

25 InSAR velocities before converted to the GNSS reference frame.

Fault geometry	centX (lon)	Depth (km)	Dip (°)	Wid (km)	Slip (cm/y)	Notes/RMSE
Thrust (front)	17.96	4.67	1.67	5.92	6.64	3.741
Thrust +	17.92	4.30	4.18	6.10	5.77	3.785
Decol	38.24	5.24	2.40	34.58	0.20	
Thrust +	18.16	3.98	3.86	6.14	5.24	3.827
Hinge +	34.58	4.70	2.23	26.74	0.40	
Decol	21.23	3.98	88.07	0.41	0.35	
Thrust +	18.20	4.04	4.22	5.86	5.9	13.888
Duplex +	41.50	5.09	2.33	40.80	0.2	
Decol	40.80	4.15	18.94	6.33	19.84	
BThrust	17.76	6.08	88.57	3.52	12.34	4.061
(back)						
BThrust +	16.33	3.93	16.82	4.96	3.75	4.606
Decol	17.65	4.74	1.38	7.4	5.86	

Table S2: Best-fitted model parameters for the northern section (A-A').

Fault	centX	Depth	Dip (°)	Wid (km)	Slip	Notes/RMSE
geometry	(lon)	(km)			(cm/y)	
Thrust	8.6	0.53	0.69	8.19	1.03	1.935
(front)						
Thrust +	88.06	6.4	17.22	39.06	5.91	2.682
Decol	168.59	16.03	3.55	123.98	6.28	
Thrust +	68.51	2.89	19.69	8.49	8.11	2.604
Hinge +	100.99	7.42	6.21	57.3	1.97	
Decol	72.76	2.89	80.15	2.91	2.77	
Thrust +	1.37	3.08	0.62	24.66	0.83	1.471
Hinge	26.03	3.08	0.62	24.66	0.83	
BThrust	17.99	9.78	0.52	12.81	2.2	2.25
(back)						
BThrust +	69.07	6.91	10.17	13.53	11.56	2.903
Decol	83.04	9.03	2.57	41.3	3.48	

Table S3: Best-fitted model parameters for the central section (B-B').

Fault geometry	centX (lon)	Depth (km)	Dip (°)	Wid (km)	Slip (cm/y)	Notes/RMSE
Thrust (front)	18.91	2.17	8.03	29.4	2.56	3.167
Thrust +	7.8	1.32	3.7	7.57	4.13	1.892
Decol	29.54	2.15	1.84	35.96	1.24	
Thrust +	32.98	9.93	8.58	17.61	10.95	3.775
Hinge +	71.98	11.58	0.65	60.60	44.33	
Decol	41.78	9.93	85.71	2.63	1.64	
Thrust +	21.03	3.26	10.14	34.68	3.50	3.142
Hinge	55.16	3.26	10.14	34.68	3.50	
BThrust (back)	2.18	9.94	86.35	4.28	19.97	3.178
BThrust +	65.11	9.9	25.61	25.25	0.59	5.307
Decol	79.25	15.44	0.19	51.05	46.96	

Table S4: Best-fitted model parameters for the Chattogram section (C-C').





Figure S1: Baseline plot of all the pairs. Accepted pairs consist of 106 out of the 186 pairs. 35

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Constrained





Figure S2: Best-fitting models for the northern transect with constrained slip (maximum of 20 39 mm/yr and depth minimum of 2 km). Left panels show the median elevation, model fitting, and 40 fault model. Right panels show the Monte Carlo iterations for the best fitting model. 41

Unconstrained



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Figure S3: Best-fitting models for each transect. Left panels show the median elevation, model
 fitting, and fault model. Right panels show the Monte Carlo iterations for the best fitting model.

Original Ionosphere Corrected A Fr IBR 150330-151123 Successful Correction 150511-151012 Failed Correction Original Ionosphere Corrected B IMR 150330-151123 Successful Correction 150511-151012 Failed Correction Original Corrected Ionosphere IMR East 150330-151123 Successful Correction 150511-151012 Successful Correction

Example set	Filter size	Filter strength	Total ion (r × a)
	32	0.3	80 × 32
B	64	1	160×64
0	64	1	40 × 16

- 49 Figure S4: InSAR correction with different window size. We removed bad interferograms and
- 50 checked the effectiveness of the removal iteratively over time. A total of three ALOS-2 scenes
- 51 were removed including 2019-05-06 due to low burst sync where interferograms could not be
- 52 produced with this scene and 2021-05-03 and 2021-08-23 are removed due to remaining
- 53 ionospheric effects even after correction.
- 54



- 57 Figure S5: Corrected InSAR LOS and GNSS LOS in the same reference frame. Bottom right
- 58 figure shows the relationship between uncorrected and corrected InSAR LOS compared to the
- 59 GNSS LOS.
- 60







- 63 velocity from InSAR, *w* is the width of the uplifted anticline as seen from the cross-section
- 64 (meters), h is the depth to the decollement (meters). T_0 and T_n represents the initial time and after
- 65 certain time has passed.



67

Figure S7: Depth to decollement estimates from anticline wavelengths.

70 Shortening rate =
$$\frac{(V_{LOS} * w)}{h}$$

- 71
- 72 Equation S1: Modified equation from Li et al., (2018) where the V_{LOS} (meters/yr) is the line-of-
- raging sight velocity from InSAR, w is the width of the uplifted anticline as seen from the cross-section
- 74 (meters), h is the depth to the decollement (meters).
- 75