New estimates of minimum geological convergence for the eastern Himalaya, India

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1. Motivation

- Geological studies along the HFT inferred geological convergence rates of 13.8 mm/yr in the western Himalaya (Wesnousky et al., 1999), 21 mm/yr in the central (Lave & Avouac, 2000), 20.8 mm/yr in Bhutan (Berthet, et al., 2014), 23 (Burgess et al., 2012) and 27 mm/yr (De Sarkar et al., 2014) in the eastern Sub-Himalayan zone.
- GPS convergence studies reveal convergence rates of 13 mm/yr in the Kashmir Himalaya (Schiffman et al., 2013), 18 in the eastern Nepal Himalaya (Ader et al., 2012), 16-20 in the eastern Indian and Bhutan Himalaya (Jade et al., 2007; Drukpa et al., 2012; Vernant et al., 2015).
- Suggested clockwise rotation of the Brahmaputra Valley (Vernant et al., 2014) has led to the decrease in the convergence velocity eastward from 18-12 mm/yr east of Sikkim.
- Previous estimates of higher geological convergence rate estimates for the eastern Himalaya are inconsistent with the GPS estimates.
- Burgess et al. (2012) proposed a slip rate of ~5 mm/yr for the frontal thrust of the eastern Himalaya, India.
- Present study draws motivation from the inconsistency between the geological and GPS rates proposed for the eastern Himalayan front.

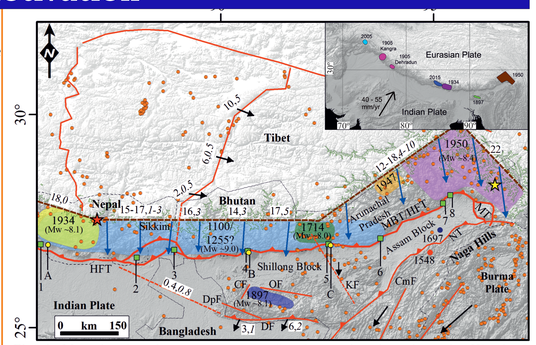
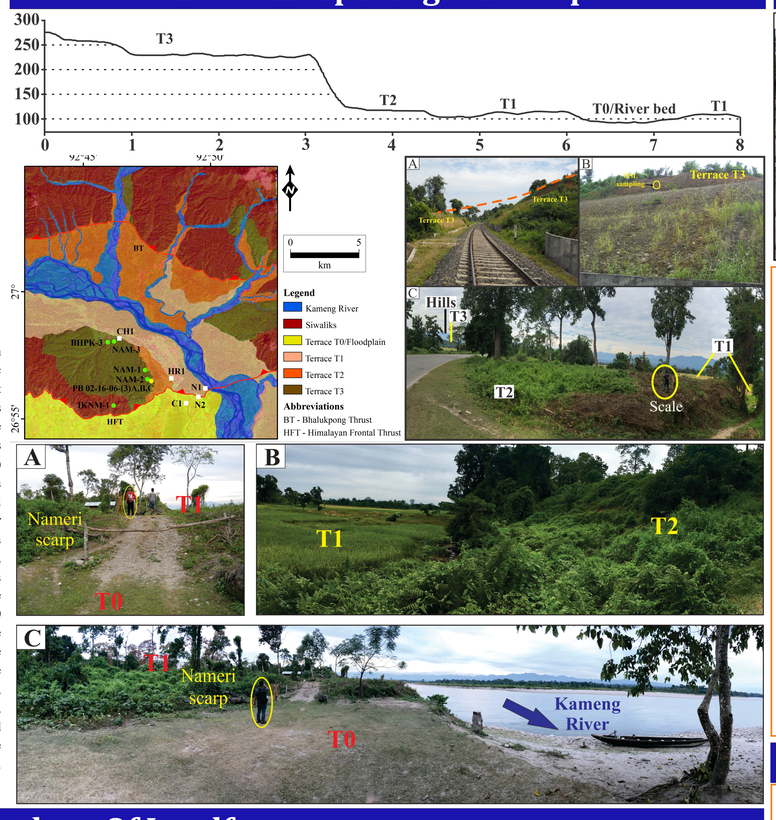
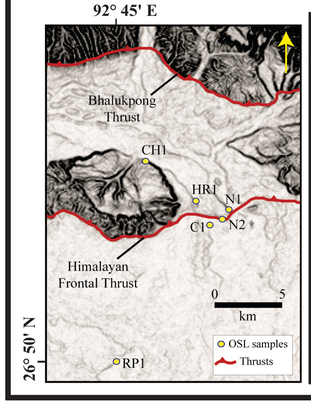


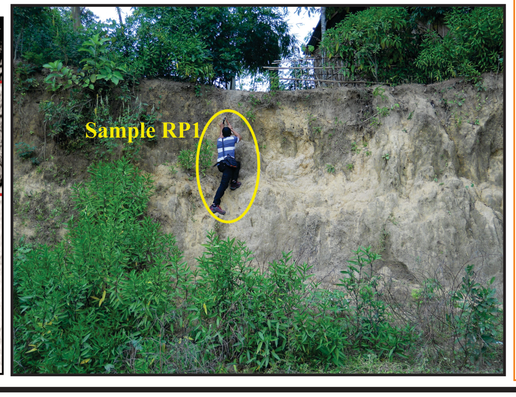
Fig. 1. Map showing the rupture zones of major earthquakes along the Himalayan arc (inset). SRTM-derived map showing the relationship between major tectonic blocks of the eastern Himalaya determined from GPS observations by Vernant et al. (2014). Thin dotted line represents the approximate international borders between India and the adjoining countries. Polygons denote the earthquake rupture zones of 1934, 1100/1255, 1713, 1947 and 1950 earthquakes. Green solid squares denote previous paleoseismological trench sites at, 1 - Marha Khola (Lave et al., 2005) and Sir Khola (Sapkota et al., 2013), 2 - Hokse (Upreti et al., 2000), 3 - Chalsa (Kumar et al., 2010) and Panijhora (Mishra et al., 2016a), 4 - Sarpang (Le-Roux Mallouf et al., 2016), 5 - Nameri (Kumar et al., 2010), 6 - Harmutty (Kumar et al., 2010), 7 - Marbang (Jayangondaperumal et al., 2011), 8 - Pasighat (Priyanka et al., 2017). Yellow dots represent the sites of geological fault slip rate studies by, A - Lave and Avouac (2000), B - Berthet et al. (2014), C - Srivastava and Misra (2008), Burgess et al. (2012), De Sarkar et al. (2014), and the location of the present study. Red and yellow stars are the epicenters of the 1934 and 1950 earthquakes. Brown dashed line is the locking line which coincides with the 3.5 km contour (green curves). Numbers above the locking line are convergence rate in mm/a and dextral slip (in italics) from Vernant et al. (2014). Faults are indicated as HFT - Himalayan Frontal Thrust, MBT - Main Boundary Thrust, MT - Mishmi Thrust, DpF - Dapsi Fault, CF - Chedrang Fault, NT - Naga Thrust, OF - Oldham Fault, DF - Dauki Fault, CmF - Churachandpur-Mao Fault, and KF - Kopili Fault. Orange solid dots represent the microseismicity data since the year 1900 to 2014 downloaded from the website of the International Seismological Centre, United Kingdom (www.isc.ac.uk).

2. Geomorphological Setup



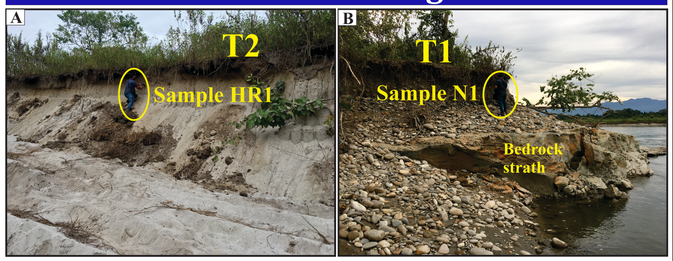
3. Methodology Employed & Chronology Of Landforms





- Six sediment samples, CH1, HR1, N1, N2, C1 and RP1, collected from the Quaternary landforms were dated using Optically Stimulated Luminescence to determine the time frame of their deposition, rate of tectonic uplift and bedrock incision.
- For terrace T3, previously reported depositional ages of 13.9 ± 3.1, 10.4 ± 1.4, 9.6 ± 1.4 and 5.7 ± 0.7 ka, in addition to 11 ± 2 ka in the present study (CH1), brackets its deposition between ~14 and 11 ka;
- Ages of 9.0 ± 0.9, 7.2 ± 0.7, 5.6 ± 0.8, 2.6 ± 0.4, 3.8 ± 0.6 and 1.1 ± 0.2 ka obtained in previous studies for T2 terrace, along with 11 ± 0.8 ka in the present study (HR1) suggests its deposition between ~11 and 7.2 ka;
- Two samples obtained from the terrace T1 in the present study yielded ages 7 ± 1.5 ka (N1) and 2.4 ± 0.5 ka (N2) bracket its deposition between ~7 and 2 ka.
- The previously undated lower terrace T0 (flood plain) has been dated in the present study yielding ages 19 ± 3 ka (C1) and 26 ± 3 ka (RP1).

4. Holocene Convergence



- Uplift (or incision) rates are measured from dated fluvial terraces, assuming the approximate height of the bedrock strath from the river bed as the total uplift and their chronology obtained from the alluvial cover of the strath (Wesnousky et al., 1999; Lave & Avouac, 2000; Kumar et al., 2006; Srivastava & Misra, 2008; Burgess et al., 2012).
- Srivastava and Misra (2008) estimated an uplift rate for the sub-Himalayan zone between ~7.5-11.9 mm/yr.
- Burgess et al. (2012) inferred an incision rate of 5.4 ± 0.4 mm/yr.
- We used 25 ± 5° as the dip angle for the frontal thrust and the vertical uplift rate of 0.44 ± 0.09 mm/a to derive slip and horizontal shortening rates of 1.04 ± 0.02 and 0.95 ± 0.02 mm/a across the NT during the Holocene.
- The calculations are based on a simple trigonometric equations $S = \dot{I}/\sin\theta$ and $H = \dot{I}/\tan\theta$ (where S and H are the slip and horizontal shortening rates along the NT, $\dot{I}$ is the vertical incision rate, and θ is the dip angle)

5. Highlights

- The vertical uplift, slip and shortening rates of 0.44, 1.04 and 0.95 mm/a in the present study are contrastingly lesser than that previously inferred in the western, central and eastern Himalaya.
- Together with the previous studies, the present study thus broadly indicates a contrastingly eastward decrease in the Indo-Eurasian convergence rates between the Brahmaputra Valley and southern Tibet east of Sikkim.
- Our study across the NT provides new implications towards the geological convergence and regional seismotectonics of the eastern Himalaya.
- The ages of samples C1 (19±3 ka) and RP1 (26±3 ka) suggest that the deposition of older sediments by the Kameng River to the south of the frontal thrust due to rampant erosion and incision in the upstream by significant tectonic uplift.
- We suggest that, during Holocene or later (< 3 ka), the bed rock incision has reduced significantly, but during Pleistocene the bed rock incision was rampant.