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ABSTRACT VOLUME

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GPS constraints on Indo-Asian convergence in the Bhutan Himalaya: Segmentation and potential for a 8.2<Mw<8.8 earthquake

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The seismogenic setting of Bhutan is unusual due to its lower-than-average 20th century seismic moment release (Drukpa et al. 2006), its absence of a reliable historical record, and its unusual location near the Shillong plateau where a great earthquake in 1897 resulted in ≈10 m of N/S shortening of the Indian plate to its south (Gahalaut et al. 2011). Despite these indicators that lower than normal convergence velocities should currently prevail, the GPS velocity between Shillong and Lhasa suggests that convergence in Sikkim and Bhutan occurs at velocities exceeding 20 mm/yr. GPS points between the Greater Himalaya and the Shillong Plateau measured in 2003, 2006 and 2012 permit us to quantify Bhutan's seismogenic potential.

Sikkim GPS data (Mukul et al. 2008; Mullick et al. 2009) and new data presented here can be explained by a convergence velocity of 22 mm/yr with a locking line at 20 km depth. No evidence for creep is manifest south of the locking line. Our preferred solutions suggest 7°N dip similar to the centroid solution for a 2009 Mw=6.1 earthquake in E. Bhutan.

Given the foregoing values for velocity, dip and depth we searched for the probable northern limit of the locking line, and hence the down-dip width of the Himalayan décollement in Sikkim and Bhutan (Table 1). In E. Bhutan we use the 2009 earthquake as a proxy for the locking line. Our inferred locations for the locking line approximately follow the 3.5 km contour (Avouac 2003).

We next proceed to determine the maximum magnitude earthquake that could occur in the Bhutan Himalaya at the present day assuming that a historical earthquake with 18 m of slip may have occurred c.1100 as recorded in trenches at 88.8°E and 92.8°E (Kumar et al. 2011), or in 1713 (Ambraseys and Jackson 2003) as recorded in Tibetan histories.

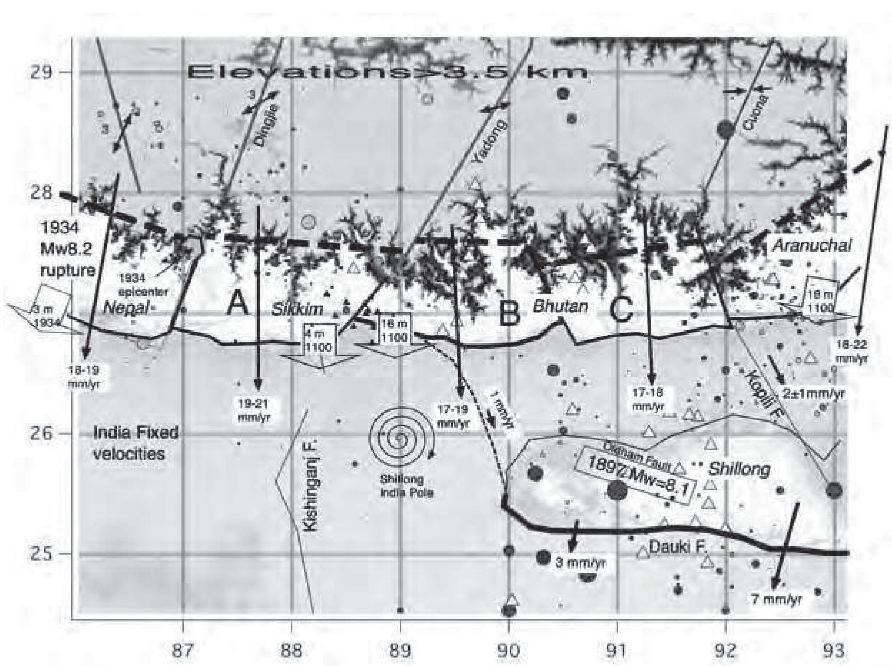

Fig.1: GPS points in Sikkim, Bhutan, Shillong and southern Tibet, and rupture segments A, B and C discussed in the text. Grey line is the inferred locking line south of which great ruptures propagate.

The Sikkim-Bhutan Himalaya is bounded by prominent along-arc changes of strike that we invoke to suggest favorable locations for rupture termination or initiation (King and Nabelik 1985). In the west, at 87°, a 10° change in strike of the Himalaya occurs between the 1934 rupture zone (Feldl 2005) and the almost east-west 500-km-long Sikkim-Bhutan segment (A-B-C). An abrupt 20° change in strike of the Himalayan arc occurs in 91.7°E in eastern Bhutan at the start of the 400-km-long, N70°E striking, Aranuchal Pradesh segment close to the intersection of the inferred Kopilli fault.

Between these major segment boundaries we identify A) the E.Nepal-Sikkim segment west of the Gish fault (Mukul et al., 2008), Yadong rift and Kishinganj Fault (Ni and Barazangi, 1984). The west end of the Shillong plateau is invoked to separate segments B) and C) on the basis that the 1897 earthquake may have reduced stress in segment C (Bilham and England 2001; Gahalaut et al. 2011) and there is weak evidence to suggest a slightly narrower décollement there (Table 1).

Table 1: Décollement widths, depths and anticipated maximum Mw earthquakes in Sikkim and Bhutan inferred from GPS convergence rates assuming no rupture since 1713, or c. 1100.

	E. Nepal/ Sikkim	W. and Central Bhutan	*E.Bhutan
latitude locking line	27.65°N	27.6°N	27.33°N
width décollement	94 km	99 km	67 km
along-arc rupture	150 km	150 km	150 km
1713 & 6 m of slip	Mw=8.3	Mw=8.3	Mw=8.2
c.1100 & 18 m slip	Mw=8.5	Mw=8.5	Mw=8.4
18 m segments A, B&C	Mw=8.5	Mw=8.7	
18 m segments AB&C	8.8<Mw<8.9		

* constrained by the epicenter of the 21/9/2009 Bhutan Mw=6.1 earthquake

We conclude that if no great earthquake has ruptured this entire region since 1100 AD a cumulative slip deficit of ≈18 m could be released in single 8.8<Mw<8.9 earthquake. The current 18 m slip deficit is disconcertingly similar to slip estimated to have occurred in paleoseismic trenches near Bhutan (Kumar et al, 2011), suggesting that the failure all or part of the Bhutan décollement soon would not be unexpected. An alternative interpretation based on a possible intervening great earthquake in 1713 (for which we have no paleoseismic evidence) suggests that a Mw≈8.2 earthquake, similar to the 1934 event could repeat at the present time in any of the segments we have identified. The apparent absence of creep suggests that, given our current state of knowledge, a future great earthquake is inescapable.

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