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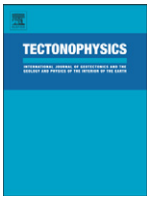

Active lower crustal deformation and Himalayan seismic hazard revealed by stream channels and regional geology

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ABSTRACT

Thick Tibetan crust stores energy driving large earthquakes along its margins. At its southern margin, it is hypothesized that its lower crust is extruded between two shear zones, such that strain in the ductile lower crust is fed into the higher seismogenic portions of the crust predicting rock uplift between these structures. The upper shear zone is regionally referred to as the South Tibetan detachment (STD) and the lower shear zone as the Main Central thrust (MCT). We use field mapping and k_{sn} channel steepness analysis to test this hypothesis in northwestern Nepal within a notable gap in historic seismicity. Here we show an ~170 km × 40 km swath of rapid rock uplift at the southern margin of the Tibetan plateau that overlaps a regional anticline suggesting active folding. The area of rapid uplift coincides with peak interseismic strain determined by GPS and overlies the inferred locked-to-creeping transition along the India–Asia plate boundary. The fold is cored by thick ductiley deformed crust and defined by a shear zone interpreted as the STD. Because the STD is folded it cannot facilitate active extrusion of a mid-crustal channel. A regional cross section across the fold shows that while the uppercrust has little post-Miocene shortening the lower middle crust is anomalously thick. We explain this by duplexing whereby thrust-sense shear zones stack ductile lower-middle crust beneath the STD north (downdip) of the locked-to-creeping transition. The plate boundary here last ruptured during the Mw >8.2 AD 1505 earthquake whose inferred rupture area encompasses the region of rapid rock uplift shown here, predicting a high slip potential. Integrating the structural geology and k_{sn} analysis with microseismicity patterns and the 1505 surface rupture suggests that in western Nepal the locked-to-creeping transition is ~40 km wide and lies 100–120 km north of the Himalayan thrust front.

1. Introduction

The Himalayan thrust wedge actively absorbs ~2 cm yr^{-1} of convergence between the Indian plate and stable Eurasia, resulting in large amounts of crustal shortening, surface uplift and recurring large (Mw > 8) earthquakes (Ader et al., 2012; Bilham et al., 2001). Geometrically, the thrust wedge contains several major thrust faults that sole into the basal Main Himalayan Thrust (MHT) (Pandey et al., 1999). The MHT "decouples" the Himalayan wedge from the subducting Indian plate and breaks the surface in the sub-Himalaya along the Main Frontal Thrust (MFT; Fig. 1a, b) (Kumar et al., 2006; Sapkota et al., 2013). In central Nepal coeval slip on thrust and normal faults is inferred to facilitate active southward extrusion of middle-lower crust (Hodges et al., 2004; McDermott et al., 2013; Wobus et al., 2005). The inferred active thrust fault(s) near the Main Central Thrust (MCT) broadly coincide with the lone belt of microseismicity in central Nepal. This spatial relationship and has been hypothesized to represent a kinematic link between ductile lower crustal strain and surface deformation (Hodges et al., 2004). Whereas microseismic epicenters in central Nepal form a single linear cluster 80–100 km north of the MFT coincident with an interpreted major ramp in the MHT (Cattin and Avouac, 2000; Pandey et al., 1995; Schelling and Arita, 1991), in western Nepal at 82° 15′E this linear cluster bifurcates into two subparallel belts (Fig. 2) 80–100 km and 120–150 km from the MFT. These belts remain distinct until 81°15′ where they converge again into a single belt with a different orientation than observed in central Nepal (Cattin and Avouac, 2000). These belts of microseismicity appear to be collocated with small ramps in the MHT (Pandey et al., 1999), indicating that the geometry of the MHT is different in central and western Nepal. In this interpretation the geometry of the MHT in central Nepal is best described by a single large ramp 100 km from the MFT while in western Nepal its geometry is better described by a series of smaller ramps (Pandey et al., 1999). The northern limit of MHT microseismicity has been interpreted to mark the locked-creeping transition along the plate boundary between India and Asia (Cattin and Avouac, 2000) which appears to be 50 km further from the MFT in western Nepal than in central Nepal. This is consistent with a regionally segmented MHT whose dip is significantly shallower in western Nepal than in central Nepal.

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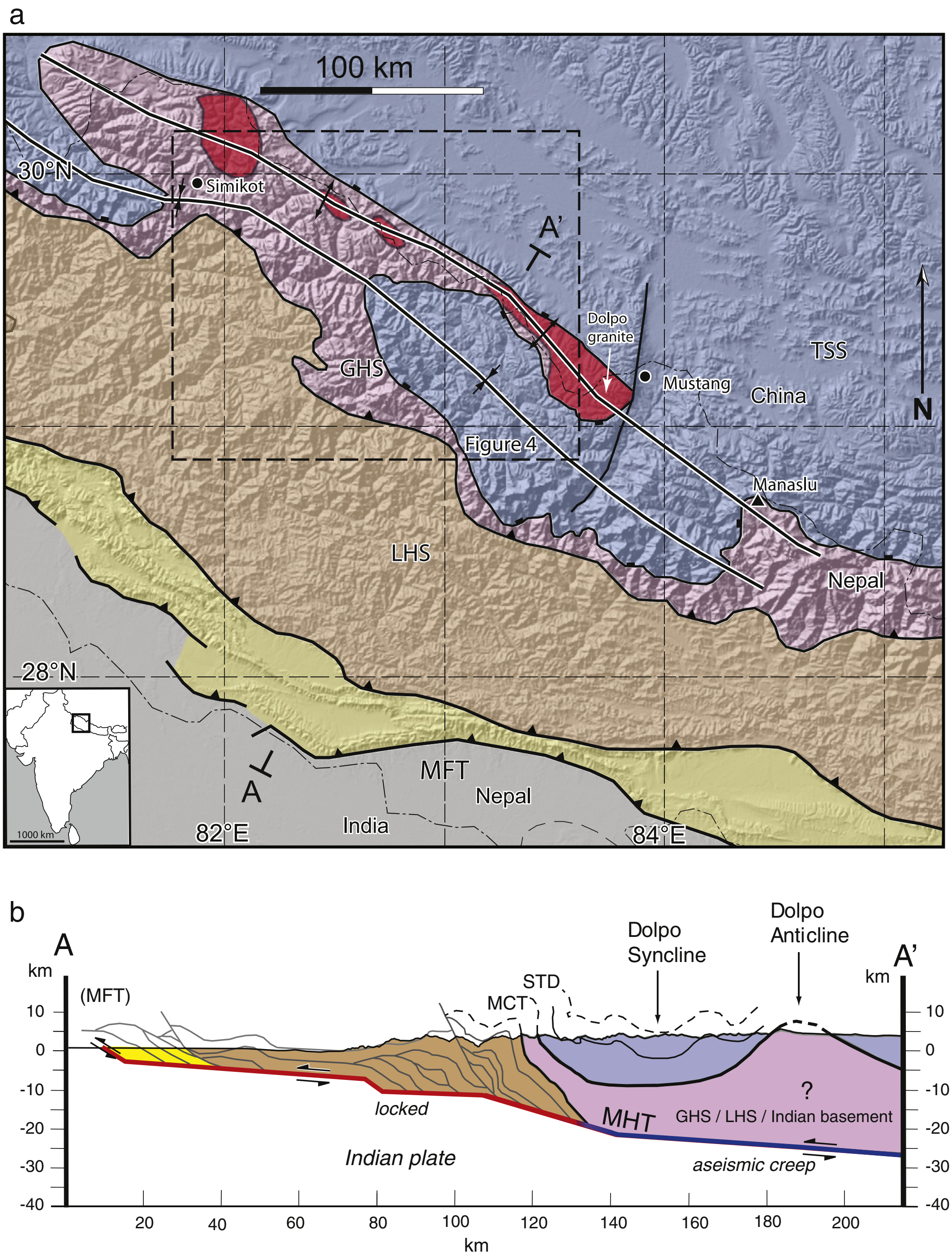

Fig. 1. a. Regional geologic map of the Himalayan thrust wedge highlighting the Dolpo fold which coincides with significant crustal thickening and high GPS-derived vertical uplift rate (Ader et al., 2012). Insets show rupture areas of historical earthquakes (Bilham and Ambraseys, 2005) and GPS determined uplift rates (Ader et al., 2012). (b) Cross section across Dolpo folds, geology south of syncline after (Robinson, 2008), MHT geometry north of syncline is from Caldwell et al. (2013), the transition from aseismic creep (blue) to locked (red) corresponds to the intersection of the 350 °C isotherm with the MHT (Herman et al., 2010).

Much of the convergence of India relative to Tibet is stored elastically along the southern margin of plateau and is released in great earthquakes which rupture patches of the plate boundary extending from southern Tibet to the MFT (Bilham et al., 2001; Feldl and Bilham, 2006). The rate of south directed creep of Tibet relative to a fixed India is within error of the Pliocene to recent MFT slip rate calculated from offset river terraces (Lavé and Avouac, 2001) suggesting that the creep imparted strain is entirely elastic and does not significantly deform the thrust wedge (Cattin and Avouac, 2000). In this view the moment magnitudes of all great Himalayan earthquakes in the 500 year historical record (Fig. 3) can be summed and compared with an extrapolation of GPS derived interseismic strain rates over the same time period to calculate how much strain is currently stored in the wedge (Bilham and Ambraseys, 2005). This calculation results in a 75% strain deficit equivalent to four Mw 8.5 earthquakes implying that either large earthquakes are imminent, missing from the historical record, or that the magnitude of historical earthquakes has been underestimated (Bilham and Ambraseys, 2005). Alternatively the strain