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Patterns of active surface deformation along the eastern margin of the Tibetan Plateau: a role for flow in the lower crust?

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The growth of high topography in eastern Tibet continues to challenge our conceptual understanding of how orogenic plateaus develop. Although numerous lines of evidence suggest that large regions of the eastern Tibetan Plateau attained their current elevation through flow and thickening in the lower crust (Royden et al., 2008), the great earthquake of 12 May 2008 in Sichuan Province clearly attests to significant deformation within the brittle portions of the crust. The magnitude and complexity of this rupture has led some to argue that crustal shortening accomplished during this event obviates the need for flow in the deep crust. Here, I address this question from a combination of perspectives that utilize geomorphic and exhumational proxies to characterize the rates and patterns of differential rock uplift across the plateau margin.

The topographic margin of the plateau adjacent to and north of the Sichuan Basin is one of the more enigmatic mountain fronts in the world. Despite nearly 6km of relief between the peaks of the Longmen Shan and the Sichuan Basin, geodetic data prior to the earthquake revealed little to no shortening across this margin of the plateau (Burchfiel et al., 2008). How such topography can develop and be maintained in the face of limited shortening of the upper crust remains an outstanding problem. Some insight is provided by studies of the low-temperature cooling history of this region. Prior to Late Miocene time, the entirety of eastern Tibet experienced extremely slow denudation rates (20 – 50 m/Myr) since Mesozoic time. Such rates are consistent with the preservation of Mesozoic cooling ages from samples atop the plateau surface. Thermal histories of rocks exposed in the deep canyons of Sichuan reveal that rocks in the immediate hanging wall of the Sichuan rupture have been exhumed from 8-10 km depth, during the past 12- 14 Ma. Thus, the rapid erosion that presently characterizes the deeply-incised topographic margin of the plateau has been maintained by a continued influx of rock mass, either via a lower crustal channel, or by thickening during slip on upper crustal structures.

Geomorphic analyses of the longitudinal profiles of major river systems developed along the topographic margin reveal a region of anomalously steep channels coincident with the edge of the Tibetan Plateau. This region of steep channels coincides with high topography along the margin of the Sichuan Basin (and with the southern portions of the 2008 surface rupture). To the north, however, the region of steepest channels turns away from the Sichuan Basin, following the Min Shan northward along the topographic margin of the plateau. The spatial pattern of steep channels has been interpreted to reflect a locus of active differential rock uplift along the topographic front of the plateau (Kirby et al., 2003). Here I present three new data sets that confirm this interpretation. First, recent studies of erosion rate measured by cosmogenic isotope inventories in modern sediments reveal a positive, monotonic correlation between channel steepness and erosion rate (Harkins et al., 2007; Ouimet et al., in press). These data reveal that modern erosion rates along the steep Longmen Shan margin range from 300 – 600 m/Myr and contrast sharply with low erosion rates atop the plateau surface (30 – 60 m/Myr). Second, the complex rupture pattern of the 2008 Sichuan earthquake, ranging from oblique-thrust slip in the south to nearly strike-slip in the north, provides confirmation of the basic pattern of differential rock uplift revealed in channel profiles (Kirby et al., 2008). Finally, fluvial terraces preserved along two of the major rivers draining the Min Shan (Jian Jiang and Bailong Jiang) confirm that variations in channel steepness are matched by variations in incision rate.

Collectively, these data reveal a contrast in the style of upper crustal deformation associated with proximity to fault systems along the margin of the Sichuan Basin. Abrupt changes in channel steepness across the

Yingxiu-Beichuan fault system reflects relatively short wavelength differential incision in the hanging wall that appears to record deformation associated with repeated earthquakes along this fault. In contrast, long-wavelength (>80 km) warping of terrace treads along the Bailong Jiang is not associated with faulting of the upper crust and apparently reflects surface deformation in response to deep-seated flow in the lower crust and/or upper mantle. These results suggest that lower crustal flow is indeed a driver for crustal thickening in eastern Tibet, but that the mechanical behavior of the upper crust is strongly influenced by pre-existing anisotropy along the margin of the Sichuan Basin.