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Active Deformation and Mountain Building in Eastern Tibet

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Despite decades of study, the question of how active deformation throughout the Tibetan Plateau is linked to the development of high topography remains at the forefront of debates over the driving dynamics of intracontinental deformation (Houseman and England, 1986; Tapponnier et al., 2001). At issue is how the rheology of the deep crust, and its evolution in both time and space, may influence the distribution and style of deformation (Royden et al., 1997; Beaumont et al., 2001). Here, I address this question in two regions of the eastern Tibetan Plateau – along the eastern segments of the Kunlun fault and along the plateau margin adjacent to and north of the Sichuan Basin. In both regions, I utilize a combination of observations drawn from structural geology and tectonic geomorphology and show how these can help assess the degree to which recent deformation is localized along faults versus distributed throughout the surrounding crust.

The role of intracontinental strike-slip faults in accommodating Indo-Asian convergence – whether these faults represent the boundaries of relatively rigid crustal blocks (Tapponnier et al., 1982) or whether they are the consequence of strain localization along preexisting heterogeneities in an otherwise continuously deforming medium (England and Houseman, 1985) – continues to engender debate. One approach is to examine how slip rates along these faults at present vary along strike. The Kunlun fault is well-known to exhibit left-lateral slip rates in excess of ~10-12 mm/yr south of the Qaidam basin (Van der Woerd et al., 2002). However, along the eastern ~200km of the fault system slip rates decrease systematically toward the east, from > 10 mm/yr to < 2 mm/yr (Harkins et al., 2010). This slip rate gradient is coincident with high topography in the Anyemaqen Shan and with a broad zone of distributed shear and clockwise vorticity within the Tibetan Plateau (Shen et al., 2005). Geomorphic analysis of river longitudinal profiles, coupled with inventories of cosmogenic radionuclides in fluvial sediment, reveal correlated variations in fluvial relief and erosion rate across the Anyemaqen Shan. These variations are argued to reflect ongoing differential rock uplift across the range that absorbs ~2 – 6 mm/yr of shortening between the high plateau and the Gong He region to the north. These results imply that the termination of the Kunlun fault system is accommodated by a combination of distributed crustal thickening and by clockwise rotation of the eastern fault segments. Collectively, it appears that high rates of slip along the Kunlun fault adjacent to the Qaidam basin reflect strain localization against this mechanically strong crustal block (Molnar and Dayem, 2010), whereas lower rates of deformation toward the east reflect distributed deformation within the Tibetan Plateau.

Along the eastern margin of the plateau, a parallel debate exists regarding the development high topography adjacent to and north of the Sichuan Basin. In these regions, respectively known as the Longmen Shan and Min Shan, several lines of evidence suggest that flow and thickening of the deep crust is an integral part of the development and support of the mountain ranges flanking the plateau (e.g., Clark and Royden, 2000). Yet, the M 7.9 Wenchuan earthquake in 2008 clearly attests to significant deformation within the brittle crust (Burchfiel et al., 2008; Zhang et al., 2010). Coincidence among the regions of greatest topographic relief, steepest fluvial channels, deepest exhumation recorded by thermochronometers, and rapid present-day erosion rates (Kirby and Ouimet, 2011) suggests that differential rock uplift and exhumation have been sustained at the plateau margin since at least the Late Miocene (Wang et al., 2012). The fact that most of the fault systems active today in the Longmen Shan are reactivated structures that initially formed in the Mesozoic (Burchfiel et al., 1995), however, confounds an assessment of their significance in the development of thickened crust. North of the Sichuan Basin, however, the topographic margin of the plateau trends at high angle to crustal anisotropy, such that patterns of active deformation along this margin may provide insight into the process of crustal thickening. Analysis of patterns of erosion rate determined from channel profiles reveals a locus of rapid erosion that trends

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north-south, coincident with the highest topography along the Min Shan (Kirby and Ouimet, 2011). The Bailong Jiang transects this high topography, flowing from the plateau to the foreland, and flights of strath terraces along the reveal differential incision that confirm the pattern inferred from channel profiles. Incision rates are low on the plateau surface, increase to > 1 mm/yr as the river carves a narrow gorge through the Min Shan, and decrease toward the east as the river drains across the western Qinling orogen. Optically-stimulated dating of terrace tread material reveal that this pattern of high incision has been sustained for >40 ka and does not likely reflect a transient response of the fluvial system. Rather, I argue that differential incision reflects long-wavelength (~80-100 km) warping of terrace treads during differential rock uplift. This warping is not associated with faults expressed at the surface and apparently reflects surface deformation in response to deep-seated flow in the lower crust. Overall, these results suggest that mountain building along the eastern margin of the Tibetan Plateau occurs in response to thickening in a relatively weak lower crust, but that the mechanical behavior of the upper crust is strongly modulated by pre-existing anisotropy adjacent to the Sichuan Basin.

Key words: tectonic geomorphology, active tectonics, Tibetan Plateau

References

Beaumont, C., Jamieson, R.A., Nguyen, M.H. and Lee, B., 2001. Himalayan tectonics explained by extrusion of a low-viscosity crustal channel coupled to focused surface denudation. *Nature*, 414(6865): 738-742.

Burchfiel, B.C., Chen, Z., Liu, Y., and Royden, L.H., 1995. Tectonics of the Longmen Shan and adjacent regions, central China. *International Geology Review*, 37: 661-735.

Burchfiel, B., Royden, L., Van der Hilst, R., Hager, B., Chen, Z., King, R., Li, C., J, L., Yao, H. and Kirby, E., 2008. A geological and geophysical context for the Wenchuan earthquake of 12 May 2008, Sichuan, People's Republic of China. *GSA Today*, 18(7): 4-11.

Clark, M.K. and Royden, L.H., 2000. Topographic ooze: Building the eastern margin of Tibet by lower crustal flow. *Geology*, 28(8): 703-706.

England, P. and Houseman, G., 1985. Role of lithospheric strength heterogeneities in the tectonics of Tibet and neighbouring regions. *Nature*, 315: 297-301.

Harkins, N., Kirby, E., Shi, X., Wang, E., Burbank, D., and Chun, F., 2010. Millennial slip-rates along the eastern Kunlun fault: Implications for the dynamics of intracontinental deformation in Asia. *Lithosphere*, 2(4): 247-266.

Houseman, G. and England, P., 1986. Finite Strain Calculations of Continental Deformation 1. Method and General Results for Convergent Zones. *J. Geophys. Res.*, 91(B3): 3651-3663.

Kirby, E. and Ouimet, W., 2011. Tectonic geomorphology along the eastern margin of Tibet: Insights into the pattern and processes of active deformation adjacent to the Sichuan Basin. *Geological Society, London, Special Publications*, 353: 165-188.

Molnar, P. and Dayem, K.E., 2010. Major intracontinental strike-slip faults and contrasts in lithospheric strength. *Geosphere*, 6 (4): 444-467.

Royden, L.H., Burchfiel, B.C., King, R.W., Wang, E., Chen, Z. L., Shen, F. and Liu, Y.P., 1997. Surface deformation and lower crustal flow in eastern Tibet. *Science*, 276(5313): 788-790.

Shen, Z-K., Lu, J., Wang, M., and Burgmann, R., 2005. Contemporary crustal deformation around the southeast borderland of the Tibetan Plateau. *J. Geophys. Res.*, 110 (B11409): doi: 10.1029/2004JB003421.

Tapponnier, P., Peltzer, G., Le Dain, A.Y., Armijo, R., and Cobbold, P., 1982. Propagating extrusion tectonics in Asia: New insight from simple experiments with plasticine. *Geology*, 10: 611-616.

Tapponnier, P., Zhiqin, X., Roger, F., Meyer, B., Arnaud, N., Wittlinger, G. and Jingsui, Y., 2001. Oblique stepwise rise and growth of the Tibet Plateau. *Science*, 294(5547): 1671-1677.

Van der Woerd, J., Tapponnier, P., Ryerson, F.J., Meriaux, A-S., Meyer, B., Gaudemer, Y., Finkel, R.C., Caffee, M.W., Zhao, G., and Xu, Z., 2002. Uniform postglacial slip-rate along the central 600 km of the Kunlun fault (Tibet), from ^{26}Al, ^{10}Be, and ^{14}C dating of riser offsets, and climatic origin of the regional morphology. *Geophys. J. Int.*, 148: 356-388.

Wang, E., Kirby, E., Furlong, K.P., van Soest, M., Xu, G., Shi, X., Kamp, P.J.J., and Hodges, K.V., 2012. Two-phase growth of high topography in eastern Tibet during the Cenozoic. *Nature Geoscience*, 5: 640-645.

Zhang, P-Z., Wen, X-Z., Shen Z-K., and Chen, J-H., 2010. Oblique, high-angle, listric-reverse faulting and associated development of strain: The Wenchuan earthquake of May 12, 2008, Sichuan, China. *Annual Reviews of Earth and Planetary Sciences*, 38: 351-380.