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Reading the signal of tectonics in landscape topography: challenges and opportunities

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The degree to which topography in active mountain ranges reflects deformation of the Earth's surface remains a tantalizing, but elusive, goal of tectonic geomorphology. A substantial body of research in the past decade demonstrates that incising channel systems play a central role in setting relationships among topographic relief, differential rock uplift rate, and climatically modulated erosional efficiency. A review of existing data finds support for positive, monotonic relationships between channel steepness index and erosion rate in systems at equilibrium. In systems developed within uniform lithologic substrate, and subject to relatively uniform climate, the functional relationship between erosion rate and channel slope appears to be moderately to strongly non-linear, consistent with theoretical expectations for morphodynamic adjustment of both channel gradient and hydraulic geometry and/or a role for thresholds for incision. In systems subjected to perturbations away from equilibrium, the morphologic signature depends strongly on the direction of forcing, and may yield even more complex relations between channel gradient and erosion rate. Despite these complexities, under certain conditions, spatial patterns in channel profiles can be used to infer some general aspects of the forcing.

I illustrate this latter point with a case study from the southwestern Basin and Range province in North America. The Inyo Mountains are the footwall block to an active fault system along the western margin of Saline Valley; relief along the range front approaches $\sim$3 km. Normal-oblique slip along the range-front fault is linked to strike-slip displacement on the Hunter Mountain fault. Geologic data suggest that displacement initiated along this system range between 2.8 - 4.0 Ma, implying average slip rates of 2.1 - 3.3 mm/yr. However, geodetic measures suggest modern slip rates reach or exceed $\sim$4.5 mm/yr. To explore whether this difference reflects a sustained increase in slip rate, I combine analysis of transient channel profiles draining the Inyo Range with 10Be-derived estimates of erosion rate. The results reveal pronounced knickpoints that separate relatively low-gradient, slowly eroding ($\sim$50-100 m/Myr) headwater reaches from exceedingly steep, rapidly eroding (700-1200 m/Myr) lower reaches. Reconstruction of former profiles implies $\sim$500-800 m of relative base level fall across the range front fault system. Estimates of the response time of detachment-limited incision models suggest that transient profiles reflect an increase in fault slip at ca. 0.7 - 1.0 Ma. Notably, both the channel steepness/erosion rate relationship in this setting, and the implied rate of knickpoint retreat, are consistent with a non-linear functional relationship between erosion rate and channel slope. Thus, although it appears that focused, quantitative analysis of channel morphology can provide insight into the spatial and temporal dynamics of active deformation, extant feedbacks among climate, hydraulic geometry, and sediment transport may significantly influence the rate of transient adjustment and control the degree to which morphologic signals are preserved in landscape topography.