How rivers incise to survive periodic inputs of immobile landslide-derived boulders

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Bedrock landsliding provides a strong negative feedback on bedrock river incision by causing long-lived burial events and hence hiatuses in downcutting. Nevertheless, rivers in tectonically active settings carve deep canyons despite being periodically inundated with immobile boulders. How is this possible? In this contribution, we explore the processes through which rivers incise bedrock canyons within the Franciscan mélange in the actively uplifting California Coast Range. The Franciscan mélange is well known for its “melting ice cream topography” in which slow-moving landslides (“earthflows”) festoon the walls of river canyons and deliver car- to house-sized boulders to channels.

Analysis of valley widths and river long profiles over ∼19 km of Alameda Creek (185 km² drainage area) and Arroyo Hondo (200 km² drainage area) in central California shows a very consistent picture in which earthflows that intersect these channels deposit immobile boulders that force tens of meters of gravel aggradation for kilometers upstream, leading to apparently long-lived sediment storage and channel burial at these sites. In contrast, over a ∼30 km section of the Eel River (5547 km² drainage area), there are no knickpoints or aggradation upstream of locations where earthflows impinge on its channel. Neither boulder supply nor transport capacity explains this difference. Rather, we find that the dramatically different sensitivity of the two locations to landslide blocking is linked to differences in channel width relative to typical seasonal displacements of landslides. The Eel River is ∼5 times wider than the largest annual seasonal displacement. In contrast, during wet winters, earthflows are capable of crossing and blocking the entire channel width of Arroyo Hondo and Alameda Creek. Hence, by virtue of having wide valley bottoms, larger rivers are more likely to simply flow around the toes of earthflows.

For the smaller rivers in our study area that are chronically buried in landslide debris, our field observations provide evidence for two processes that may allow periodic bedrock river incision. Narrow channels in the Franciscan mélange that are buried in debris can incise epigenetic gorges around the margins of boulder jams during periods of earthflow dormancy when boulders are no longer input into channels. Alternatively, during periods of earthflow dormancy, abrasion (and hence size reduction) of boulders in place from suspended sediment may ultimately render boulders mobile.

Without explicit representation of these three processes, modeling the coupling of hillslope and channel evolution in this setting is not possible.