Measurable impact of river incision on rift tectonics

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Models that couple tectonics and surface processes commonly predict that efficient erosion and sedimentation help focus crustal deformation onto fewer, longer-lived faults. However, because their geomorphic parameters are difficult to calibrate against real landscapes, the sensitivity of tectonic deformation to a realistic range of surface process efficiencies remains poorly known. Here we model the growth of structurally simple half-graben structures subjected to fluvial incision of specified efficiency and sedimentation. Numerical simulations predict that infinitely-efficient erosion and deposition (i.e., complete surface leveling) can more than double the maximum offset reached on a master normal fault before crustal strain localizes elsewhere. Further, leveling footwall relief tends to promote the migration of strain towards the hanging wall to form new grabens instead of horsts.

To test whether the efficiency of river incision can vary sufficiently across real rifts to exert a control on tectonic styles, we analyze the profiles of rivers draining half-graben footwalls and horst blocks in the Basin & Range, Taupo, Rio Grande, and East African Rift. We adapt the standard methodology of equilibrium river profile analysis to account for spatial variations in uplift expected from crustal flexure in a fault-bounded block. Erosional efficiency (EE) is defined as the inverse of the (dimensionless) slope of uplift- and drainage area-corrected river elevation plots. Measured EEs range between ~0.1 and ~4, reflecting natural variability in lithology, climate, and uplift rates across sites. Incorporating EEs within this documented range in numerical simulations, we find that increasing EE can increase the maximum throw on half-graben master faults by ~50%. Changing EE also affects the geometry of subsequent faults, with lower EEs favoring the transition from half-graben to horsts. These models predict that rifting in a colder, stronger continental crust is less sensitive to surface processes and requires even lower EE to develop horst structures. Our simulations are consistent with a compilation of EE, crustal strength proxies, and fault characteristics across real rift zones. These results suggest that natural variability in climatic conditions and surface erodibility has a measurable impact on the tectonic makeup of Earth’s plate boundaries.