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Migrating divides induce drainage reversal toward cliffs and escarpments

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Observations from around the globe show that drainage reversal toward cliffs (and at a larger scale, toward escarpments) is a common phenomenon. Drainage reversal occurs when a channel that used to grade in one direction reverses its gradient while exploiting its antecedent valley, forming barbed tributaries with junction angle >90°. Drainage reversal is an important end-member of fluvial reorganization that drastically shifts the hydrologic and geomorphic functionality of the landscape. The processes that induce drainage reversals, however, remain largely enigmatic. In many cases, tectonic or structural tilt of the surface is invoked to explain reversal toward the tilt direction, but independent evidence for tilting is rare. Moreover, in great escarpments, geodynamic models predict tilting away from the escarpment, opposite to the sense of reversal discussed here.

We study drainage reversals toward the southern Arava Valley escarpment in Israel, along the Sinai-Arabia transtentional plate boundary. In this area, we establish reversals by observations of barbed tributaries, valley-confined windgaps, and terraces and interfluves that grade opposite to the grading direction of the active channel. Detailed morphological and geological analysis of the field area gives rise to a new, tilting independent mechanism for drainage reversal toward cliffs. The initial condition for this mechanism is a cliff that truncates fluvial channels that flow over the highland and away from the cliff, and a water divide that coincides with the cliff. The truncated channels appear as saddles along the cliff and are commonly filled with alluvial and colluvial sediments. Such initial conditions characterize shoulder-type great escarpments and cliffs that form following river capture events. Importantly, in these settings, the sediments that fill the truncated channels are more erodible than the bedrock that builds the interfluves.

According to the mechanism we propose, the erodible valley fill near the steep cliff is initially transported down the cliff via hillslope processes, which results in a gradual migration of the divide along the antecedent valley and away from the cliff. A reversed channel segment forms between the receding divide and the cliff, such that along the channel, the divide and the cliff are not coincident anymore. The faster fluvial incision in the reversed segment with respect to the antecedent channel further pushes the divide away from the cliff. When the receding divide traverses a tributary confluence, a barbed tributary forms. The increased discharge of the

reversed segment facilitates cliff embayment that eventually affects cliff retreat and morphology.

This new mechanism indicates that a relatively thin layer of erodible valley fill could be a tipping point that completely changes the trajectory of landscape evolution via drainage reversal. Importantly, however, flow reversal towards cliffs does not necessitate such a layer but instead could be triggered by other hydrological and geological conditions that promote faster erosion toward the cliff within the antecedent channel with respect to the interfluves.

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