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Waterfall formation driven by interacting flow hydraulics, sediment cover, and erosion in an experimental bedrock canyon

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Waterfalls are ubiquitous in steep landscapes and have been documented to retreat upstream at rates far outpacing standard fluvial incision into bedrock. While the formation of waterfalls following changes in climate and base-level lowering have been well-documented, little work has explored the formation of waterfalls via the internal dynamics from interacting flow hydraulics, sediment flux, and evolving channel morphology. Distinguishing between waterfalls formed via external versus internal forcing is important, as waterfall formation and retreat rate is often applied in inverse to determine the timing of external forcing. Here, we present results from a laboratory experiment designed to explore channel incision and waterfall formation. We fed water and sediment at constant rates over an initially planar surface tilted to 19.5% slope. A channel rapidly incised into the artificial bedrock substrate, and small-wavelength variations in erosion rate created steps and pools which grew in amplitude. As pools deepened, sediment cover at the downstream portion of pools locally limited erosion, while erosion in the upstream portion of the pool created steep faces. At the topographic breaks between these steep segments and their upstream treads, water detached from the bed forming ventilated waterfall jets which impacted the plunge pools below. Individual waterfalls were short-lived as pool-deepening promoted alluviation which prevented further pool-incision, while amplified erosion at the waterfall lip incised a new pool into the bedrock previously composing the waterfall face. Repetition of this process in our experiment suggests that interactions between bedrock erosion and sediment cover can result in the formation of a series of plunge pools which retreat upstream.