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Condition for incision of alluvial fan in an experimental coupled catchment-fan geomorphic system forced by oscillatory precipitation

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Alluvial fans are cone-shaped bodies of alluvial deposits accumulated along mountain range fronts at the outlet of catchments. They represent valuable archives of mass transfer in their feeding catchment and can potentially be used to infer the impact of tectonic and climatic variations on erosion and landscapes, because of the influence of these factors on the sediment and water fluxes coming from the upstream catchment. Although a transition from aggradation to incision is observed in many natural alluvial fans, the conditions driving such change remain unclear. We investigate this problem here through a laboratory-scale approach where eroded materials from an uplifting mountain may deposit on a plateau, erosion being driven by the surface runoff of water from an artificial rainfall device. We consider here results from 8 experiments, 700 to 900 minutes-long, performed with the same uplift rate but with different sequences of variations of the rainfall rate (10 to 40 minutes-long) between two extreme values. The topography was digitized every 10 minutes thanks to a high-resolution laser sheet.

We observe that the mean slope of the alluvial fans is inversely proportional to the mean rainfall rate on the mountain and that the denudation rate of the uplifting landscape varies in phase with the cyclic variations of rainfall. Because catchments are out of equilibrium (denudation equals uplift) during most of the time, the sediment (Qs) and water (Qw) fluxes at their outlet continuously vary with time: Qs varying depending on the balance between erosion and uplift, Qs and Qw varying depending on whether the catchments enlarge or shrink. Depending on these conditions, catchments show a variety of trends of Qs vs Qw for a given value of rainfall, Qs increasing or decreasing with Qw, or being independent of Qw. Then for each catchment, oscillations of rainfall drive alternations between two individual Qs vs Qw trends, the slope of these trends being indicative of the sediment concentration in the mini-rivers at the outlet of catchments that feed alluvial fans.

From the analyze of our whole dataset, we conclude that incision of alluvial fans occurs when rainfall increases and when it goes with a decrease of the Qs/Qw ratio, i.e. with a decrease of concentration at the outlet of the catchment. This control is modulated by the slope of the fan, incision only occurring for fans above a threshold slope. Then, the decrease in sediment concentration required to initiate the incision is weaker for steeper fans and decreases with

increasing fan slope.

Several studies already demonstrated how a decrease of Qs or an increase of Qw drives incision. We show here that these two parameters are coupled and covariate following the dynamical state of catchments. We also demonstrate that the decrease of the Qs/Qw ratio required for initiating the incision of a fan is lower for steeper fans, that is for fans that develop under more arid condition.

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