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Autogenic dynamics of debris-flow fans

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Alluvial fans develop their semi-conical shape by cyclic avulsion of their geomorphologically active sector from a fixed fan apex. These cyclic avulsions have been attributed to both allogenic and autogenic forcings and processes. Autogenic dynamics have been extensively studied on fluvial fans through physical scale experiments, and are governed by cyclic alternations of aggradation by unconfined sheet flow, fanhead incision leading to channelized flow, channel backfilling and avulsion. On debris-flow fans, however, autogenic dynamics have not yet been directly observed. We experimentally created debris-flow fans under constant extrinsic forcings, and show that autogenic dynamics are a fundamental intrinsic process on debris-flow fans. We found that autogenic cycles on debris-flow fans are driven by sequences of backfilling, avulsion and channelization, similar to the cycles on fluvial fans. However, the processes that govern these sequences are unique for debris-flow fans, and differ fundamentally from the processes that govern autogenic dynamics on fluvial fans. We experimentally observed that backfilling commenced after the debris flows reached their maximum possible extent. The next debris flows then progressively became shorter, driven by feedbacks on fan morphology and flow-dynamics. The progressively decreasing debris-flow length caused in-channel sedimentation, which led to increasing channel overflow and wider debris flows. This reduced the impulse of the liquefied flow body to the flow front, which then further reduced flow velocity and runout length, and induced further in-channel sedimentation. This commenced a positive feedback wherein debris flows became increasingly short and wide, until the channel was completely filled and the apex cross-profile was plano-convex. At this point, there was no preferential transport direction by channelization, and the debris flows progressively avulsed towards the steepest, preferential, flow path. Simultaneously, the debris flows started to channelize, forced by increasingly effective concentration of the flow impulse to the flow front, which caused more effective lateral levee formation and an increasingly well-defined channel. This process continued until the debris flows reached their maximum possible extent and the cycle was reverted. Channelization occurred in the absence of erosion, in contrast with fluvial fans. Backfilling and channelization cycles were gradual and symmetric, requiring multiple debris flows to be completed. These results add debris-flow fans to the spectrum of fan-shaped aqueous systems that are affected by autogenic dynamics, now ranging from low-gradient rivers systems to steep-gradient mass-flow fans.