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Cascade of sediment from a mountainous watershed: What can we learn from integrating erosion rates at annual and millennial temporal scales?

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A balance between tectonic and geomorphic processes drives landscape evolution, over different spatial and temporal scales. In mountainous environments, the river network sets the pace of landscape evolution, and hillslopes respond to river incision by e.g. gully retreat, bank erosion and mass wasting. The sediment produced during stochastic landslide events leads to episodic reorganisation of soil and sediment on the hillslopes, and is transported by gravity and water to the river network. Quantifying sediment storage and conveyance requires an integrated approach accounting for different space and time scales.

In the foothills of the central Swiss Alps, we selected the Rossloch watershed, which has a size of ca. 2 km^2, and is affected by mass-wasting processes. Sediment-associated geomorphic processes were quantified at annual and millennial timescales. The CRN-derived denudation rates integrate over up to minimum ca. 2,500 years, and show the long-term average denudation in the watershed for 7 various sub-watersheds. Very-high resolution UAV-SfM derived topographic datasets provide multi-temporal digital surface models, and allow the reconstruction of the annual sediment budget. Our UAV-SfM data provide a detailed view of the intermediate part of the watershed, where one complex earthflow is present.

Our data show that long-term erosion rates are high in the river streams directly connected to mass-wasting processes, i.e. first-order rivers, which suggests that mobilized sediments on hillslopes induce enhanced sediment fluxes in headwaters. However, in higher-order river streams, erosion rates are lower and similar to erosion rates measured in adjacent watersheds. At the annual scale, data show that hillslope processes, e.g. the studied earthflow, are very intense and act as major driver of sediment mobilization and reorganisation on slopes. Despite intense sediment fluxes within the earthflow body, only a small fraction of the entire mass of mobilized material is annually entering the river network.

Consequently, the combination of both analyses carried out over annual and millennial time frames suggests that there is a clear time lag between sediment mobilization by mass-movement processes and transportation into lower reaches of watersheds. Sediments are produced on hillslopes by stochastic events but do not enter into the river network at once. The sediment mass is intensively re-organized on-site and in the meantime available for progressive transportation to river streams. On the long term, landslide-affected first-order watersheds are characterised by enhanced sediment fluxes. However, the strong impact of mass movements on the sediment budget in headwaters is quickly averaged both spatially and temporally in mountainous area.