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Sediment transport dynamics in steep, tropical volcanic catchments

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How volcanic landforms in tropical mountainous regions are eroded, and how eroded materials move through these mostly steep landscapes from the headwaters to affect sediment fluxes are critical to water resources management in their downstream rivers. Volcanic landscapes are of particular importance because of the short timescales (< years) over which they transform. Owing to volcanism and seismic activity, landslides and other mass movements frequently occur. These processes are amplified by high intensity precipitation inputs resulting in significant, but natural runoff, erosion and sediment fluxes. Sediment transport is also directly linked to carbon and solute export. However, knowledge on the sediment sources and transport dynamics in the humid tropics remains limited and their fluxes largely unquantified.

In order to increase our understanding of the dominant erosion and sediment transport dynamics in humid tropical volcanic landscapes, we conducted an extensive monitoring effort in a pristine and protected (biological reserve Alberto Manuel Brenes, ReBAMB) tropical forest catchment (3.2 km2), located in the Central Volcanic Cordillera of Costa Rica (Figure 1A). Typical for tropical volcanic and montane regions, deeply incised V-form headwaters (Figure 1B) deliver the majority of water (>70%) and sediments to downstream rivers. At the catchment outlet (Figure 1C) of the San Lorencito stream, we established high temporal resolution (5min) water quantity and sediment monitoring (turbidity). We also surveyed the river network on various occasions to characterize fluvial geomorphology including material properties. We could show that the rainfall-runoff-sediment relationships and their characteristic hysteresis patterns are directly linked to variations in the climatic input (storm intensity and duration) and the size, form and mineralogy of the transported material. Such a relationship allowed us to gain the following insights:

(i) periodic landslides contribute significant volumes of material (> 100m3 per year) to the stream network,

(ii) rainfall events that exceed a threshold of around 30mm/h rain intensity activate superficial flow pathways with associated mobilization of sediments (laminar erosion). However, the erosion processes are spatially very heterogeneous and mostly linked to finer material properties of the soils that mostly developed on more highly weathered bedrock.

(iii) extreme events (return period > 50 years) mainly erode the streambed and banks cutting deeper into the bedrock and re-distribute massive amounts of material in the form of removed old alluvial deposits and new deposits created elsewhere,

(iv) recovery after such extreme events in the form of fine material transport even during low intensity rainfall towards pre-event rainfall intensity thresholds takes only about two to three months.

We conclude that the study catchment geomorphologically represents a low-resistance, but highly resilient catchment that quickly recovers after the impact of extreme rainfall-runoff events. The latter was indicated by a different pre and post-event hysteretic pattern of sediment-runoff dynamics and associated different material properties. The combined use of high-temporal resolution monitoring with spatially distributed surveys provided new insights into the fluvial geomorphology of steep, volcanic headwater catchments with potential to establish more complete sediment budgets and time-scales of land-forming processes of such highly dynamic environments in the humid tropics.