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Landsliding and sediment flux in the Central Swiss Alps: A photogrammetric study of the Schimbrig landslide, Entlebuch

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Abstract

This study explores the effects of hillslope mass failure on the sediment flux in the Waldemme drainage basin, Central Swiss Alps, over decadal time scales. This area is characterized by abundant landslides affecting principally flysch units and is therefore an important sediment source. The analysis concentrates on the Schimbrig landslide that potentially contributes up to 15% to the sediment budget of the Waldemme drainage basin. Volumetric changes are quantified using high-resolution elevation models that were extracted using digital photogrammetric techniques. Sediment discharge data were used to constrain the significance of the landslide for sediment flux in the channel network. The temporal extent of the photogrammetric analysis ranges from 1962 to 1998, including an earth slide event in 1994. The analyses reveal that during periods of low slip rates of the landslide, nearly all of the displaced sediments were eroded and supplied to the channel network. In contrast, during active periods, only a fraction of the displaced landslide mass was exported to the trunk stream. Interestingly, the 1994 earth slide event did not disturb the long-term sediment discharge pattern of the channel network, nor did it influence the sediment flux at a weekly scale. However, suspended sediment pulses correlate with higher-than-average precipitation events. This was especially the case in August 2005 when a storm event (>100 years return period) triggered several debris flows and earth flows in the whole drainage basin and in the Schimbrig area. This storm did not result in a significant increase in the slip rates of the entire landslide's main body. It is therefore proposed that debris flows and earth flows perform the connectivity between hillslope processes (e.g. landsliding) and the trunk stream during and between phases of landslide activity in this particular setting.

Keywords: Landslide; Sediment yield; Photogrammetry; Digital elevation models; Geomorphic coupling; Switzerland

1. Introduction

Landslides are geomorphic instabilities that mobilize substantial amounts of sediment. Material from landslides can be transferred to the channel network if the landslides are connected with channels. The interface or connectivity between hillslope and channel processes appears in different forms (Korup, 2005), and the efficiency of the connectivity exerts a major control on the magnitudes and rates at which sediment is transferred from the hillslopes to the channel network. This efficiency of connectivity scales the coupling between various landform elements, and has become an important part in the study of geomorphic coupling (Brunsden and Thornes, 1979; Harvey, 2001).

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The landslide-channel system, which is the focus of this study, consists of an assemblage of superimposed processes resulting in erosion and transport of sediment at different spatial and temporal scales (Harvey, 2002). In low-relief areas, such as the foothills of the Swiss Alps, the channelized nature of erosion and sediment transport comprises fluvial processes and debris flows (Schlunegger and Schneider, 2005). Sediment transport by fluvial processes occurs as solute load, bedload and suspended load. The latter transport mechanism, i.e. the floating of clay and silt particles, necessitates the presence of lift forces that are commonly observed even if flow occurs under laminar conditions (Allen, 1997). In contrast, bedload transport by fluvial processes requires that critical flow strengths are exceeded (e.g. Tucker and Slingerland, 1997). Alternatively, sediment is transported as debris flows if slopes and fluid pore pressures surpass specific thresholds (McArdell et al., 2007). This situation is frequently observed in the headwaters of drainage systems (e.g. Benda et al., 2005). Erosion and sediment transport on hillslopes include weathering and soil creep, often referred to as hillslope diffusion in modeling studies (e.g. Tucker and Slingerland, 1994, 1996), and shallow overland flow erosion. Presumably the most important hillslope processes are landslides such as earth flows, mud flows and particularly debris slides and earth slides (Cruden and Varnes, 1996). Despite the importance of landslides on the sediment yield of mountainous catchments (Korup et al., 2004), the number of quantitative studies on sediment discharge in the channel network related to hillslope mass wasting is still limited (e.g. Pearce and Watson, 1986; Hovius, 2000; Lavé and Burbank, 2004; Korup et al., 2005; Schuerch et al., 2006).

Recently, an increasing number of studies have been addressing the importance of understanding the interface between hillslope and fluvial processes (Fryirs and Brierley, 1999; Harvey, 2001; Slattery et al., 2002). These studies lead to the concept of the connectivity between landform elements that operate at different spatial and temporal scales (Brierley et al., 2006). The recovery time of a system to a geomorphic instability (e.g., landsliding) depends then on the magnitudes of these scales and the relationship between them (Harvey, 2007).

These studies are the motivation for the temporal and spatial analysis of landslides and associated processes, and for the identification of the relevant scale for sediment production and export. The objectives of this paper are to analyze mass movements on the Schimbrig landslide (Central Switzerland, Fig. 1) and to explore if the sediment flux pattern of the receiving Waldemme River was influenced by this sediment source over the past few decades. Of particular interest is the response of the channel network to an exceptional earth slide event in 1994. The analysis is based on sediment yields of the Schimbrig landslide between 1962 and 1998, as well as on information about the pattern of sediment discharge of the Waldemme River since 1977, when the hydrologic survey started. Sediment yields of the Schimbrig landslide are measured using quantitative comparisons between high-resolution Digital Elevation Models (DEMs) for different time intervals. The pattern of sediment flux of the receiving Waldemme River is based on suspended sediment concentration data (SSC) and water discharge at downstream gauging stations.

2. Regional setting

2.1. The Waldemme drainage basin

The Waldemme drainage basin is a tributary of the Reuss drainage basin and has a planimetric extent of 324 km^2. It is made up of the Kleine and Grosse Entlen, Waldemme, Fontanne and Rümlig tributaries (Fig. 1) that are all characterized by perennial flows. All of the tributaries display multiple knickzones in the longitudinal stream profiles (Fig. 2) with exposure of bedrock, and several cut terraces. As these geomorphic features are indicative of active incision and supply-limited sediment transport (Hancock et al., 1998), we anticipate that the sediment that is supplied to the channel network will be efficiently transported downstream. Major discharge events occur in summer after severe thunderstorms, and in early spring during snow melt (Schädler and Weingartner, 1992). Present-day climatic conditions are humid with average precipitation rates of approximately 1500 mm a^{-1} (Meteoswiss rain gauge in Entlebuch, Fig. 1).

The bedrock of the Fontanne tributary is made up of a succession of Miocene conglomerates (Matter, 1964; Schlunegger et al., 1996). The frequent occurrence of bedrock in channels and on adjacent hillslopes, and the thickness of the regolith cover, ranging from the dm- to m-scale, led Schlunegger and Schneider (2005) to infer that sediment flux in the Fontanne tributary is limited by the supply of unconsolidated sediment through weathering. The hillslopes of the other tributaries (e.g., Entlen and Waldemme) comprise several-m-thick sequences of till and colluvium (Mollet, 1921; Schlunegger, 2007), and they commonly border bedrock channels.

Of particular interest for the production of unconsolidated sediment is the Upper Cretaceous to Early Tertiary alternation of marls and sandstone beds that are referred to as Flysch nappes in classic Alpine literature