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Variations in debris-flow occurrence in an Alpine catchment — A reconstruction based on tree rings

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ABSTRACT

Past debris-flow activity in the Birchbach torrent (Swiss Alps) was assessed using tree-ring data. Based on the analysis of 210 *Larix decidua* and *Picea abies*, 50 events were reconstructed for the period AD 1752–2006. On average, 3.2 events per decade occurred in the torrent during the last century with distinct differences between the decades and a considerable decrease in the number of events during the last decade. Comparison with debris-flow reconstructions in neighboring catchments provided more insight in the similarities and differences in debris-flow occurrence. The recurrent debris-flow activity and current geomorphic settings suggest that the occurrence of debris flows in the torrent is rather transport-limited than supply-limited. Therefore, future investigations on debris-flow occurrence in transport-limited basins should focus on triggering rainfall events.

1. Introduction

The evolution of high mountain environments is closely related to meteorological trends and to climatic changes in general (Becker and Bugmann, 2001; Beniston, 2003). Alpine landscapes change rapidly as a result of slope dynamics, mainly through weather- and climate-dependent processes such as debris flows. Sediment supply and channel recharge rates are important factors controlling debris-flow entrainment (Bovis and Jakob, 1999). Where sediment sources are readily accessible, debris flows represent important geomorphic agents in steep mountain terrains (Passmore et al., 2008) with varying occurrences over time. The release of debris flows is in general closely related to triggering meteorological events (e.g. Caine, 1980; Guzzetti et al., 2008). Recent reviews have highlighted the importance of precipitation intensity and temperature for the release of debris flows (Deganutti et al., 2000; Saemundsson et al., 2003; Chen, 2006).

There is currently much debate about future changes in the intensity and frequency of rainfall events under a changing climate. Some studies suggest that current global warming will in some cases increase the frequency of extreme precipitation events (e.g. Fowler and Hennessy, 1995; Easterling et al., 2000; Fowler and Kilsby, 2003). Furthermore, temperatures seem to rise more significantly in alpine regions where the warming appears to influence permafrost bodies and therefore has a direct influence on material cohesion and slope stability (Zimmermann and Haeberli, 1992; Jomelli et al., 2004; Chiarle et al., 2007). Regarding all these potential future evolutions of climate and sediment availability, we would need to assume that there will be an increase in frequency and intensity of mass movements as several authors suggest (Frei et al., 1998; Beniston and Stephenson, 2004; Christensen and Christensen, 2004).

However, before making any predictions on the future evolution of debris-flow occurrence, there is a pressing need to better understand the changes in past and contemporary debris-flow activity (VanDine and Bovis, 2002). Even though debris flows occur repeatedly in mountain areas and even though they represent a major hazard to infrastructure, data on their past occurrence remains generally very scarce.

Therefore, it is the aim of this paper to assess past debris-flow frequency in an alpine catchment in order to help the understanding of possible future changes. To do so, geomorphic features of past debris flows were mapped and trees affected by past activity were sampled. We report on results obtained from 210 heavily affected trees sampled on the cone of the Birchbach torrent, Zermatt Valley, Swiss Alps.

2. Regional setting

The Birchbach torrent (46°07′N; 7°47′E) is located on the west facing slopes of the inner-alpine Zermatt valley, Southern Switzerland (Fig. 1). Its catchment area is dominated by glaciers and periglacial environments including permafrost bodies where the torrent takes its source. The geology of the area is dominated by gneisses of Permian age (Labhart, 2004). Glacial activity and the climatic conditions of the study area which are characterized by low temperature, snow precipitation and a high annual and day-time thermal range, favor the activity of the morphogenetic processes related to cycles of

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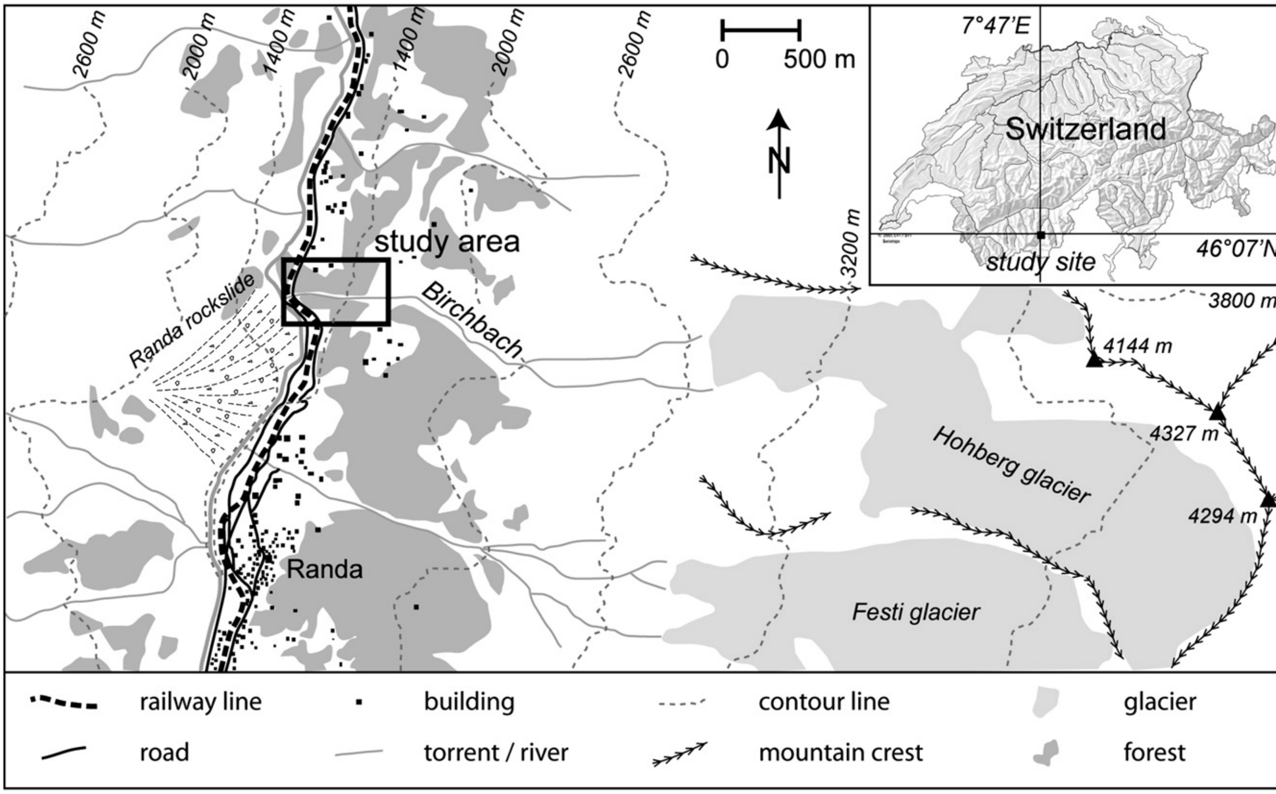

Fig. 1. The study site is located in the Zermatt Valley in Southern Switzerland, approximately 2 km south of the village of Randa. The catchment area of the Birchbach torrent extends from the cone apex at 1440 m asl to nearly 4300 m asl and is dominated by the Hohberg glacier.

freezing and thawing. Therefore, loose material for the initiation of debris flows is readily available and the steep topography (mean slope angle: 25°) abets the transport through the channel to the cone. The debris-flow cone is situated where the torrent reaches the valley floor and extends from 1440 to 1300 m asl. The approximate size of the cone amounts to 20 ha whereof half is covered with forest mainly composed of European larch (*Larix decidua* Mill.) and Norway spruce (*Picea abies* (L.) Karst.). In the forested sector, deposits of past debris-flow activity are visible on the current-day cone surface. Within this study, an area of 6 ha has been investigated where deposits can still be discerned and where trees were obviously influenced by past debris-flow activity. Sectors with the apparent influence by other geomorphic or intense anthropogenic activity were disregarded for analysis. Archival data on past debris-flow events depict events in 1898, 1926, 1966, 1989, 1998 and 2000 (WSL, 2007).

3. Materials and methods

All forms related to debris-flow activity on the cone surface were mapped in a scale of 1:1000. Based on this geomorphic map, trees showing obvious signs of influence by debris flows were sampled. Selected trees showed evidence of former activity such as injuries, burial of the stem base, inclination of the trunk or decapitation (Stoffel and Bollschweiler, 2008, 2009). In general, two cores per tree were extracted using increment borer. One sample was taken in the direction of the impact, the other one on the opposite side of the stem. Position of sampled trees was precisely marked on the geomorphic map. In total, 210 trees (201 *L. decidua*, 9 *P. abies*) have been sampled for analysis.

Samples were then prepared and analyzed using standard dendrogeomorphic methods (Stoffel and Bollschweiler, 2008, 2009). Individual preparation steps included mounting of the samples on woody support, drying and sanding. Afterwards, tree rings were counted and ring-width measured. Individual growth curves were then compared to a local reference chronology (Cook and Kairiukstis, 1990; Vaganov et al., 2006) in order to identify missing or false rings (Schweingruber, 1996). Growth disturbances (GD), such as injuries, callus tissue, tangential rows of traumatic resin ducts (TRD), abrupt growth suppression or release and compression wood were noted.

Finally, master plots outlining the number of damaged trees per year were created to separate noise from signal. For all years where a signal was identified, maps representing the spatial distribution of trees with GD were produced. For the dating of deposits, the last disturbing event in the tree-ring series of a tree associated with a certain deposit was considered. For deposits where no trees with GD could be analyzed, the age of the oldest successor tree was determined to approximate the minimum age of the deposit (Shroder, 1980; McCarthy et al., 1991; McCarthy and Luckman, 1993; Bollschweiler et al., 2008).

4. Results

4.1. Debris-flow features

On the cone surface, an area of approximately 9 ha has been mapped covering the sectors with distinct signs and features of past debris-flow activity. In the investigated sector, a total of five previously active debris-flow channels, 37 segments of levees and 33 debris-flow lobes were identified and mapped.

Block sizes normally remained below 0.5 m diameter with individual boulders showing sizes of up to 2 m. Features were more pronounced and offered generally bigger block sizes at the cone apex than further down on the cone. In the southern part of the cone, material was rather deposited in the form of lobes whereas deposits in the northern sector were rather levee-type. Previously active flow paths could only be identified in the northern sector.