Assessing the Spatio-Temporal Debris-Flow Activity on a Forested Cone using Tree-Ring Data

Michelle Bollschweiler,[1)] Markus Stoffel[2)] and Dominique Schneuwly[3)]
1) Laboratory of Dendrogeomorphology (Dendrolab.ch), Department of Geosciences, Geography, University of Fribourg, Pérolles, 1700 Fribourg, Switzerland (michelle.bollschweiler@unifr.ch)
2) Laboratory of Dendrogeomorphology (Dendrolab.ch), Department of Geosciences, Geography, University of Fribourg, Pérolles, 1700 Fribourg, Switzerland (markus.stoffel@unifr.ch)
3) Laboratory of Dendrogeomorphology (Dendrolab.ch), Department of Geosciences, Geography, University of Fribourg, Pérolles, 1700 Fribourg, Switzerland (dominique.schneuwly@unifr.ch)

Abstract

Although debris-flow are a common process in Swiss Alps and repeatedly cause damage, research in Switzerland started only after the severe events of 1987 and data on past events is very limited. It was therefore the purpose of this study (i) to reconstruct former debris-flow events and (ii) to date debris-flow deposits on a forested cone in the Swiss Alps (Grosse Grabe, Valais). The analysis was based on a detailed geomorphic map (1:1′000) of all forms related to debris-flow activity such as lobes, levees and abandoned flow paths. In addition, 152 tree-ring sequences from 71 heavily disturbed trees (*Larix decidua* Mill. and *Picea abies* (L.) Karst.) growing in the deposits were analyzed and growth disturbances related to debris-flow activity assessed, such as scars and callus tissue, rows of traumatic resin ducts, the onset of reaction wood as well as abrupt growth decrease or release. Furthermore, 71 undisturbed trees growing in the abandoned flow paths were sampled so as to approximate the time elapsed since the last event passed through. So far, 40 event years between 1782 and 2005 could be identified. The coupling of tree-ring data with the geomorphic map will allow spatial representation of reconstructed event years.

Keywords: debris flow, tree rings, spatial behavior, deposits, flow path

Introduction

Debris flows are a major threat in many parts of the Alps, where they repeatedly cause severe damage to infrastructure and transportation corridors or even loss of life. So far, studies on the process mainly focused on the flow behavior and rheology (e.g., Costa 1988; Rickenmann 1999; Bollschweiler et al. 2005) or on the assessment of threshold values for the triggering of events (Wilson and Wieczorek 1995; Bovis and Jakob 1999; Huggel et al. 2002; Cannon et al. 2003). Nonetheless, knowledge on past events is extremely important for the understanding of the process and the prediction future evolution. In order to reconstruct past events, different methods have been used. Field investigations at different locations (Hungr et al. 1984; Rickenmann 1990; Corominas and Moya 1999) helped reconstructing the spatial impact of debris flows. Former approaches used lichenometric methods for the dating of deposits (Innes 1983, 1985; Winchester and Harrison 1994). Even though these methods allowed reconstruction of debris-flow events, they did not provide data on the exact moment, the frequency and the spatial behavior of past activity.

In contrast, tree-ring analysis proved to be a valuable tool to date geomorphic events with yearly precision. Past studies using dendrogeomorphological methods primarily focused on the dating of single events or deposits (Stefanini and Ribolini 2003), on the reconstruction of magnitude and/or frequencies (Strunk 1997; Baumann and Kaiser 1999; May and Gresswell 2004; Stoffel et al., 2005a 2006) or on regional comparisons of flooding with debris-flow data (Stoffel et al. 2003). While these tree-ring studies furnished valuable data on recurrence intervals of debris flows, they widely neglected the spatial behavior of past debris-flow activity and the analysis of areas affected during particular events.

It is therefore the purpose of this study to date growth disturbances in heavily affected *Larix decidua* Mill. and *Picea abies* (L.) Karst. trees on a cone in the Swiss Alps (Grosse Grabe, Valais) so as (i) to reconstruct former debris-flow events and (ii) to date debris-flow deposits on a forested cone in the Swiss Alps.

We report on results obtained from detailed geomorphic mapping (1:1000) and dendrogeomorphological analysis of 152 tree-ring series from 71 heavily disturbed trees growing on the Grosse Grabe cone near St. Niklaus (Valais, Switzerland). In addition, undisturbed trees growing in the abandoned flow paths were sampled so as to approximate the time elapsed since the last event in a particular flow path. The geomorphic map served as

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a basis for the sampling strategy and helped positioning the trees on the map. The coupling of tree-ring data with the geomorphic map will allow assessing the spatial representation of reconstructed event years.

Study site

The study was conducted on the debris-flow cone of the Grosse Grabe torrent, located on the west-facing slope of the Mattertal Valley (Valais, Swiss Alps; 46°10′ N, 7°47′ E; Figure 1). The catchment area of the torrent is about 1.5 km^2 and extends from the Breithorn (3178 m a.s.l.) to the Vispa River (1200 m a.s.l.). This big difference in elevation leads to a very steep torrent topography. The upper part of the catchment area is dominated by gneissic rocks belonging to the crystalline Mischabel unit, while in the lower part, debris originating from various gravitational processes (e.g. rockslides, rockfalls) covers the bedrock (Labhart 2004). A considerable part of the area is characterized by steep scree slopes without any vegetation or dominated by scarce patches of alpine grass. The debris-flow cone extends from 1200 m a.s.l. to 1600 m a.s.l. and is covered by a forest built of European larch (*Larix decidua* Mill.) and Norway spruce (*Picea abies* (L.) Karst.). Slope gradients on the cone average 14°. In the lowermost part of the cone, a gallery has been built in order to protect the main road connecting Zermatt to Visp from debris-flow activity against the impact of debris-flows.

Debris-flows at the study site are normally triggered by intense rainfall (Seiler and Zimmermann, 1999). Archival data only cover the last 13 years with events known for 1993, 1994, 1999 and 2000.

Methods and Material

Geomorphic mapping

In a first analytical step, all forms and deposits related to former debris-flow activity (i.e. lobes, levees or abandoned channels) were mapped in a scale of 1:1000. Due to the presence of forest on the cone, GPS devices could not be used, reason why the map was based on detailed measurements using compass, tape

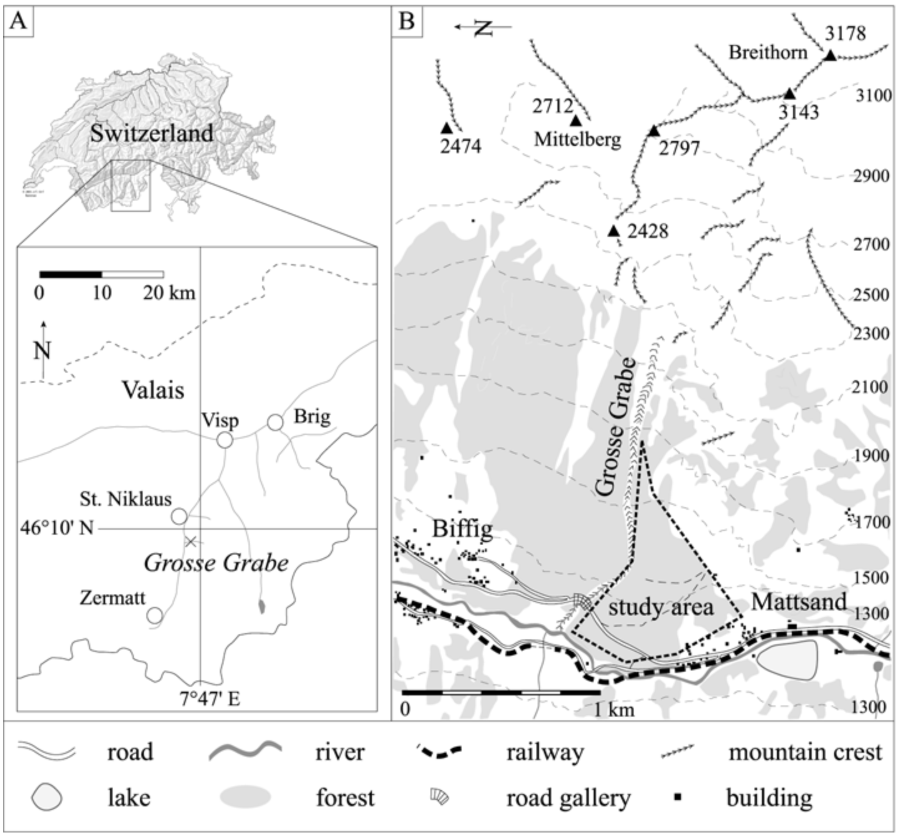

Fig. 1. (a) The Grosse Grabe torrent is located in the Swiss Alps near the village of St. Niklaus (Canton of Valais). (b) Sketch map of the Grosse Grabe with the study area, the main road connecting Zermatt to Visp and the railway close to the cone.

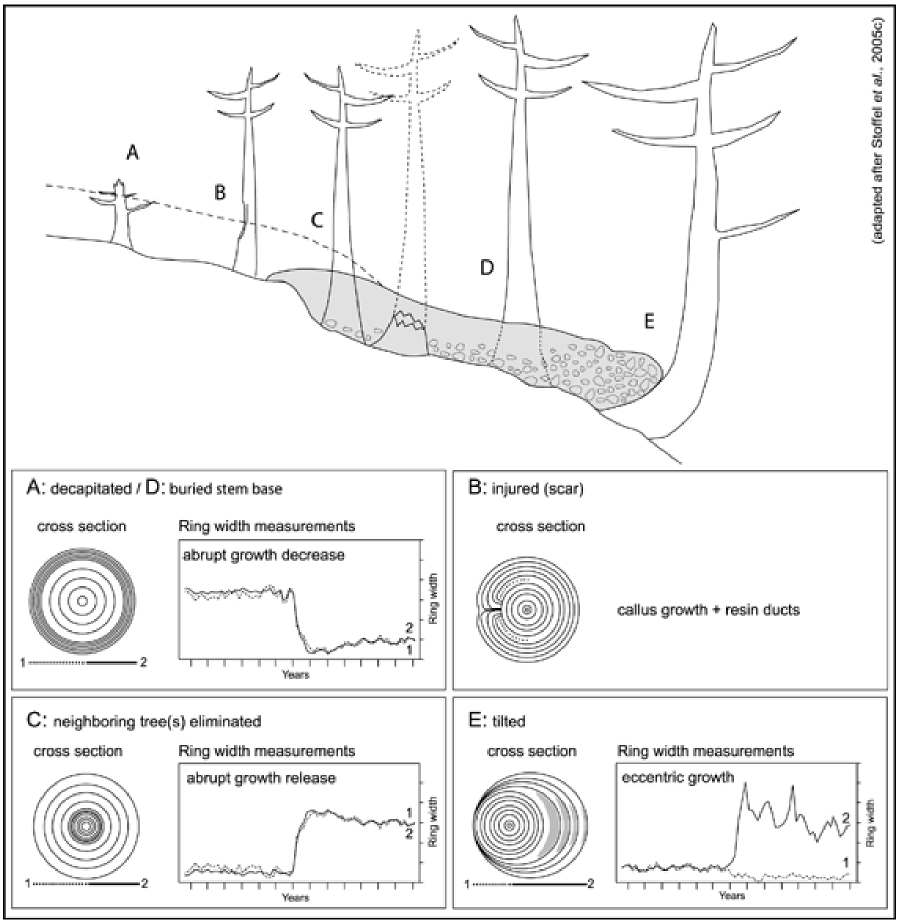

Fig. 2. Growth reactions of trees affected by debris flows: (A/D) sudden growth suppressions through decapitation or burying of the stem base, (B) callus growth and rows of traumatic resin ducts after injuries, (C) growth releases when neighboring trees are eliminated or (E) reaction wood after tilting of the stem.

measure and inclinometer.

Sampling strategy and tree-ring analysis

On the basis of the geomorphic map, trees that have obviously been affected by debris flows were selected. Consequently, trees disturbed by other geomorphic processes (e.g., rockfall), browsing, or anthropogenic influence were disregarded. From the selected trees, two cores were extracted with Suunto increment borers. Sampling height was chosen according to the morphology of the stem. Tilted trees were cored at the height of the bending where compres- sion wood could be expected whereas buried or decapitated trees were sampled as low as possible in order to extract a maximum number of tree rings. Scared trees were sampled close to the wound. Affected *Picea abies* (L.) Karst. and *Larix decidua* Mill. trees react upon the impact by debris flows with callus tissue, rows of traumatic resin ducts (Stoffel et al., 2005b, c; Perret et al., 2006), the formation of reaction wood (Braam et al., 1987; Fantucci and Sorriso- Valvo, 1999; Stefanini, 2004; Stoffel et al., 2005a) or an abrupt growth reduction or release (Strunk, 1997). Figure 2 gives an overview on the different impacts of debris flows on trees and their reactions to the disturbances.

For this study, 71 heavily disturbed trees have been sampled. Analyses included surface preparation, counting of tree rings, measuring of tree-ring widths using a LINTAB measuring table and TSAP 3.0 software (Time Series Analysis and Presentation; Rinntech, 2006). Growth curves of trees were then crossdated with a reference chronology built with undisturbed trees, representing climatically driven tree growth of the area (Cook and Kairiukstis, 1990). Afterwards, growth disturbances in the tree-ring series have been assessed in order to date former debris-flow events. Signals such as the onset of compression wood, rows of traumatic resin ducts, injuries or have been noted on skeleton plots (Schweingruber et al. 1990). In addition, the increment curves of the samples have been compared to the reference curve so as to determine the initiation of abrupt growth changes such as decrease or recovery (Schweingruber, 1996; 2001).

Spatial representation of event years

The position of all trees with growth reactions in the same event year was marked on the geomorphic map. This representation of trees affected during individual events allowed (i) reconstruction of the reach of events on the cone, (ii) identification and interpretation of spatial patterns of past events as well as (iii) an assessment of activity in currently abandoned channels.

Preliminary results

Geomorphic mapping

An area of about 30 ha was mapped in a scale of 1:1′000. The lowermost part of the cone, the area below the main road, has been neglected since deposits have been remodeled in this sector. The sector around the houses in the southern part of the cone has not been mapped either, as the anthropogenic influence was too important here. As can be seen in Figure 3, in total, 18 formerly active flow paths and 61 additional segments of levees could be identified and mapped. The number of debris-flow lobes was relatively small with only 21 lobes identified. In contrast, the levees were very well developed and normally visible over a long distance, i.g.

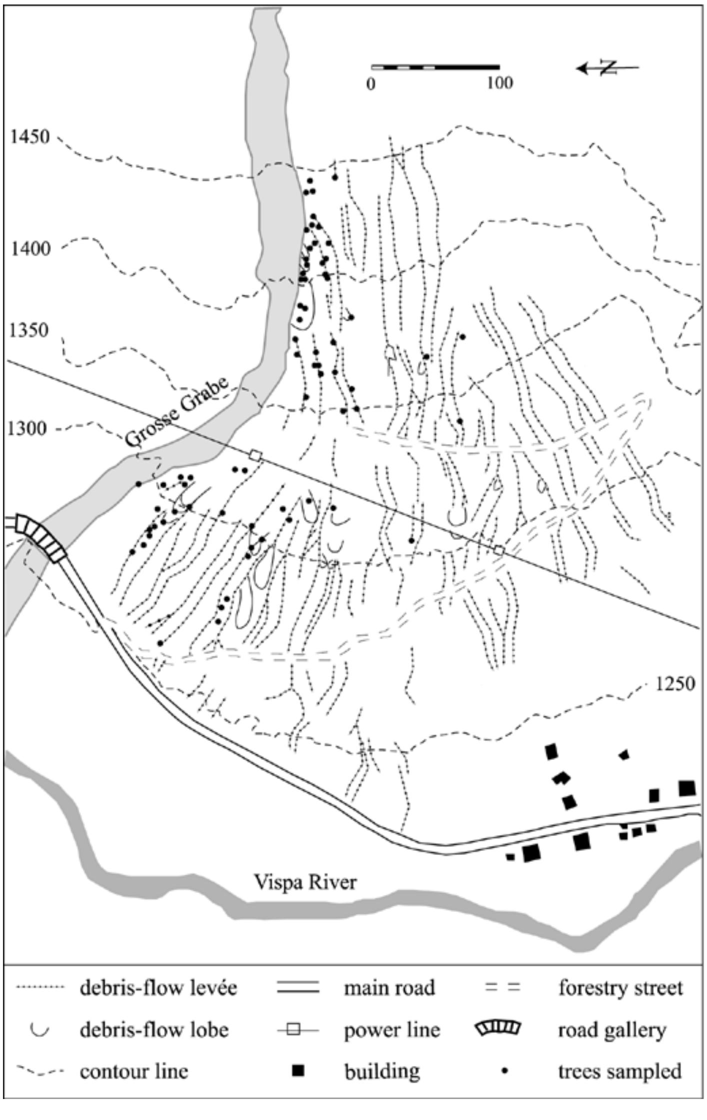

Fig. 3. Detailed geomorphic map (1:1′000) of the Grosse Grabe cone representing all forms related to past debris-flow activity (levees and lobes) and the position of all disturbed trees sampled.

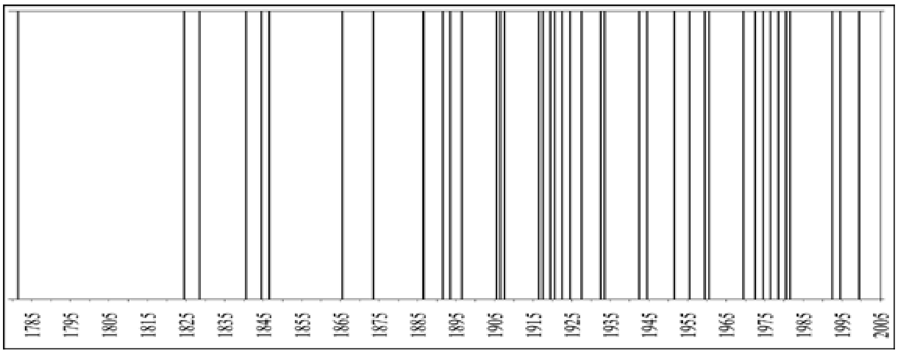

Fig. 4. Reconstructed frequency of debris flows in the Grosse Grabe torrent with 40 events between A.D. 1782 and 2005.

some of the levees in the uppermost part of the cone showed a length of more than 200 m.

Tree-ring analysis and minimum frequency of debris-flow events

So far, the analysis of the 152 tree-ring series from 71 trees allowed identification of 176 growth disturbances. Disturbed trees essentially showed three different types of growth disturbances: onset of compression wood, rows of traumatic resin ducts as well as abrupt growth changes (decrease or recovery). In contrast, injuries could only rarely be assessed. In total, dendrogeomorphological analyses allowed reconstruction of 40 event years between 1782 and 2005. As can be seen from Figure 4, only a small number of events could be reconstructed for the 19th century. In contrast, several episodes with increased activity are observable in the 20th century, i.e. between 1917 and 1928 as well as between 1970 and 1982. After the event of 1982, only three events could be identified.

Spatial behavior of events

The precise localization of all trees showing reactions in a specific event year allowed reconstruction of the spatial behavior of past debris-flow events. Figure 5 gives an example for the spatial distribution of trees showing growth disturbances following the event of 1917. Debris-flow material seems to have left the currently used bed of the Grosse Grabe torrent at between about 1320 to 1350 m a.s.l., affecting trees in a channel in the lower part of the cone. In addition two trees in the uppermost part of the cone seem to have been affected by the event.

Discussion and perspectives

In the study we report here, a coupling of detailed geomorphic mapping and tree-ring analysis has been used to assess the frequency and the spatial behavior of debris-flow events on the large cone of the Grosse Grabe (St. Niklaus, Valais, Swiss Alps) for the last two centuries. So far, analyses allowed reconstruction of 40 event years between A.D. 1782 and 2005. The dendrogeomorphological reconstruction of debris-flow events was, however, mainly limited by two factors. First of all, only a limited number of trees heavily affected by debris-flow events can be found on the cone due to logging activity. In addition, the average age of these trees is relatively limited, especially the ones growing in the lower part of the cone and close to the channel.

Furthermore, small debris-flow surges may have remained in the incised channels and did not necessarily cause growth disturbance to any of the investigated trees. Therefore, the debris-flow frequency has to be seen as a minimum frequency for past events. Nevertheless, the frequency could be extended from 1993 back to 1782.

Only a very small number of events could be reconstructed for the last two decades, even though a large number of trees were present and events occurred in the Grosse Grabe torrent. This might be explained by the fact that the channel of the torrent is actually deeply incised in formerly deposited material. Moreover, after the event of 1993, the levees of the channel have been heightened so as to prevent debris-flow material from leaving the flow path and reaching the main road.

Through the uneven distribution of affected trees on the cone — most of them were growing close to the channel — the spatial representation of the event years remains limited. In the uppermost part of the cone no trees were sampled since influence from rockfall activity could not be excluded.

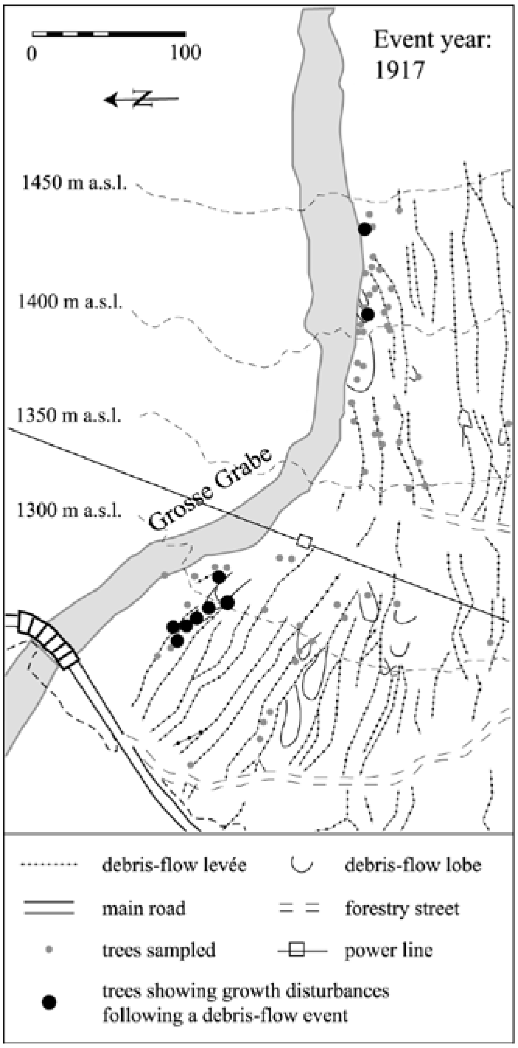

Fig. 5. Spatial distribution of trees with growth disturbances following an event in 1917.

To get a better idea of the spatial activity of former debris-flows on the entire cone, trees in the other sectors have to be analyzed. Since the affected trees in the outer parts of the cone have been removed by foresters, another method has to be used to collect data. Therefore we sampled undisturbed trees in the abandoned flow paths so as to approximate the time elapsed since the last event occurred in the flow path.

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