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# Chronology of processes in high-gradient channels of medium-high mountains and their influence on the properties of alluvial fans

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ABSTRACT

High-gradient channels are the locations of the greatest geomorphological activity in medium-high mountains. The channels' frequency and character influence the contemporary morphology and morphometry of alluvial fans. There is currently no detailed information regarding the frequency of these processes in high-gradient channels and the evolution of alluvial fans in medium-high mountains in Central Europe. This study in the Moravskoslezské Beskydy Mts. analysed 22 alluvial fans (10 debris flow fans and 12 fluvial fans). The processes occurring on the fans were dated using dendrogeomorphological methods. A total of 748 increment cores were taken from 374 trees to reconstruct 153 geomorphological process events (60 debris flow and 93 floods). The frequency of the processes has been considerably increasing in the last four decades, which can be related to extensive tree cutting since the 1970s. Processes in high-gradient channels in the region (affecting the alluvial fans across the mountain range) are predominantly controlled by cyclonal activity during the warm periods of the year. Probable triggers of local events are heavy downpours in the summer. In addition, spring snowmelt has been identified as occasionally important. This study of the relations affecting the type and frequency of the processes and their effect on the properties of alluvial fans led to the creation of a universal framework for the medium-high flysch mountains of Central Europe. The framework particularly reflects the influence of the character of hydrometeorological extremes on the frequency and type of processes and their reflection in the properties of alluvial fans.



## 1. Introduction

High-gradient channels are the locations of the highest activity of geomorphological processes in medium-high mountains (Gawlick and Rudolf-Miklau, 2006; Malik and Owczarek, 2009; Šilhán and Pánek, 2010), where the most common processes comprise debris flows (Van Steijn, 1996; Rickenmann, 1999; Helsen et al., 2002) and floods (Zielonka et al., 2008). The occurrence of these types of processes is largely based on the predisposition factors of the drainage basin such as morphometry and land cover. The frequency of these processes is controlled by triggering factors: precipitation characteristics including the occurrence of extreme rainfall events (Iverson, 2000; Goudie, 2006; Pelfini and Santilli, 2008; Schneuwly-Bollschweiler and Stoffel, 2012; Šilhán et al., 2012). At the same time, these processes are currently the most dynamic land forming agents in medium-high mountains and are perceptible primarily in the accumulative parts of the landscape such as alluvial fans, where they lead to both erosion and deposition (Harvey et al., 2005; Schneuwly-Bollschweiler et al., 2012). Alluvial fans formed by various processes have different morphological characteristics (Scott and Erskine, 1994; Scally et al., 2010). The morphology of alluvial fans formed by debris flows is represented by conspicuous lateral levees along incised gullies, accumulation lobes and large blocks on fan surfaces (Kostaschuk et al., 1986; Jackson et al., 1987; Jakob and Hungr, 2005). In contrast, fluvially formed alluvial fans are characterised by smoother morphology and permanent or temporary streams with braided channels. Large differences between individual alluvial fans can also be expressed using the morphometric parameters of the fans and their source basins (Crosta and Frattini, 2004; Scally and Owens, 2004).

In the medium-high mountains of Central Europe, the origins of alluvial fans often date back to the Atlantic period, especially in areas of Neolithic settlement related to land cover change (Zygmunt, 2009). Other changes in the frequency and character of processes forming alluvial fans were recorded during the Little Ice Age (LIA; Klimek et al., 2006). At present, discussion focuses on the influence of current climatic changes on the character, intensity and frequency of geomorphological processes (Evans and Clague, 1994; Jomelli et al., 2004). To understand these relations and to predict future landform development, the frequency of these processes in the past needs to be understood.

Records of individual geomorphic events are often incomplete particularly in high-gradient channels that affected alluvial-fan surfaces in mountainous areas. In such a situation, dendrogeomorphological methods are considered to be suitable for dating events (Wiles et al., 1996; Bollschweiler et al., 2008). They allow us to determine the periods of geomorphological processes with a monthly or seasonal resolution

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up to the past several hundreds of years (Stoffel et al., 2008). Moreover, they can qualitatively reconstruct the frequency of both debris flows (Strunk, 1997; Bollschweiler and Stoffel, 2010b) and floods (Harrison and Reid, 1967; Gottesfeld and Gottesfeld, 1990; St. George and Nielsen, 2003; Zielonka et al., 2008; Ruiz-Villanueva et al., 2010).

The objectives of this study are to (i) reconstruct a historic chronology of the individual process events (debris flow and floods) in high-gradient channels, (ii) analyse their triggering factors and (iii) construct a framework of the genesis of these processes in high-gradient channels and their effect on the morphological and morphometric features of alluvial fans in medium-high mountains.

## 2. Regional settings

Alluvial fans and their source basins were analysed across the Moravskoslezské Beskydy Mts. (Fig. 1), i.e., a medium-high mountain range with local relief of up to 600 m (1 km wide window) located in the eastern part of the Czech Republic and representing the culmination zone of the flysch Outer Western Carpathians. The accretional wedge of the Outer Western Carpathians originated from compressive tectonics during Late Miocene, when nappe stacks, including predominantly Cretaceous and Palaeogene strata, was thrust over the Northern European Platform (Menčík et al., 1983; Danišík et al., 2008). Geologically, the mountain range is formed of flysch rocks with layers of sandstones or conglomerates alternating with siltstones or claystones, slightly tilted (10–15°) to the S–SE. It consists of a system of ridges and isolated peaks with steep slopes and deeply incised valleys, which was void of Pleistocene glaciation. The highest peak is Lysá hora Mt (1323 m a.s.l.), which is also the location of the highest precipitation in the Czech Republic: 1407 mm per year for the period 1961–2000. The majority of the precipitation falls in July, often in the form of heavy downpours. Long and steep slopes with thick layers of weathered material, high precipitation totals and low rock strength give rise to numerous slope deformations of various types (Hradecký and Pánek, 2008). At present, a significant portion of the mountain range surface is forested. In the past, however, large areas became deforested, particularly in connection with the Wallachian colonisation (15–16th centuries). Intensive deforestation occurred in the 1970s, especially due to the cutting of trees damaged by pollutants coming from the Ostrava industrial zone.

Alluvial fans are present here in two forms. Some 20 several-km-long alluvial fans whose origins date back to the last glacial period (Menčík et al., 1983; Hradecký et al., 2011) are found in the northern forefield of the Moravskoslezské Beskydy Mts. The fans analysed in this study, which are of much smaller dimensions, are located within the mountain range, namely at the mouth of high-gradient gullies or minor valleys. All of the fans are covered by coniferous or deciduous trees of various species, primarily sycamore maple (*Acer pseudoplatanus* L.), Norway spruce (*Picea abies* (L.) Karst.) and European beech (*Fagus sylvatica* L.).

## 3. Methods

### 3.1. Geomorphic mapping and morphometric analysis

Individual alluvial fans were geomorphologically mapped at a scale of 1:500. Detailed mapping focused on erosional landforms (gullies) and depositional landforms (lobes and levees). Based on their specific morphology, the alluvial fans were classified into debris flow fans and fluvial fans following Iverson (1997), Scally and Owens (2004) and Jakob and Hungr (2005). At the same time, the positions of all sampled trees were identified and marked.

The dimensions of each alluvial fan were measured directly in the field using a laser rangefinder. Morphometric parameters of source basins were extracted in ArcGIS 9.3 (ESRI) on a hydrologically correct grid with a resolution of 5 m. The standard parameters identified were basin area and mean basin gradient. Additionally, the ruggedness number ($R$; Melton, 1965) was calculated as the index of debris flow susceptibility using:

$$R = \frac{H_b}{\sqrt{A_b}}, \tag{1}$$

where $H_b$ is local relief and $A_b$ is basin area. According to Melton (1965) and Wilford et al. (2004), the limit value for debris flow occurrence

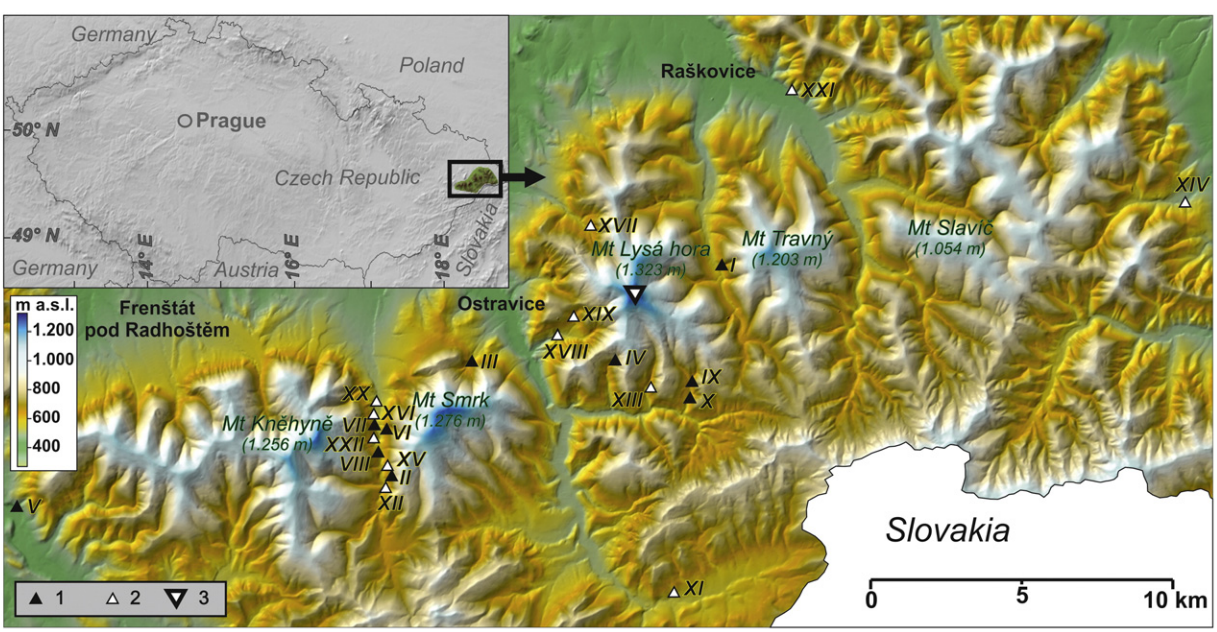


**Fig. 1.** Location of the studied area within the Czech Republic and the locations of all of the studied alluvial fans within the Moravskoslezské Beskydy Mts. 1 – debris flow fans, 2 – fluvial fans, 3 – meteorological station.