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Significance of extreme hydro-geomorphological events in the transformation of mountain valleys (Northern Slopes of the Western Tatra Range, Carpathian Mountains, Poland)

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ABSTRACT

Extreme events disturb the development paths of geomorphological systems. The effect of such events on relief tends to persist for long periods of time and affects the future development of such systems. This paper focuses on changes in middle mountain valleys associated with an extreme hydro-geomorphological event that occurred in the Western Tatra Mountains (Polish Carpathian Mountains) in June of 2007. The geomorphological effects were mapped and an analysis of valley-bottom deposits and dendro-geomorphological data on tree roots and stems was used to identify patterns in the geomorphological transformation taking place during such events. In addition, the organic material obtained from fans was dated by means of carbon-14 dating. The effects of previous extreme events in the study area and their geomorphological outcomes were compared. Four main valley section types were identified in the valley longitudinal profile. Unevenly aged (from 14C 390 ± 30 years YBP (1441–1631 cal AD) to 14C 3760 ± 70 YBP (4318–3962 cal BP)) organic material was revealed at different depths of each studied fan. A complex structure with alternating layers of fine and coarse material from the analysed fans was identified. The colluvial-alluvial structure of fans suggests that extreme high-energy events did occur more than once per century during the Holocene. This type of fan structure can be referred to as a patchwork. In the study area, rainfall with high energy potential occurs once in every 6–9 years and extreme hydro-geomorphological events occur every 15 years. This type of extreme event may not be exceptional in the history of middle mountain areas.

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1. Introduction

Catastrophic events produce the highest possible rates of change in mountain landforms, as thresholds of various processes with high geomorphological potential are exceeded. This leads to a loss of equilibrium in natural geomorphological systems such as slope and channel systems (Gorczyca, 2004; Kotarba, 1998, 2004a; Kotarba et al., 1987; Krzemień, 1992; Selby, 1993; Thornes and Brunsden, 1977). Events of this type are caused by short torrential rains. Their frequency of occurrence tends to be low, and they typically affect small areas (Gorczyca et al., 2013; Krzemień, et al., 1995; Starkel, 1996, 2006). The long-lasting nature of landform changes that occur during such events results in the development of new equilibriums in geomorphological systems. On June 5, 2007, an event of this type affected small valleys in the middle mountain zone of the Tatras. Local extreme events are typical of mountainous areas (Gomi et al., 2002), and have occurred many times not only in the Tatras (Kotarba et al., 1987; Kotarba, 2004a, 2006; Krzemień et al., 1995), but also in many other mountains of the temperate climate zone (Benda and Cundy, 1990; Ellen et al., 1988; Izmaiłow et al., 2006; Kapusta et al., 2010; Poesen and Hooke, 1997; Šilhán and Pánek, 2010b; Starkel, 2000, 2006; Stoffel et al., 2007; Wrońska-Wałach, 2014; Zielonka et al., 2008).

2. Study area

Field studies were carried out in five small valleys in the Western Tatras (Fig. 1). The Tatra Mountains, along with the Bucegi and Retezat Mountains, form high-mountain islands in the 1300-km long arch of the Carpathians. The Tatra Mountains, culminating at 2,663 m, belong to the Alpine orogeny (Michalik, 1985; Stupnicka, 2007) and feature a typical high-mountain character (Kotarba et al., 1987; Krzemień, 1992). However, their northern section of slope is characterized by a midsize mountain relief, including their characteristic fluvio-denudational morphology (Klimaszewski, 1988). For 71% of the days in the year, local precipitation conditions develop in Polar maritime air masses. This type of air mass produces heavy and intense precipitation (Niedźwiedź, 2003). In June of 2007, an extreme rainfall event in this area produced physical effects that prompted the authors to carry out a geomorphological study intended to understand the role of extreme events in landform

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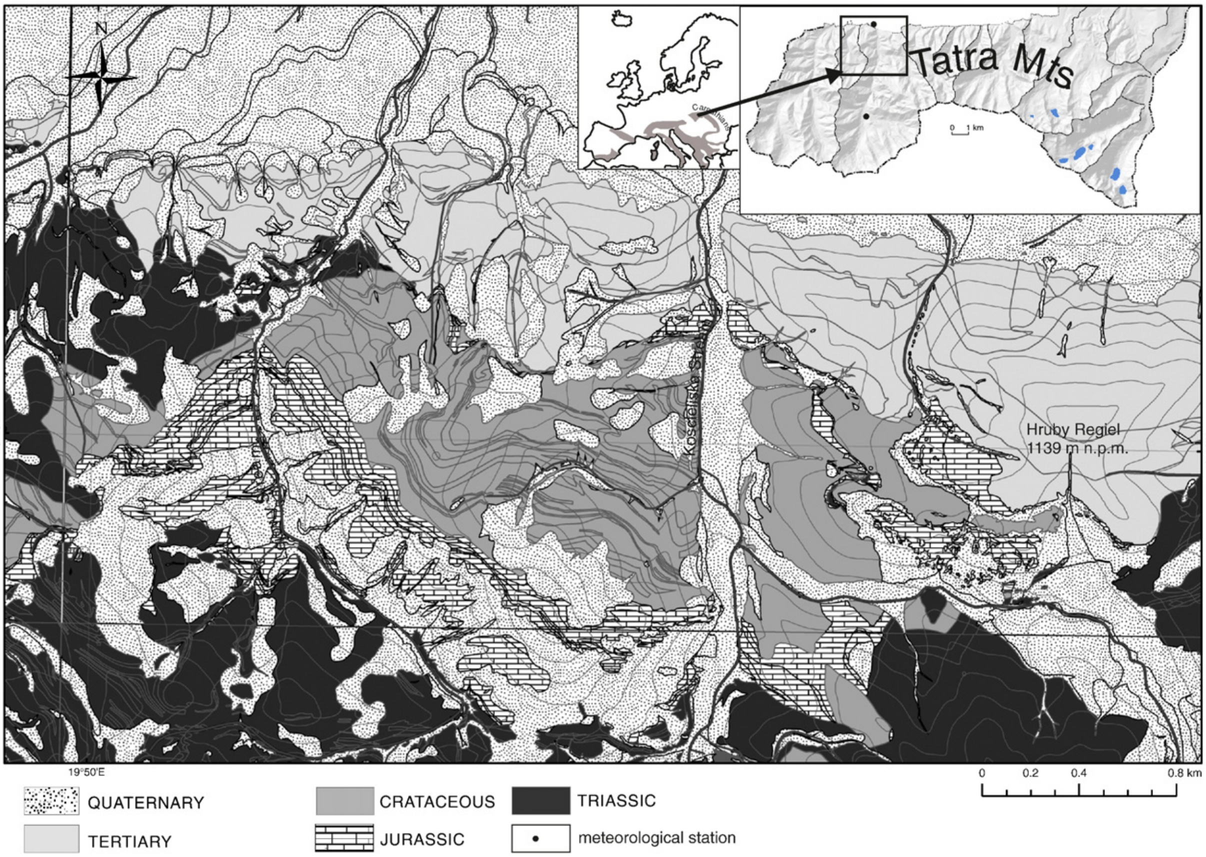

Fig. 1. The study area and its geology.

development. The rainfall event covered a section of the Reglowe Tatry including the following valleys: Kościeliska, Lejowa, Miętusia, Stanikowy Żleb, Jaroniec (Fig. 1). The geology of the area includes mostly limestone, dolomite and marl from the Triassic, Jurassic and Cretaceous, as well as limestone, shale and conglomerate from the Eocene (Bac-Mosaszwili et al., 1979). The main consequent valleys, including Lejowa, Kościeliska and Jaroniec cut into marl, limestone and sandstone, while their tributary valleys dissect limestone, conglomerate and marl (Fig. 1). The study area includes the northern slope of the Tatra Mountains descending steeply from 1100–1380 m a.s.l. into the erosional Subtatra Depression filled with Tertiary deposits. The area is drained by Kościeliski Stream and its small tributary valleys (denudational-fluvial valleys). Kościeliska Valley has an asymmetrical channel pattern, whereby its eastern slopes tend to be undercut by the stream. The valley floor is filled with fluvial and fluvioglacial alluvia. Tributary valleys, gullies and other V-shaped valleys, show typical features of young river valleys with relatively little depth and an uneven slope. Their upper sections are bowl-shaped. The valleys broaden within softer substratum rock, including marls and conglomerates, and narrow down in the gap sections of resistant limestone and dolomite (Klimaszewski, 1988). During the Pleistocene and Holocene, the valleys were periodically filled with debris, which built torrential fans at their mouth sections and in the mountain foreland of the Subtatra Depression.

3. Research methods

The fieldwork was carried out on several trips, which took place between June and August in the period 2007–2012. It involved geomorphological mapping of the geomorphic effects of the catastrophic rainfall event using a topographic map at a scale of 1:5 000 (Figs. 2, 3, 4).

Transects across and through the valleys were used to identify features of the terrain that had been transformed as a result of the rainfall event as well as to perform measurements of the maximum diameter of the boulders deposited (Fig. 3). The results of the fieldwork were used to classify the valleys into characteristic sections using valley morphology as the main distinguishing factor. The focus was on valley floors, rock and debris steps, lateral undercuts and the location of landslides that provided slope debris, which had moved across valley floors. In addition, deposition zones of large woody debris were identified and measurements were performed of the maximum diameter of logs and the height of dams made of accumulated logs and tree branches. Valley cross-sections and longitudinal profile were analysed in order to study unique stages in the development of valley landforms.

The fieldwork also included a study of the material found in complex fans built of mixed debris-rich material. In this type of landform, it is not always easy to distinguish between colluvial and alluvial material (Fairbridge, 1968). Therefore, the term colluvial-alluvial fans was used in accordance with work done by Fernald et al. (1968). Sediments were sampled from exposures in colluvial-alluvial fans in Kościeliska Valley (Valleys I and II, Kościeliska Valley, Fig. 2). The profiles studied were located within natural incisions in Valley I (1.39 m and 1.46 m deep) and Valley II (1.75 m and 1.28 m deep). Two profiles that were the most representative of the fans were selected for detailed study. The grain-size distribution, carbonate content, and organic matter content of each layer identified in the studied profiles were determined. Each sediment sample was described in terms of mean grain diameter (Mz), skewness (Sk), standard deviation (δ), and kurtosis of granulometry (KG) by Folk and Ward (1957) Geometric Graphical Measures Method. Statistical analysis of the sediment was performed using the GRADISTAT software 4.0 package. Sieve and laser methods were used for granulometric measurements and sediment size was analysed in intervals of 0.5 phi. Lithological identification involved the use of the granularity classification system by Uden and Wenthorth, as modified by Krumbein and Lan (Mycielska-Dowgiałło,

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