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DEBRIS FLOW ACTIVITY IN THE SLOVAK PART OF THE HIGH TATRAS IN THE LIGHT OF LICHENOMETRIC DATING

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Abstract

Rock walls and talus slopes, which are the most common features of high-mountain relief, have been researched for many years. Geomorphologists have taken particular interest in debris flows, which play a major role in the development of talus slopes. This paper presents the results of the first lichenometric dating of debris flows on the southern slopes of the Tatra Mountains. The greatest debris flow activity took place in the Little Ice Age and in the last two decades.

Key words

lichenometric dating • debris flow • High Tatra Mts.

Introduction

Rock walls and debris slopes are the most common features of high-mountain relief. How talus slopes evolve depends on the geology and climate, with the latter being the key trigger of weathering and erosion, as well as of transport and accumulation (Klimaszewski, 1978, 1988; Kotarba & Strömquist, 1984; Kotarba et al., 1987; Sass & Krautblatter 2007; Fort et al., 2009; Krautblatter et al., 2012). In the Tatra Mountains, talus slopes have long been the subject of many geomorphological studies on the origin and morphodynamics of slopes (Kotarba et al., 1983, 1987; Klimaszewski, 1988; Kaszowski et al., 1988; Krzemień et al., 1995; Ferber, 2002; Kotarba, 2004). Many researchers on the relief of mountains believe that debris flows play a crucial role in the formation of talus slopes (Kotarba et al., 1987; Krzemień, 1988; Francou, 1991; Kotarba, 1992, 1995, 1997; Hinchliffe et al., 1998; Curry & Morris, 2004; Rączkowska, 2006; Rączkowska et al., 2012; Kotarba et al., 2013).

The intensity of this process can be studied, inter alia, by analysing aerial photographs. However, this method, which allows large and hard-to-reach areas to be investigated rapidly and with relatively high accuracy, has two major limitations. One of them is the length of the data series, which typically begin as late as the second half of the 1940s or even the 1950s. Another is the frequency at which such photographs are taken. Currently, aerial photographs are taken every few years, and sometimes even once a year. However, in the mid-20th century, flights were completed every several or even several dozen years (Kapusta et al., 2000; Kapusta, 2009; Kędzia, 2010). Usually, aerial photography is not sufficient to determine the timing and frequency of flows, but it provides an insight into the scale of processes that take place within the timespans of several years to several decades between individual flights.

The frequency of debris flows can also be studied by lichenometric dating, the key principles of which were defined by Beschel (1950, 1957) around 70 years ago. In the Tatra Mountains, this method was first employed by Kotarba, who determined the growth curves for thalli of the *Rhizocarpon geographicum* lichen (Kotarba, 1988). The curves were constructed for thalli in the Alpine and sub-Alpine zones on the northern slopes of the Tatra Mountains. Since that time, many studies have been undertaken to determine the age of the surface of talus cones, talus-rockfall cones and the phases in debris flow activity (Kotarba, 1989, 1991, 1995, 2001, 2004; Jonasson et al., 1991; Ferber, 2002; Kotarba & Pech, 2002; Kędzia, 2010, 2017; Gądek et al., 2010, 2016). The greatest number of lichenometric dating surveys has been carried out in the Sucha Woda Valley, the Rybi Potok Valley and in the Kežmarská Biela Voda Valley (Fig. 1).

Although the phases of debris flow activity identified through lichenometric dating did not coincide at all the sites surveyed, many of them did overlap in time terms. Such coinciding periods include the years 1820-1830, 1850-1860, 1880-1890, 1910-1925, 1970 to the present (Kotarba, 1989, 1991, 1995, 2001, 2004; Ferber, 2002; Kotarba & Pech, 2002; Kędzia, 2010, 2017; Gądek et al., 2010, 2016). The differences in debris flow activity

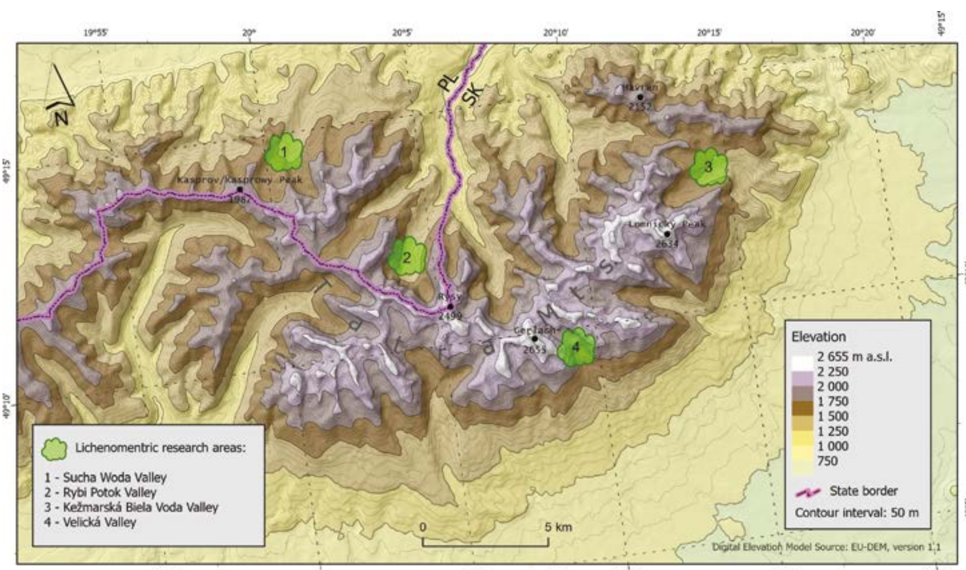

Figure 1. Map of the Tatra Mountains with the research areas marked

from one valley to another are mainly attributable to variations in precipitation. Heavy rains with the intensity of > 1 mm/min, which trigger debris flows, did not occur in all the valleys studied at the same time.

The identification of the phases in the intensity of debris flows on the southern slopes of the Tatra Mountains through lichenometric dating only became possible once the lichenometric curve was determined for this part of the Tatras. This curve was determined by Kędzia, Hresko and Bugar in 2020 (Kędzia et al., 2020). Despite the difference between the climates of the northern and southern slopes of the Tatra Mountains, the *Rhizocarpon geographicum* thallus growth curves have turned out to be gentle, especially for the first 100 years (Kędzia et al., 2020). Therefore, the aim of this study is to present the first results of lichenometric dating of debris flows and the periods of their activity on the southern slopes of the Tatras.

Study area and methods

The Velická Valley in the Slovak part of the High Tatras was chosen as the research area (Fig. 1). The lichenometric dating was carried out on five debris flows. Two are situated in the area of Velicke Pleso lake at an altitude of about 1600-1750 m above sea level, while the remaining three lie within the area of the Kvetnica meadow at an elevation of approximately 1800-1870 m above sea level (Fig. 2). The Velická Valley was chosen because of the numerous debris flows that occur there and the debris flow research that has been previously conducted in this valley (Kapusta et al., 2000; Kapusta, 2009).

The debris flows surveyed were chosen because they satisfied the assumptions of the lichenometric dating methodology and there were thalli of different ages present. When measuring the diameter of the thalli, use was made of the same method as that utilised previously to construct the lichenometric curve (Kędzia et al., 2020), i.e. in measuring the largest diameter (Fig. 3). The diameter used for the dating was calculated as the average of the five largest measured thalli found on different boulders. The measurements were taken with a transparent ruler. A Garmin Oregon GPS device with a topographic map was used to locate the debris flows.

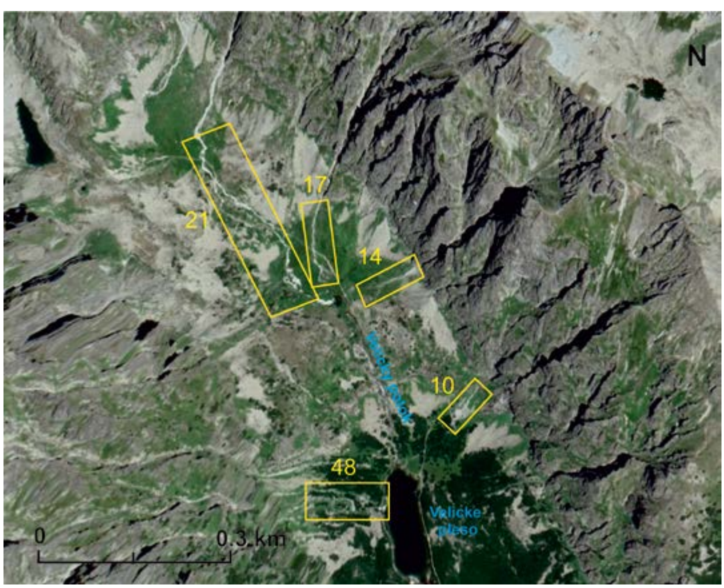

Figure 2. Velická Valley with the debris flows surveyed (Phot. Google Earth 2022)

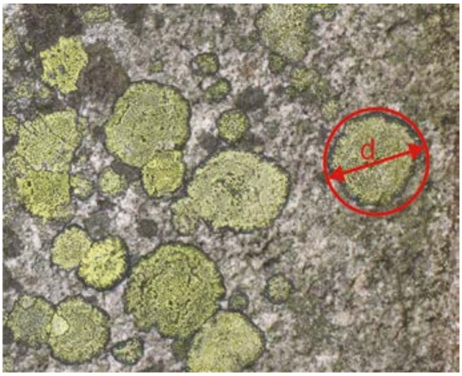

Figure 3. Method for measuring the thalli of the *Rhizocarpon geographicum* lichen

Results

Figure 2 shows the debris flows which were dated lichenometrically. They were assigned the same numbers as those assigned by Kapusta in his 2009 study. Debris flow No 10 (Figs. 3, 4) is one of the shortest flows that were dated. The measurements of the thalli were completed along the stretch from the tourist trail to as far as the start of the gully. The material dates back to different times. A large proportion of the boulders, i.e. more than half, had no thalli at all. The largest amounts of fresh material were found in the upper reaches, at the mouth of the gully. As shown by colonisation time measurements completed by Kędzia (2021), this material was deposited no earlier than in 2013-2014. In the upper part of the debris flow, water produced by heavy rains was likely to have had the predominant share in the deposition of fresh debris, while in the remaining parts, water and snow avalanches played the key role. The largest thalli from the youngest thallus sequence had a maximum diameter of about 12 mm (Tab. 1). As is indicated by the thallus growth curve for this altitude, the rock boulders colonised by such thalli were brought in towards the end of the 1980s. It is not daily precipitation totals that form the threshold value for the triggering of debris flows, but instead rainfall with an intensity of >1 mm/min. lasting at least 20 minutes (Kotarba, 1989; Gądek et al., 2016). Therefore, the boulders with thalli of 12 mm or so in diameter are most

Figure 4. Debris flow No 10

likely a remnant of a debris flow caused by intense rainfall on 16 August 2018. On that day, the Skalnate Pleso meteorological station recorded a daily precipitation total of 91.7 mm, but the rainfall intensity was 42 mm/h (Kapusta, 2009).

The next thallus sequence was formed by thalli with a maximum diameter of about 21 mm (Tab. 1), with their age estimated at around 60 years (Kędzia et al., 2020). On 21 July 1959, the Skalnate Pleso meteorological observatory recorded daily rainfall of only 71.8 mm, but the rainstorm intensity was as high as 49 mm/h (Kapusta, 2009), which was probably the highest intensity in Skalnate Pleso in the period 1949-2008. Therefore, boulders with 12 mm thalli were attributed to the date mentioned above. The next group of maximum-diameter thalli which were found in nearly all the debris flows surveyed were those with a diameter of about 31 mm (Tab. 1). This is most likely a record of the flood of 13-17 July 1934. On 16 July 1934, the diurnal rainfall total in Hala Gąsienicowa was 255 mm. The next sequence of thalli found across the debris flows was characterised by maximum thalli with a diameter of about 41 mm. Their age was estimated at about 110 years and they should be associated with floods which, according to Kotarba (2004), occurred in 1910 and 1912. In turn, the sequence of thalli with a maximum diameter of about 60 mm, which also occurs across the five debris flows investigated, is likely to have come into being as a result of floods in 1846 and/or 1954. The largest thalli observed were about 80 mm in diameter and their origins date back to a large flood in 1813 (Kotarba, 2004).

Debris flow No 14 is located within Kvetnica and is also relatively short. As with the previously described debris flow, this one also includes a lot of fresh material with no thalli (Tab. 1). Even though it lacks 12 mm thalli and the oldest ones with a diameter of 80 mm, it records the 1882-1885 floods.

Another debris flow, No 17, is also located within Kvetnica (Fig. 5). As with the debris flows discussed above, it has also accumulated a lot of fresh material with no presence of thalli (Tab. 1). It lacks boulders with 50 mm (1882-1885) and 80 mm (1813) thalli. Debris flow No 21, which is situated within the Kvetnica area, is the longest of the flows analysed (Fig. 2) and the one with the greatest amount of material with fresh thalli-free surfaces. Some boulders only have thalli in the upper parts, while their lower parts have been exposed by water in the last 5-6 years and do not have any thalli yet (Fig. 6). In general, the diameters of the thalli start at 32 mm, and they colonised the boulders from the 1934 flow. The last of the debris flows surveyed, numbered 48, is adjacent to Velicke Pleso lake. It is overgrown by thalli

Table 1. Debris flows with maximum thallus diameters and corresponding dates

The date of the activity	Number of debris flow and thallus diameter [mm]				
	10	14	17	21	48
>2014	0	0	0	0	0
2002			5		7
1988	12		11		11
1959	25	25	23		
1934	31	33	33	32	
1910-1912	41	43	40	40	41
1882-1885		52			50
1846-1854	60	61	60	62	61
1813	80			82	80

Figure 5. Debris flow No 17

Figure 6. Flow No 21 with exposed boulders in the lower area

from all the events described above, except for the 1959 and 1934 ones.

Conclusions

The presence of fresh boulders without thalli is typical of all the debris flows surveyed. The proportion of fresh material varies from about 1/4 to over 3/4 of the boulders examined. Such large amounts of fresh material provide evidence of high debris flow activity, at least over the last few years. Some debris flows involved the complete remoulding of the flow channel and its levees, and some only caused the upper reaches of the channel bed to be remodelled. As is shown in Fig. 6, not all debris flows entail a new supply of fresh rock material. In the absence of weathered material in rock walls, water erodes the bottom of the upper section of the channel and deposits the eroded material on the lower reaches of the debris flow, causing fresh surfaces to be exposed on rock boulders. Often, boulders exposed in the uphill part are covered with very old thalli, some of which are even more than 100 years old.

Not all debris flows show equally intensive activity. In addition to fresh boulders, debris flows Nos 14 and 48 also include boulders deposited in 2002 and 1988 and older.

Meanwhile flow No 21 consists of both fresh boulders and old ones deposited in 1934 and earlier. This proves that the latter flow was inactive in the years 2002 and 1988 or was active, but the material from those years has eroded in recent years. This is where aerial photos are useful, confirming the activity of this debris flow in the above years (Kapusta, 2009; Kapusta et al., 2010), which means that the 2002 and 1988 material has been carried away by water since its deposition.

The relatively high share of thalli with a diameter of 40 mm and more across the debris flows proves that the Little Ice Age, in a similar manner to recent years, was a period of high debris flow activity.

That debris flow activity in the last 20 years has been high is also evidenced by an analysis of 1949, 1973, 1986, 1998, 2002, 2003, 2006 aerial photographs carried out by Kapusta (2009) and Kapusta et al. (2010). In the period 1949-1986, debris flow activity within the Kvetnica area was low, with some flows having been partially overgrown by high-mountain grass. By contrast, from 1986 their activity began to increase. However, the greatest activity in the last twenty years has been observed in the Velickie Pleso area debris flows. They have become very active since 1988, with the surface area of some of them having increased significantly. Debris flow No 48 has grown the most – by the factor of several times (Kapusta, 2009), which is confirmed by the lichenometric dating completed. The lower part of the flow does not have any old thalli.

The results of lichenometric dating on the southern slopes of the Tatra Mountains are largely consistent with the results of such dating carried out on the northern slopes. Ferber (2002), Kotarba (2004), and Gądek et al. (2010, 2016) have also demonstrated high debris flow activity during the Little Ice Age and in the last few decades.

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Unless otherwise stated, the sources of tables and figures are the authors', on the basis of their own research.

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