S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
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RECENT GEOMORPHIC HAZARDS IN THE TATRA MOUNTAINS

Abstract. The paper presents a state-of-the-art in recognition of nature and course of geomorphic hazards in the Tatra Mts. Debris flows, avalanches, rockfalls, wind and floods, and geomorphic effects of the above in relation to environmental conditions are discussed. Their spatial and temporal variability at present and in the recent past, during Little Ice Age is presented. The geomorphic hazards are indicated as main geomorphic factor in the area.

Key words: geomorphic hazard, debris flow, avalanche, rockfall, flood, the Tatras

INTRODUCTION

Geomorphic hazards are those extreme or catastrophic events, which cause danger to man or settlements (Rosenfeld 2004). As the Tatra Mts., are sparsely inhabited in both Polish and Slovak parts, in this paper we will discuss geomorphic hazard considering only the nature of these events disregarding their damaging effects to the public/inhabitants.

Geomorphic hazards are understood as the phenomena which are rapid, trigger and transport a great amount of material for relatively long distances. The events are short-lasting and time-limited. Most often they cause distinct changes in relief as well as damage the vegetation. Among the geomorphic hazards affecting the high-mountain area of the Tatras are debris flows, avalanches, rockfalls, wind and floods.

The aim of the paper is to present a state-of-the-art in recognition of nature and course of geomorphic hazards which have been subjected to relatively intensive studies in various aspects for the last 25 years. These years are also a period of the more frequent occurrence of summer storms of high precipitation totals and intensity in the Tatra Mts. (Kotarba 1997, 2004; Niedźwiedź 2004; Kotarba and Pech 2002), what generated an additional impulse for such interest. Various aspects of the above mentioned geomorphic events were recognized to different degree.

The studies of geomorphic hazards concentrated on two main groups of problems:

1. current activity of geomorphic hazards — their magnitude, spatial and temporal variability, rainfall thresholds of geomorphic events and resulting effects in morphology;
2. extent and magnitude of geomorphic hazards during last few hundreds years until the Little Ice Age.

The high-mountain range of the Tatras, reaching up to 2,655 m a.s.l., representing a classical alpine landscape, is located at the border between Poland and Slovakia. The highest parts of the Tatras are built predominantly of granite and metamorphic rocks, while in the lower parts carbonate rocks dominate. The relief is of alpine character. Glacial transformation in the Pleistocene and periglacial processes in the Holocene produced a system of alpine cliffs and talus slopes. On debris mantled slopes, weathering cover is relatively thin, built of coarse material. At present, the most favourable temperature-moisture conditions for frost weathering occur in the 1,700–2,050 m altitudinal belt (Klimaszewski 1971). At altitude 2,000 m a.s.l. snow cover persists 230 days in a year (Hess 1965). Maximum monthly and daily precipitation in the summit parts are definitely smaller than those recorded in the middle parts of the Tatras exposed to the north (Hess 1974; Cebulak 1983; Niedźwiedź 1992). High intensity rainfalls of short duration, which are important for a debris flow activity, are also related to the middle part of the N-facing slopes above the upper timberline (i.e. 1,500 m a.s.l.).

GEOMORPHIC HAZARDS CHARACTERISTICS

DEBRIS FLOWS

Fresh as well as inactive debris flows gullies accompanied by levees are very common landforms on all types of slopes in the Tatras (Photo 1). Debris flows are believed to be the most important geomorphic agents modelling slopes even in the area of cryogenic domain above the timberline (Midriak 1984; Stankoviansky and Midriak 1998; Kotarba and Strömquist 1984; Kotarba et al. 1987). Debris flows are especially active on the slopes and at the bottom of glacial cirques where debris flows accumulation buried glacial and at the periglacial relief (Kaszowski et al. 1988; Kotarba 1992c; Rączkowska 1999).

On debris slope in the High Tatra, A. Kotarba (1992a, 2004) determined two groups of debris flows:

1. valley-confined debris flows, which originate in or above bedrock gullies, and are channelled for part of their length along gully floors, always having the same tracks;
2. hillslope debris flows which occur on open slope and are not topographically constrained.

Photo 1. Example of debris flow activity at talus slopes in the High Tatras (the Mengusovská valley)

The tracks of valley-confined debris flows occur always in the same location in rockwall/rocky slopes — talus slope system. Hillslope debris flows form systems of intersected and overlapping gullies accompanied by levees. However, these two categories are often transitional. In the Western Tatra, according to K. Krzemień (1988), the present-day debris flows occur mainly in pre-existing systems of gullies or chutes and, therefore, might be included to the first category.

Most often, debris flows affect talus slopes (Kotarba 1992b, 1997, 2004; Kaszowski et al. 1988; Midriak 1984) as coarse, granite debris on such slopes favour fast infiltration of water during intensive rainfalls, leading to increasing pore pressure and triggering of waste movement (Kotarba 2004). On 30–35° inclined debris-mantled slopes the present-day debris flows are triggered by overloading the waste material with rainwater or meltwater (Hreško et al. 2005). A. Kotarba (2005) denies the role of meltwater in triggering the debris flows on the debris-covered slopes.

The spatial distribution of debris flows is unequal. On the map of debris flows in the Slovak part Tatra Mts., compiled by R. Midriak (1984), 830 distinct flow tracks are marked. Most of debris flows (65%) are triggered at altitude 1,900 m a.s.l. and higher, in the alpine and subnival belts (Midriak 1996). The Polish part of the Tatra Mts. is lacking any special map of debris flows. Only the most distinct forms are marked on geomorphologic maps (Kotarba et al. 1987; Kotarba 1992c). A. Kotarba (2002), based on interpretation of the air photo of 1994, depicts fresh debris flow tracks on the map of the present-day geomorphic processes in the Tatra National Park. Nevertheless, the comprehensive and standardized map of debris flows, presenting their morphometry and activity is not available for the entire Tatras.

Debris flow gullies and levees appearing on the slopes of the Tatra Mts. differ much in size. In Slovak part of the Tatras, a half of all the debris flow gullies are 500–1,000 m long while more than one-third of them are 250–500 m long (Midriak 1984). Similar morphometry was found for over 100-year old debris flows gullies on the slopes of Skrajna Turnia in the upper Sucha Woda valley. They are 10–20 m wide and at least 500 m long (Kotarba 1989). Gullies of the present-day debris flows are usually smaller: 3–4 m deep and less than 10 m wide (Kotarba 1994), yet can reach 1,700 m in length (Krzemień et al. 1995). The size of the gullies depends on rainfall total and intensity. Therefore, it is rather impossible to use the debris flow gullies morphometry as an indicator of their age.

Importance of debris flows in relief modelling is also connected with a great geomorphic work. They are able to transport from 100 till maximum 25,000 m^3 during one event (Midriak 1984; Kotarba et al. 1987; Krzemień 1991; Kotarba 1994). Distances of transportation vary from a few hundred meters to more than one kilometre. The boulders of the maximum size of 70–150 cm in diameters are moved and deposited in levees (Krzemień 1988, 1991; Kotarba 1989; Krzemień et al. 1995). Therefore, debris flows are most important geomorphic events, which are able to transport waste material from upslope to valley bottom and, this way, connect the slope and valley systems.

A. Kotarba (1992a) states that 25 mm high rainfalls trigger debris flow, however, in his opinion, in the High Tatra 30 mm rainfalls are needed (Kotarba 1994), while P. Janačik (1971) indicates 20 mm rainfalls as debris flow triggers in the Western Tatra. Probability of occurrence of such rainfalls is 5–25% (Cebulak 1983; Kotarba 1992b). Debris flows triggered by the above-mentioned rains affected only the apex part of talus slope. As identified by K. Krzemień (1988), in the period of 1976–1988, such debris flows used to repeat every 1–5 years in particular gullies in the Starorobociańska valley, the Western Tatra.

The size and extent of debris flows depend on the rain total but also on its intensity. The storm rainfall intensity needed to trigger substantial debris flows which affect the whole length of the talus slopes was estimated to be 35–40 mm · h^{-1} (Kotarba 1992a), but not less than 30 mm · h^{-1} and 80–100 mm during 24-hours period. The latest was established based on 20-year long observation series (Kotarba 1997). The momentary intensity during the storm rains is of 1.3–1.7 mm · min^{-1} (Kotarba 1995). Probability of such rainfall events is less than 5% (Cebulak 1983; Kotarba 1992c).

Most of the debris flows triggered by short-time, high-intensity rains occur in subalpine and alpine belts as it is shown in Figure 1 (Kotarba 2002). Long-term rainfalls of low intensity, less than 1 mm · min^{-1}, trigger mudflows and rill-erosion in the zone of the upper timberline, subalpine and upper part of forest belts. According to the studies in the Starorobociańska and Jarząbcza valleys in the Western Tatra activity of debris flows and mudflows causes the upper timberline to descend (Krzemień 1988, 1991; Krzemień et al. 1995).

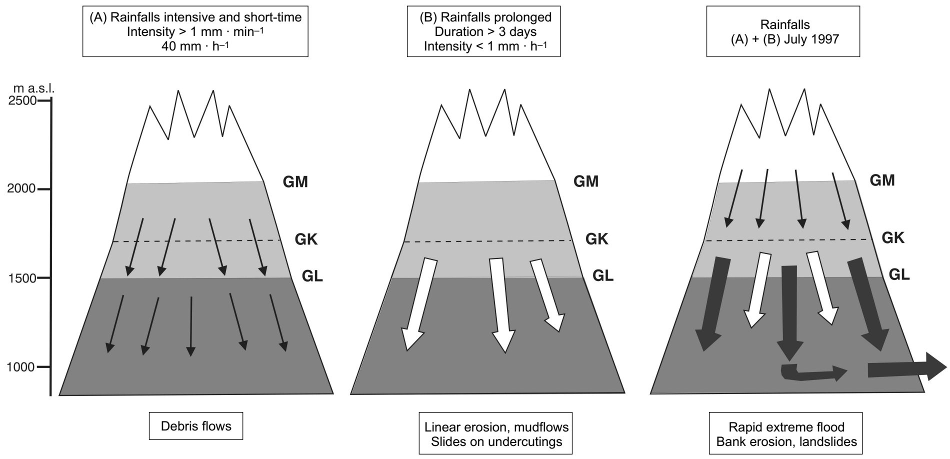

Fig. 1. Relation between rainfall characteristics and dominat geomorphological events within geoecological belts: GM — alpine meadow limit, GK — dwarf pine limit, GL — timberline (after Kotarba 2002)

Frequency of occurrence of the rainfalls triggering debris flows changes much in time, what influenced pattern of evolution of rocky slope/rockwall — talus slope system due to debris flows activity (Fig. 2) and made doubts concerning constant position of transport, erosion and accumulation processes within the track of valley-confined debris flows types.

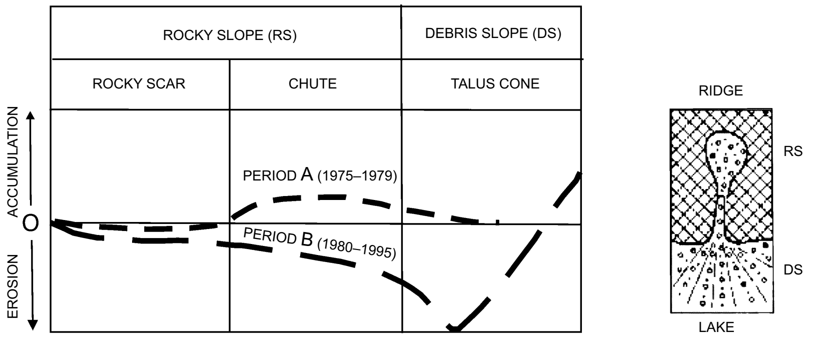

Fig. 2. Simplified sketch illustrating evolution of longitudinal profile of rocky slope/rockwall — talus slope system due to debris flow activity during (A) a calm period with maximum hourly rainfall < 20 mm (1975–1979) and (B) an extreme events period with maximum hourly rainfall > 40 mm (1980–1995). Based on field experiment in the Sucha Woda valley (after Kotarba 1997)

The main difference in frequency of debris flows occurrence is observed between the Little Ice Age (L.I.A.) period and the present. The knowledge of debris flows and other high energy, rapid geomorphic events at that time is based on lichenometric dating and lacustrine deposits analysis in the lakes being in a close connection with the slopes (Kotarba 1995). In the Morskie Oko lake the sedimentation rate, established as 0.37 mm/year during L.I.A., is higher than in other periods of Holocene and in the post Little Ice Age period (Kotarba 1993–1994, 1996a, b). It indicates that it was the time of relatively high intensity of slope modelling by geomorphic hazards. During L.I.A. debris flows occurred more often, their size and energy were larger. They modelled talus slopes from apexes to the base parts (Kotarba 1989, 1991, 1992a, b, c, 1995, 1997, 2004, 2005; Kotarba and Pech 2002; Kaszowski et al. 1988; Libelt 1988). On the Skrajna Turnia slopes, the widths of flows older than 100 years are 10–20 m and their levees consist of boulders of maximum size of 1–2 m in diameter (Kotarba 1991). Based on a number of flow tracks identified in the Sucha Woda valley, the rate of their reoccurrence has been established. The highest, 0.54 per year, is for the period AD 1820–1870, but similarly high frequency 0.55 per year is in AD 1970–1990. In contrary to the above, the number of tracks between 1920–1970 was low (0.30 per year) (Kotarba 1995).

Lichenometry has been employed widely by A. Kotarba to evaluate activity of debris flows during L.I.A. on debris slopes in different valleys in the Polish and Slovak parts of the High Tatra Mts. (Kotarba 1989, 1991, 1992a, b, c, 1995, 1997, 2004, 2005; Kotarba and Pech 2002). Occurrence of debris flows in the last 200 years varies much in particular studied areas, as it is shown by A. Kotarba (2004) in his monograph on L.I.A. in the Tatras. It is shown i.a. in Figure 3, where only the most evident periods of debris flows are compiled.

Generally, since the beginning of the 19th century till the 1930s as well as after AD 1970 high activity of debris flows is documented. According to A. Kotarba

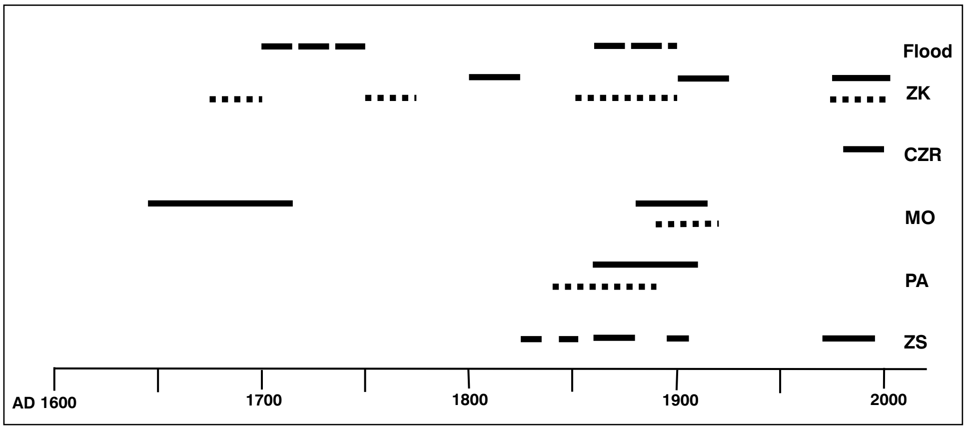

Fig. 3. The main periods of the most intense acivity of geomorphic hazards in the Tatra Mts. Compilation based on the periods as identified by Kotarba (1991, 2001, 2004) and Kotarba and P. Pech (2002). Lines: continuous line — debris flows, dotted line — rockfalls, dashed line — extreme floods. Study areas: ZK — Zelene pleso, Kežmarska valley, CZR — Czarny Staw pod Rysami valley, MO — Morskie Oko valley, PA — Pańszczyca valley, ZS — Zielony Staw Gąsienicowy valley

(2004) debris flows were triggered in majority by intense rainstorms in the period AD 1800–1870, during the final phase of L.I.A.

Individual courses of debris flow activity in particular valleys are probably related to the character of rockwall/rocky slope-talus slopes system and spatially limited by a nature of convective rains.

AVALANCHES

In the Tatra Mts. avalanches are much less recognised geomorphic hazards than the debris flows (Photo 2). Nevertheless, snow avalanches occurrence and frequency were subject of interest for many years as evidenced, for example, by M. Kłapa (1959), M. Kłapowa (1969), K. Chomicz and L. Kňazovický (1974).

The map of snow avalanche tracks in the Slovak part (Stankoviansky and Midriak 1998) and in the Polish part (Krzemień et al. 1995; Kotarba 2002) of the Tatra Mts. illustrates that avalanches are common features in the Tatras and occur disregarding a slope aspect. But frequency of their appearance as well as their magnitude vary. On the map of Slovak part of the Tatras, the number of marked avalanches is a little higher in the High Tatras than in Western Tatras, on the other hand, the avalanches are larger and occur more often in the Western Tatras (Midriak 1996). Even 20 avalanches/year were found in the Chochołowska valley during 1986–1990 (Krzemień et al. 1995) while frequency higher than 2 avalanches/year was identified only in a few places in the High Tatra (Kotarba 2002). Avalanches occur mainly in alpine and subalpine belts.

Photo 2. Dirty avalanche track in the Jalovecká valley (the Western Tatra Mts.)

The avalanche activity, similarly to other rapid morphodynamic disturbances, influences landscape structure at present, i.e. bring about corridors in dwarf pine and forest zones as documented by J. Hreśko and M. Boltižiar (2001) in the Belianske Tatra and by K. Krzemień et al. (1995) in the Western Tatra.

Only the so called dirty avalanches, including rock and wooden debris as well as uprooting trees and dwarf pines bushes, influence landforms (Stankoviansky and Midriak 1998).

Based on the studies in the Chochołowska valley (Krzemień et al. 1995) the relation between slope features and frequency and character of avalanches has been established. On the steep slopes dissected by chutes, a few small avalanches could occur in a year, while on gentler slopes avalanches occur rarely, ≤ 1 avalanche/year. Nonetheless, 50% of avalanches are large and destructive dirty ones.

Dirty avalanches are also indicated as the predominating agents modelling the morphosystems of the Belianske Tatra (Hreško et al. 2005). In the source zone, soil destruction dominates and creates the favourable conditions for consecutive processes such as nivation etc. In the transportation zone, erosional processes prevail. Spot soil covers and uprooting tree occurs in the accumulation zone. Average values of surface lowering due to the scraping of the surface by snow avalanche are from some tenths of mm to 350 mm during one event (Stankoviansky and Midriak 1998).

J. Hreško (1998) gives the formula for calculation of the avalanche hazards intensity (Av) including the following factors: slope gradient, altitude, exposition, shape and surface roughness. Using the formula, the map of avalanche hazards in the Predene Med'odoly valley (the Belianske Tatra) has been devised. The gullies and chutes on slopes of south aspect are mostly affected by dirty avalanches (Hreško et al. 2005).

On talus slopes in the High Tatra dirty avalanches always follow the same tracks as they are topographically constrained. Their most important geomorphic role is erosion of debris from the upper parts of the talus slopes, redistribution in the middle part and deposition at the bases of the slopes. The avalanche debris slopes are smooth and free of microforms. Those slope units are built up by successive events, each supplying new material, which masks the previous surface. The recent events are represented by a greater number of boulders than the older events of the same magnitude (Kotarba and Pech 2002; Kotarba 2004). The snow avalanches generate very high stresses and produce poorly sorted or non-sorted loosely packed debris.

The dirty avalanches contribute to the input of waste material to the lakes, which are in a direct contact with the slopes, for example Morskie Oko or Czarny Staw Gąsienicowy lakes. It caused the increased rate of sedimentation and, at present, the cones with coarse debris and wooden trunks are formed underwater (Kotarba 1996a).

Temporal variability is observed in avalanche occurrence, both in a particular year and in periods of longer, differentiated duration. Most often the avalanches appear between January and May (95%), with maximum (65%) in March–May. Their number can vary form 10 to 33 from the year to year (Krzemień et al. 1995).

Since winter AD 2000, the dynamics and frequency of avalanche activity reach their climax, during the last century as they occur in area not affected for

10 years. In the last 5 years, activity of avalanches increases especially in the forest zone (Hreško et al. 2005).

Drop stones found in lacustrine sediments of L.I.A. indicate accelerated avalanche activity during that time but it is impossible to reconstruct the avalanche activity on talus slopes, as L.I.A. avalanche deposits are fossilised by post L.I.A. depositional landforms (Kotarba 2004).

ROCKFALLS

Rockfalls as relatively rarer, time and space limited geomorphic events, transport rock material, contribute to diminution of rock cliffs and accumulate as boulder and coarse rock debris, often in form of cones. Rockfalls are related to changes of climatic conditions, which promote weathering, or are related to earthquakes (Kotarba 1992c, 1995, 2004). The most spectacular effect of earthquakes was deterioration of the Slavkovský štít summit in the High Tatras, in AD 1662. Localities of contemporary rockfalls are deduced from fresh fragment at rock cliffs, most often occurring in the High Tatra. The older rockfalls seem to be larger as is inferred from the sizes of giant boulders of the order of 1–5 m in diameter deposited at base of talus slopes near Morskie Oko lake (Kotarba 2001, 2004).

The rockfall deposits can be dated for a time span of 500 years using lichenometry (Kotarba 2004). Similarly as debris flows, the activity of rockfalls varies greatly from area to area and from the past to the present (Fig. 3). In the Pańszczyca valley, the more intensive physical weathering and rockfalls are attributed to the period of 1810–1910, with the peak activity between 1840 and 1890 (Kotarba and Pech 2002). Probably, the impulse came from 4 great earthquakes recorded around AD 1840 (Kotarba 1995). The intensified rockfalls occurring on the walls of the Malý Kežmarský štít summit (Slovak High Tatra) were in the periods of 1676–1700, 1751–1775, 1851–1900, 1975–2000 (Kotarba 2004). A lichenometry documented rise in rockfalls in Morskie Oko lake region, is in the first half of the 18th century and at the turn of the 19th/20th centuries, for which periods A. Kotarba distinguishes the phases of intense falls and failures in AD 1900–1920 (Kotarba 2001, 2004; Ferber 2002).

The defined periods mostly seem to correspond with earthquakes events recorded historically (Kotarba 1995, 2004). High frequency of rockfalls at the beginning of 20th century is also climatically conditioned, which is confirmed by T. Niedźwiedź (2004) who evidences distinct climate cooling in the period 1906–1926, with the coldest summer at 1913, since the 16th century.

WIND HAZARDS

Wind is significant morphogenetic agent in the Tatra Mts. (Izamiłow 1984; Kotarba 2002) and the related geomorphic hazards are linked with wind storms. Strong winds occur most often at 1,400–1,600 m a.s.l. Wind storms on northern slopes of the Tatra Mts. are foehn-type winds (Hess 1974), while those on southern slopes are bora-type (Otruba and Wiszniewski 1974; Koreň 2005).

The primary effects are great damages, especially in the coniferous forest. For example, on 6 May 1968, foehn wind with the speed of 75 m · s^{-1} during 4 hours completely damaged 500 ha of the forest, on the northern slopes of the Tatras. The most dramatic damages were found mainly on the slopes where the valleys narrow, at the valley junctions or where the valley direction changes rapidly as the wind streams concentrate there (Kotarba 1970). The greatest destruction was caused by bora winds at 19 of November 2004, when during 3.5 hours 12,000 ha of forest were completely fallen (92% of the devastated forest was coniferous), on southern slopes of the Tatra Mts in the zone between 600 and 1,500 m a.s.l., where the wind speed was the highest, reaching 200 km · h^{-1}. Similar bora wind storms were recorded in the same zone every few years or tens of years in the recent past, the oldest ones in 1835, 1855 and 1898 (Koreň 2005).

A huge destructive geomorphic work is done indirectly during wind storms, and it is known under the name "fallen tree driven denudation". The enormous amount of fine and coarse weathered material, up to 50,000 m^3 · km^{-2}, might be heaved on uprooted or deadfall trees by 0.39 m at average and moved over relatively short distances, up to 1 meter. The effects of such denudation were assessed to be significantly larger than in the case of other processes acting in the forest environment during a whole year (Kotarba 1970). During the bora events at November 2004 up to 6,000,000 m^3 of weathered material might have been moved, as could be calculated using rates estimated by A. Kotarba (1970).

Wind storm events resulted in specific slope microrelief — domes and hollows, which exist for a long time, however do not cause acceleration of slope processes (Kotarba 1970). The latest might be confirmed by monitoring of morphogenetic processes in the area affected by bora events in 2004.

FLOODS

Average floods, triggered by summer precipitation or snow melting in spring, model the relief of valley bottoms and river channels in a very limited degree (Kaszowski 1973; Kaszowski and Krzemień 1979; Krzemień 1985, 1991).

The distinct and spectacular changes in the relief of the valley bottoms and river channels are related to extreme floods like those of 1973 or 1997, caused by catastrophic rainfalls, characterised by enormously high totals during a few days (for example 330.3 mm on 4–8 July 1997 or maximum of 422 mm recorded at the upper timberline at Hala Gąsienicowa on 16–18 July 1934).

During the events in July 1997 the continuous low intensity rainfall preceded heavy high intensity storms of the final stage when the total of 223.5 mm was recorded during 18 hours (Kotarba 1998b, 1999). The effects of such precipitation pattern bring about geomorphic effects in the middle-mountain forest belt of the Tatras (Fig. 1.) and such precipitation can be treated as another rainfall threshold (Kotarba 2002). The precipitation effects are noticed both in channels and valley bottoms as well as on the slopes in the forest belt

(Kotarba 1998a, b, 1999), yet only a few debris flows appeared above the timberline.

The geomorphic effects of catastrophic floods were recorded in whole Tatras, but with different spatial intensity (Kaszowski and Kotarba 1985; Kotarba 1999; Zawiejska 2002).

Extreme floods triggered, as the bedload, the material of the size from 0.2–0.6 m in diameter (in June 1973) up to 2.0 m in diameter (in July 1997) and moved it for a distance of 20–40 and 20–30 m, respectively (Kaszowski and Kotarba 1985; Kotarba 1998b). The events accompanying the flood of July 1997 evidence that fluvial processes during such floods are of debris flow type, and wooden debris and trunks are transported in the channels of main streams as well as in small tributary streams. Formation of new channel systems, channel widening by undercutting of moraine levels and fluvioglacial terraces and development of systems of boulder levees showing imbrication features are possible. At the same time, on the slopes the weathered materials were washed out together with whole trees (Kotarba 1998a, b, 1999). In non-glaciated valleys, the channels are eroded during the catastrophic floods (Kaszowski and Krzemień 1979; Kotarba 1999).

The flood of 1997 was a real geomorphic hazard as many mountain local roads (even those reinforced with gravel), forest pathways, tourist trails and bridges were destroyed by erosion or covered with rubbles. Total losses were calculated to be as high as 1.75 millon USD (Kotarba 1998a).

Occurrence of catastrophic floods and rainfalls during L.I.A. in the Tatras and adjacent basins was recognised based on historical notes and documents. Most frequently, spectacular floods happened between AD 1700 and 1750 and were related to extreme summer precipitation (Fig. 3). The greatest floods were synchronic with the severest climate cooling and correspond well with major volcanic eruptions. It was in following years: 1662, 1712, 1813, 1882, 1934, 1973. It is worth to notice that the period AD 1850–1990 is the time of the greatest weather anomalies since the 16th century, when catastrophic floods happened most often (Kotarba 2004).

CONCLUSIONS

Geomorphic hazards seem to play the most important role in the recent modelling of relief in the Tatras as they resulted in new landforms development or in distinct reshaping of the affected forms. The debris flows and extreme floods are the phenomena capable of exerting long-lasting geomorphic impact both on slopes and valley bottoms. It refers to rockfalls even if they are more rare events. The effects of avalanches are less pronounced as they are much more controlled by topographical and environmental factors. The changes resulting from particular geomorphic hazards are visible in the landscape for a long time.

Extreme weather events and tectonic events are main agents triggering geomorphic hazards in the past and recently.

The whole area of the Tatras is affected by the geomorphic hazards but of a great spatial and temporal variability. In the area above the timberline all discussed geomorphic hazards occur, while in forest zone mainly the effects of floods and wind hazards are stated.

Usage of lichenometry, the lacustrine sediments analysis and historical sources allowed to evidence the higher frequency and magnitude of geomorphic hazards in the Tatras during L.I.A. and to indicate linkage with environmental factors conditioning them. However, further studies seem to be needed for a more precise determination of the phases of activity and for evaluating the role of climatic and human factors.

The spatial distribution of the extreme events is still inadequately recognised. The territorial extents of a singular downpour or a geomorphic event are not exactly known as well as continual recording of new events, e.g. debris flows or avalanches are missing. Advanced new techniques, e.g. GPS, GIS or repeatable air photos might be used for that purpose. Recognition of the spatial variability and repeatability of events is important from the global climate change perspective. At the same time, the intensified tourism in the mountains in various seasons in the recent years, practically in any part and under any climatic conditions, the better recognition and prediction of abrupt geomorphic events becomes more and more important from practical point of view.

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STRESZCZENIE

Zofia Rączkowska

WSPÓŁCZESNE GEOMORFOLOGICZNE ZAGROŻENIA W TATRACH

W artykule, na podstawie publikowanych wyników dotychczasowych badań, przedstawiono stan poznania charakteru i przebiegu gwałtownych, ekstremalnych zdarzeń geomorfologicznych, powodujących stałe lub długotrwałe zmiany w rzeźbie. Do tych zdarzeń zaliczono spływy gruzowe, lawiny, obrywy, silne, huraganowe wiatry i powodzie ekstremalne. Analizowano ich działanie w powiązaniu z uwarunkowaniami środowiskowymi oraz zmienność przestrzenną i czasową, uwzględniając okres małej epoki lodowej. Ekstremalne zdarzenia geomorfologiczne są najważniejszym czynnikiem zmieniającym współcześnie rzeźbę Tatr, gdyż ich działanie trwale zmienia rzeźbę lub powoduje powstanie nowych form, a ponadto przemieszcza duże masy zwietrzelin, łącząc systemy stokowy i korytowy. Wśród tego typu zdarzeń największe znaczenie mają spływy gruzowe i powodzie oraz obrywy. Skutki huraganów obserwowane są głównie w piętrze leśnym. W okresie końcowym małej epoki lodowej wielkość i częstotliwość ekstremalnych zdarzeń geomorfologicznych była większa.