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TOMASZ FERBER (KRAKÓW)

THE AGE AND ORIGIN OF TALUS CONES IN THE LIGHT OF LICHENOMETRIC RESEARCH. THE SKALNISTY AND ZIELONY TALUS CONES, HIGH TATRA MOUNTAINS, POLAND

Abstract. Gravitational talus heap and alluvial talus cone are identified in the Dolina Rybiego Potoku valley, High Tatra Mountains. The age analysis of the slopes indicated that morphogenetic processes were particularly active before AD 1880. At the time, the entire surfaces were subject to rockfall activity (Skalnisty Piarg) and debris flow activity (Zielony Piarg). A phase involving selective dissecting and/or build-up of earlier features began after 1880. Contemporary morphological activity is mainly associated with the reworking of debris flow deposits.

Key words: talus slope, debris flow, rockfall, lichenometry, Little Ice Age, High Tatra

INTRODUCTION

Talus cones in the Polish High Tatras are typical alpine features. Located beneath drops up to 800 m high they have evolved during the 12 thousand years since the melting of the Rybi Potok valley glacier. The postglacial evolution of cliffs and talus cones has continued till the present day, as evidenced by sets of features of various ages. Two types of slopes evolved as a result of selective cliff weathering and retreatment due to mass movements, gravitational talus slopes and debris flow slopes. The research project in the area of the Morskie Oko lake aimed to identify the geomorphologic processes dominant in slope transformation and their peaks of activity over the last 300 years. To this end, lichenometric dating of talus cones was applied.

STUDY AREA AND METHOD

The Skalnisty and Zielony Piarg talus cones are located within the cirque of the Morskie Oko lake, at the head of the Dolina Rybiego Potoku valley. Within the crystalline core of the highest part of the Polish Tatras (Fig. 1), the cirque is formed in granodiorite, as well as pegmatite and aplite granites. The

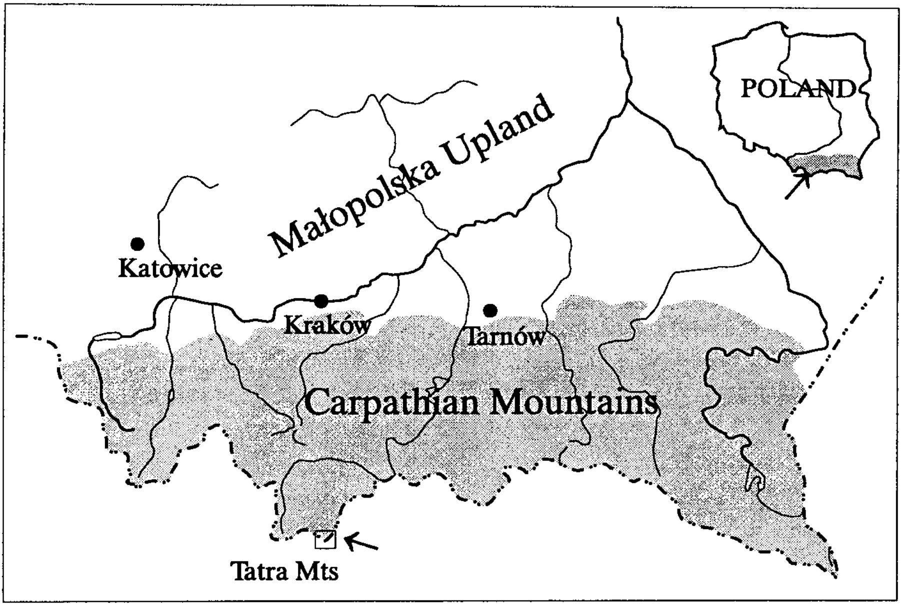

Fig. 1. Location map of the study area

main features of the ground relief follow the tectonic lines. The axis of the Rybi Potok valley is related to the main fault line. In the highly resistant to weathering rocks of the High Tatras, erosion processes work selectively concentrating on joints and faults. Mylonite zones located there are susceptible to the development of mountain passes and most of the gullies are set on joints. The gullies end with talus cones. The contemporary land relief of the High Tatras owes most to the pre-glacial land relief, the mountain glaciation during the Pleistocene and to the long-term exposure to the periglacial climate. As a result, a typical set of high-mountain features evolved including steps of post-glacial circuses, U-shaped valleys and steep undercuts in glacial throughs. The glaciers retreated during the Holocene, leaving moraine and glacifluvial formations behind. Currently, the principal role in modelling of slopes is played by gravitational processes involved in frost weathering and the effects of moving water. These processes result in rock falls, as well as debris and debris-mud flows (Fig. 2).

The Zielony and Skalnisty talus cones are located at the foot of the Mięguszowiecki Szczyt Wielki peak, with their apexes at 1,600 m, and surround the southern banks of the Morskie Oko lake at 1,395 m. The Zielony Piarg talus cone comes out of a gully at the Mały Mięguszowiecki cirque, whilst the Skalnisty Piarg cone is located at the base of a relatively under-developed 300-m cliff-face of the Mięguszowiecki Szczyt Wielki peak. The research area is located across the line separating the forest and the Alpine zones. In the High Tatras, the dwarf mountain pine is represented by *Pinetum mughi carpaticum salicicolum*.

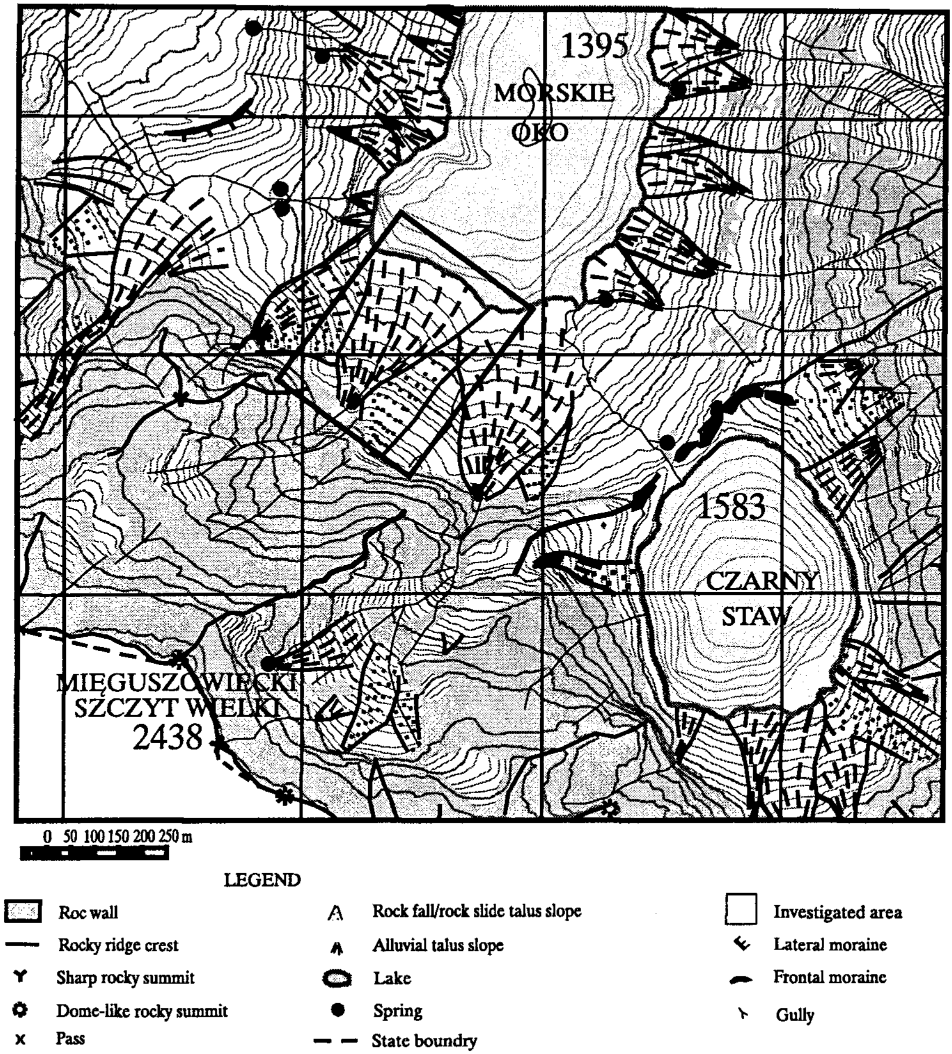

Fig. 2. Geomorphological map of the study area. Morskie Oko Lake and its environs, after M. Klimaszewski (1978)

However, due to the intensive slope processes most of the talus cone surface cannot sustain trees and the dwarf pine only grows on the lower inactive or periodically active parts of the cones. At the foot of the Mięguszowiecki Szczyt Wielki, the forest line can therefore be recognized as naturally lowered to 1,400 m (Photo 1).

The typical vegetation growing on debris is limited and consists of some dozen species, each necessarily capable of inhabiting moving rocky material. Species found at the Skalnisty and Zielony cones belong to the typical low-calcium carbonate debris vegetation (*Oxyrio Saxifragetum Carpaticae*) and granite

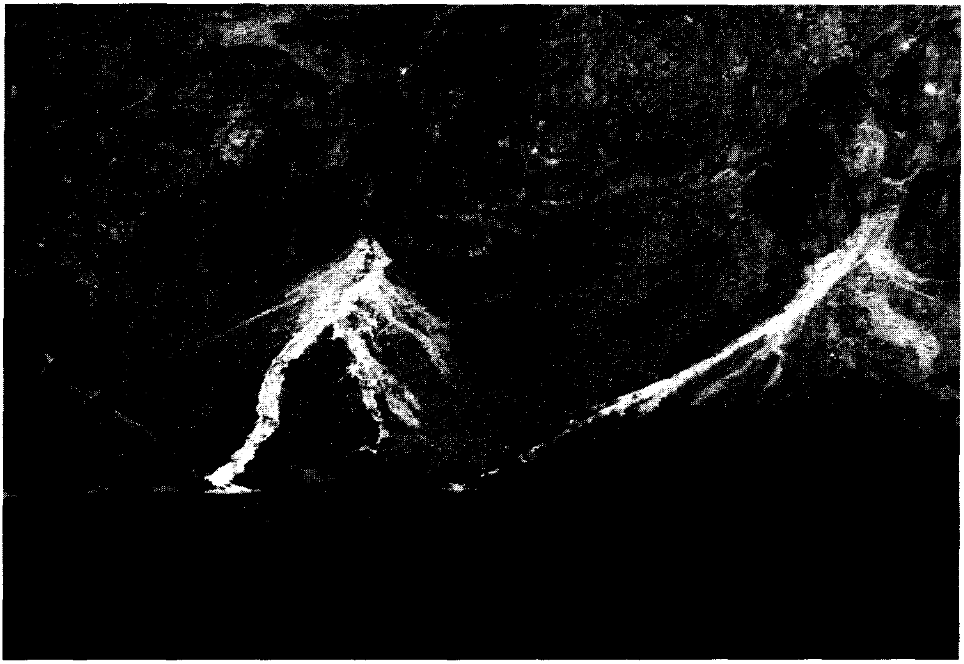

Photo 1. General view of the study area. Skalnisty Piarg (rockfall/rockslide slope) is located in the centre, while Zielony Piarg (alluvial talus cone) on the right side. On the left side of the photo a very fresh debris flow track was formed during August 2001 (Szeroki Piarg)

debris vegetation, predominately lichens and *Calamagrostion* and *Adenostylliariae* grass (Piękoś-Mirkowa and Baryła 1985). The lichenometric method was employed during the research to determine the absolute age of the rock surface and land features. The method is based on the fact that the largest lichen thalli are indicative of the age of the surface they grow on, starting from the time it was colonized by the organisms (Beschel 1950). The slowest growing lichens are the best indicators, and in this case the *Rhizocarpon geographicum* and *Rhizocarpon alpicola.* Because of the varied rate of growth of the lichens, depending on humidity and temperature, each of the study areas should have a separate growth curve illustrating the relationship between the maximum lichen size and their age. A. Kotarba (1988) developed a lichen growth rate curve for the very cold vegetation belt in the High Tatras. The curve follows the equation A = Ld + 4.87/0.429, whereby A is the age of the lichens in years and Ld is the average maximum thalli diameter in mm.

To understand the distribution of the land features I first mapped all the features within the investigated slopes. Then, set out transversals on each of the slopes by dividing them into stretches of the same origin was established. In order to ascertain the slope age along each of the stretches, five maximum lichen thalli of the type *Rhizocarpon* were measured. The average maximum values of the five lichens provided the values representing given stretches of the slope. For the

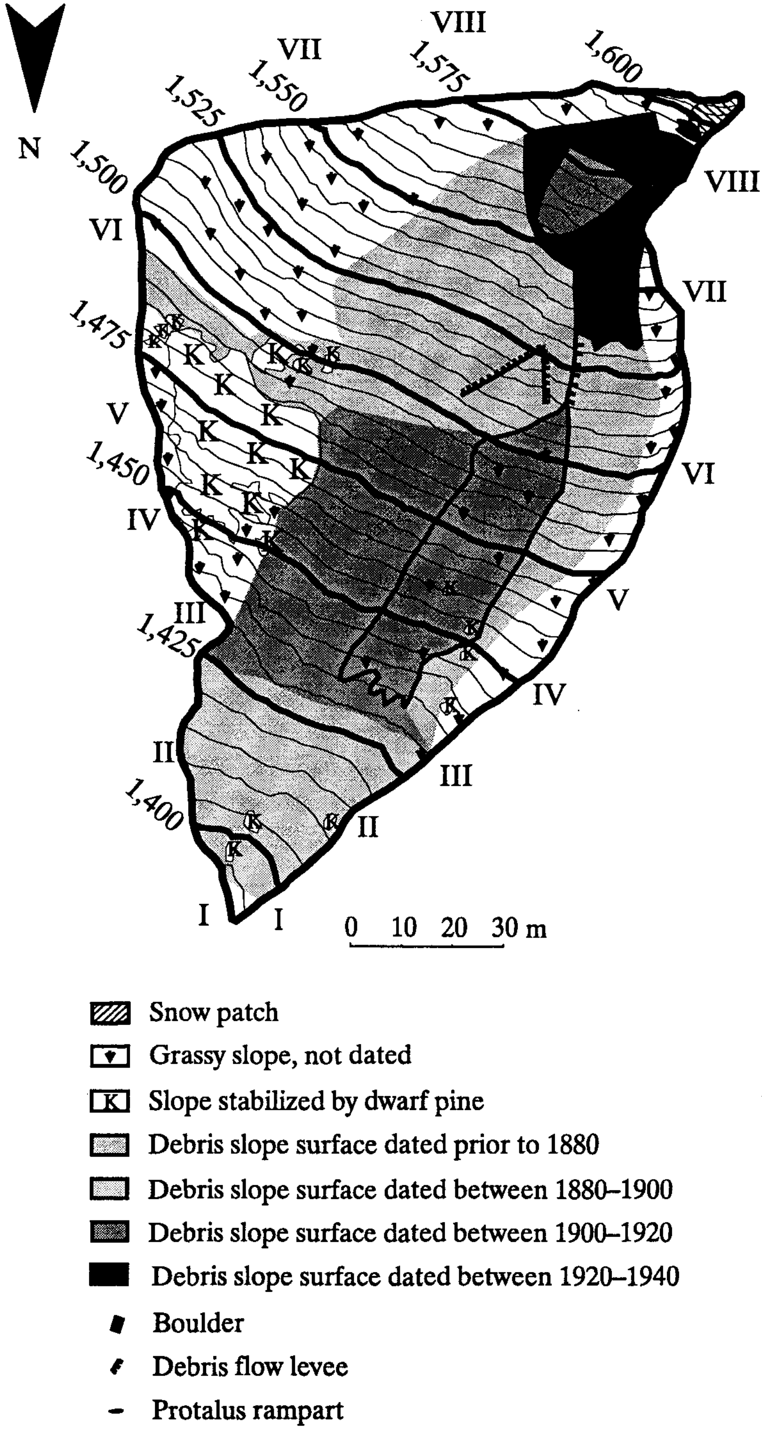

Fig. 3. Skalnisty Piarg slope. Age of debris slope surfaces dated by lichenometry

Table 1

Percentage of slope surfaces dated by lichenometry on the Skalnisty Piarg

Time intervals	Trasversal I [%]	Trasversal II [%]	Trasversal III [%]	Trasversal IV [%]	Trasversal V [%]	Trasversal VI [%]	Trasversal VII [%]	Trasversal VIII [%]
Prior to 1880	100							
1880–1900		100		17	28	36	28	
1900–1920			100	49	44	13		
1920–1940							20	61
1940–1960							52	
1960–1980								
Fresh								
Not dated				34	28	51		39

Table 2

Percentage of slope surfaces dated by lichenometry on the Zielony Piarg

Time intervals	Trasversal I [%]	Trasversal II [%]	Trasversal III [%]	Trasversal IV [%]	Trasversal V [%]	Trasversal VI [%]	Trasversal VII [%]	Trasversal VIII [%]	Trasversal IX [%]	Trasversal X [%]
Prior to 1880	6		12	3						
1880–1900		21	28	10						
1900–1920	13	16	9	26	9			29		
1920–1940	8	16	22	10	14	47	50	46		
1940–1960		10	8	19	46	21	7			
1960–1980					2	7				
Fresh	28	37	21	32	29	25	43	25	53	50
Not dated	45								47	50

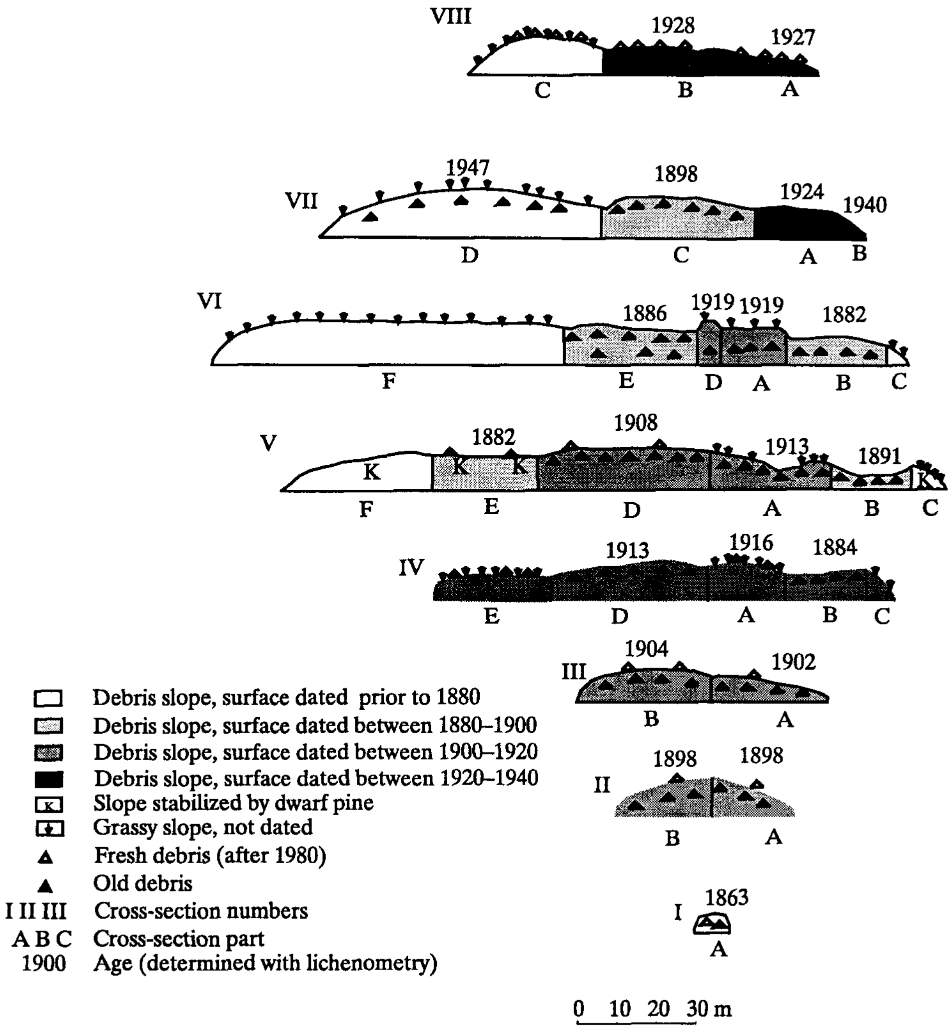

Fig. 4. Skalnisty Piarg slope. Transversals across the slope and lichenometric age of subunits

average results, the age of land features was broke down into 20-year periods and received land features with the same origin and similar age (Fig. 4). Drawing maps of the two cones with features on their surface and the estimated age (Figs. 3 and 5) concluded the cartographic part of the project. This information provided the basis for the reconstruction of the last 300 years of the development of the slopes.

RESULTS

The Skalnisty Piarg is a heap of material supplied chiefly from the weathering cliffs above, in the form of individual pieces of rock or large rockfalls. In the investigation of the selected features with the lichenometric method I had to limit myself to surfaces inhabited by *Rhizocarpon*. Surfaces unoccupied by lichens or grown-over by dwarf mountain pine have not been dated.

The largest portion of the Skalnisty cone dated back to 1880–1900 with just some 1920–1940 surfaces located at the end of the gully, at the foot of a cliff of the Mały Kocioł Mięguszowiecki cirque. Some 120–210 m away in a straight line from the gully a large portion of the slope covered with rock fall material dated to 1920–1940 is found. A large part of the cone's surface has not been dated as it was overgrown with vegetation (Figs. 3 and 4).

Table 1 shows that the longer the distance from the rock cliff, the older the material. The closer to the cliff, the less datable surfaces. This is a result of a vertical lite-rock cliff directly above the talus cone which prevents the debris falling from the top part of the Mięguszowiecki Szczyt Wielki cliff from being deposited directly at its foot. A number of boulders up to 100–500 cm in size are found at the base of the cone. They date from 1700–1750 and from the beginning of the 20th century, with one boulder dated to the mid–15th century (Kotarba 2001). This material came from huge rock falls from the upper parts of the northern face of the Mięguszowiecki Szczyt Wielki. Across the cone's surface, there are younger isolated boulders dated to 1900–1920, up to 600 cm in size, and one boulder unoccupied by lichens, 800 cm in diameter. A nival wall was built of fresh material accumulated at the base of a permanent patch of snow, at the foot of the rocky cliff.

The Zielony Piarg is chiefly modelled by debris flow. The surface of this alluvial talus cone displays a vertical age variation. The transversals nearest to the rocky cliff (nos. IX and X) revealed only recent material (no lichens) or surfaces not dated due to the snow cover. At the bottom of the cone (nos. I and II), a large portion of surfaces was not dated due to growing vegetation (up to 45%). The proportion of non-dated surfaces at the foot of the cone is even higher at more than 90% (measurement impossible; Table 2). The percentage of surfaces with recent material (still uninhabited by lichens) drops from 50% in transversal X to 28% in transversal I. In the middle part of the cone, the recent material lies on top of the older and dominates, which is not reflected in the table. The large proportion of surfaces unoccupied by lichens in the upper and middle part of the cone is due to the introduction of the fresh forms developed after the debris flows in the right-hand part of the cone and from a rock fall spout in the left-hand part (Fig. 5).

There is no rock fall spout in the lower part of the cone, which reduces the proportion of recent surfaces to 28%. The material found in the left-hand part of the cone comes from several rock falls of various ages. The latest

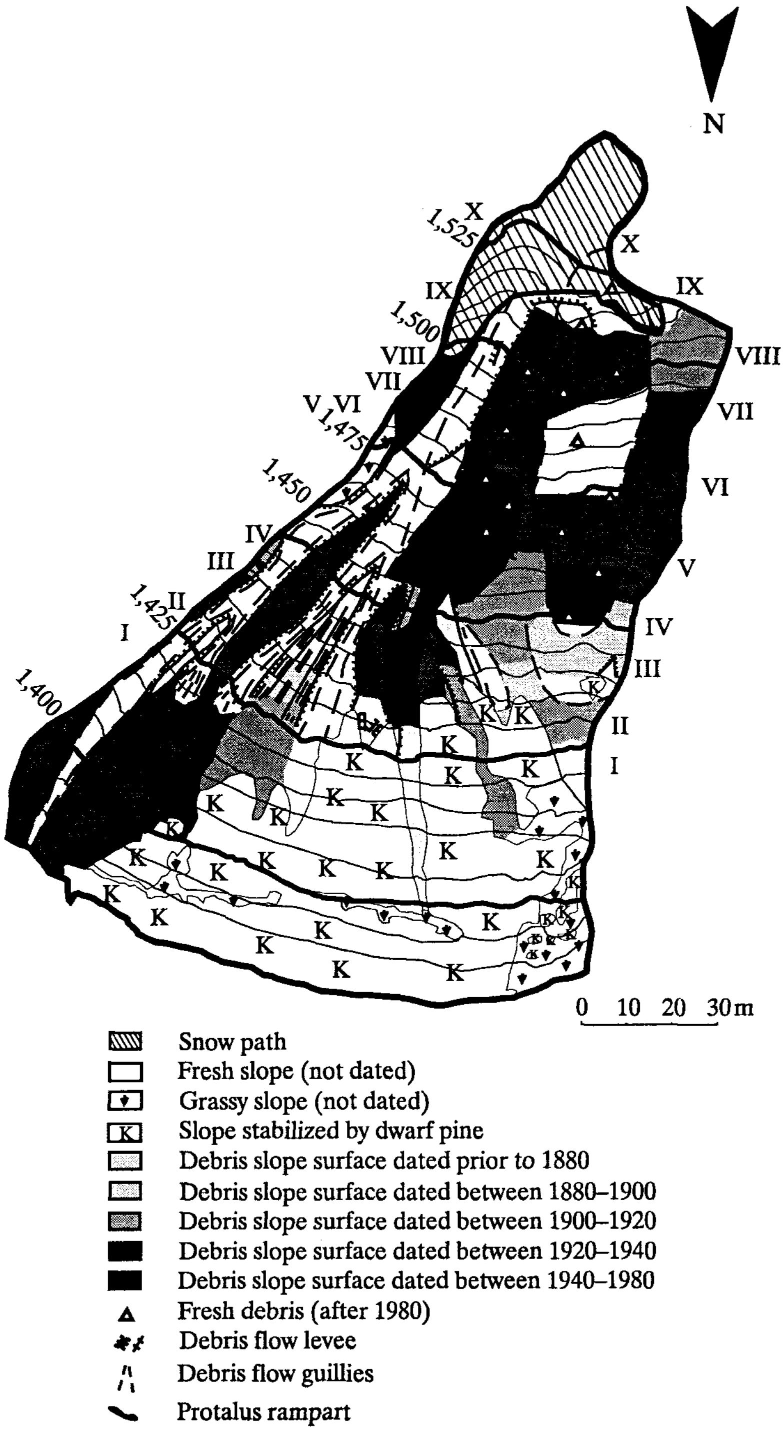

Fig. 5. Zielony Piarg slope. Age of debris slope surfaces dated by lichenometry

occurred on 23 May 2000, with its spout present on the cone's surface in the form of recent material (Fig. 5). Beneath this fresh material there is older material dating back to 1925–1945. Below the 2000-dated material, there is older and larger-sized material dated to 1880–1890. Further down, the cone surface is grown over with dwarf mountain pine and cut up by old debris flow chutes, dated to 1880–1915. Currently, no processes related to running water or accumulation of the rockfall material occur in this part of the cone. The material located in the right-hand part of the cone is subject to displacement by debris flows. New debris flow chutes and levees, inserted in the old ones dated to 1880–1920, dominate the area. The new chutes are some 220-m long and the chute at the side of the cone runs all the way to the cone base. The upper part of the Zielony Piarg cone is currently modelled by debris flows and the accumulation of debris from rock falls, which build new land features superimposed on the old ones. These processes do not, however, apply to the lower left-hand part of the cone, which is only subject to one process covering the entire surface of the cone, i.e. wintertime avalanches.

DISCUSSION

The age analysis of the cones indicated that morphogenetic processes were particularly active before 1880. To this period is dated material found at the base of the Skalnisty Piarg. At the time, the entire surface of the Zielony Piarg cone was subject to debris flows. Research by A. Kotarba (1988) in the Hala Gąsienicowa area discovered frequent debris flows during 1826–1835, 1843–1852, 1862–1870 and 1883–1890. Alpine research also confirms the occurrence of huge floods, landslides and debris flows during 1550–1850 (Govi 1984, Grove 1988).

Sources quote research on various regions pointing to cooling periods during 1780–1825 characterized by advancing glaciers in the southern (Birkenmajer 1979), as well as the northern hemisphere. The Little Ice Age made clear marks in the Rocky Mountains (Luckman 1977, Luckman and Fiske 1995) and in Europe. The climatic condition of the Little Ice Age in the Scandinavian Mountains resulted in the advance of glaciers (Grove 1988, Eriksted and Sollid 1986, as well as in increased rates of rockfall (McCarroll et al. 2001). While in the research areas around the Morskie Oko lake in the Tatras debris flows did not have any important impact, rockfalls did occur onto both cones during 1880–1900. Rockfall material covered most of the Skalnisty Piarg cone and the left-hand side of the Zielony Piarg cone. Both a surface found in the middle of the Skalnisty Piarg and some evidence of the effects of running water on the Zielony Piarg date to 1900–1920. During 1920–1940, a small rockfall took place on the Skalnisty Piarg and a large one on the Zielony Piarg covering the 1880–1900 material. At that time debris flow chutes and walls evolved running all the way to the base of the cone. No larger features younger than 1940 are found on the Skalnisty Piarg, with just isolated pieces of rock that fell off the cliffs during the last 60 years. Some of this material was dislodged by mountain climbers. During 1940–1960, more rockfalls occurred with material deposited on the left-hand side of the the Zielony Piarg cone, some 120-m from the cliff. No major debris flow chutes evolved during this time.

Beginning from 1940, there have been no debris flows, which would cover the whole surface of the cone. The contemporary flow chutes found on the Zielony Piarg follow the old chute systems in the right-hand side of the cone. Runoff from heavy rains can reach the base of the cone. On 23 May 2000, the latest rockfall on the Mięguszowiecki Szczyt Wielki peak occurred onto the Zielony Piarg. The spout covered older rockfall remains.

During field research in July 2001, following a spell of rain which triggered flooding in many areas of the country, no new features related to debris flow or rockfalls on either of the cones were found, but the chutes on the right-hand of the latter had been deepened by debris flows. However, were found a new debris flow chute on the left-hand side of the adjacent Szeroki Piarg cone. At the beginning of August, a new chute developed within the one that had formed in July, after a very heavy rainfall in the Morskie Oko area (ca 100 mm in one day). The debris flow run all the way to the Morskie Oko lake having destroyed a fragment of a tourist path in the process (Photo 1). Again, just as in July, no new features were formed or old remodelled on the researched cones. This might indicate that not even a strong stimulus can trigger a geomorphologic force capable of considerable slope transformation by debris flows, unless there is sufficient material ready for displacement in the gully (Kotarba 1992).

The Skalnisty and Zielony talus cones are representative for very cool and temperate cold zone slopes (MAAT from +2°C to 0°C), for the Morskie Oko area and the entire High Tatras. Normally, debris talus cones and alluvial talus cones located in these zones are large (up to 400 m long) and allochtonous, i.e. they are built of material that originated in the higher geoecological zones (Kotarba and Strömquist 1984). Herbage and dwarf mountain pine coves the lower slopes, which are not currently undergoing transformation by gravitational processes.

In the higher geoecological belts (cold and very cold climate belt; MAAT 0°C to –4°C, according to Hess 1965), not covered in the paper, there are autochtonous cones; smaller, they are active and free from vegetation. In the cool belt (altitudes 1,150–1,550 m), the slopes are stabilized by tree vegetation and transformed chiefly along slope chutes during particularly heavy torrential rains (valley confined debris flows) or as a result of mud avalanches. During lesser intense gravitational processes, slopes tend to overgrow with herbage followed by dwarf mountain pine.

CONCLUSIONS

In the research area covering one glacial cirque, talus slopes of different origin and age were found. After climate, the principal factor influencing the development of talus slopes was the land relief above such slopes. It can cause the falling material, or water, to concentrate or disperse, thus influencing the slope modelling processes.

Changes to climatic conditions that took place between the melting of the glaciers and today, had an impact on the intensity of the gravitational processes. The lichenometric method used to identify periods of intensified processes related to the force of gravitation and to running water over the last 300 years, yielded one such period which ended around 1880. While the rockfall/rockslide slope was modelled along its full length before 1880, its largest surfaces are dated to 1880–1900. Generally, the greater the distance from the cliff, the older the material. The great variety of dated surfaces within the alluvial talus cone leads to the conclusion that intensive modelling took place along the full length of the slope, i.e. from the cliff to the base, at the end of the Little Ice Age. A phase involving selective dissecting and/or build-up of earlier features began after 1880. Only the apex unit has been fully rejuvenated and the contemporary debris flows model the entire length of alluvial talus cones only very occasionally.

The limited time-period to which the lichenometric method can be meaningfully applied, prevented the identification of the beginning of intensive modelling of the entire slopes, ascribed to different thermal and humidity regimes of the Little Ice Age. Other sources, however, point to the beginning of the 15th century. Only on the rockfall/rockslide slope during 1880–1940 did isolated rockfalls and debris flows occur, which covered large portions of the slopes. The contemporary debris flows over the last 30 years follow the old chutes. They seldom compare to the scale of features evolved during the Little Ice Age.

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Department of Geomorphology
Institute of Geography and Spatial Economy
Jagiellonian University
31-044 Kraków, ul. Grodzka 64, Poland

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STRESZCZENIE

T. Ferber

GENEZA I WIEK STOŻKÓW PIARGOWYCH W ŚWIETLE BADAŃ LICHENOMETRYCZNYCH NA PRZYKŁADZIE SKALNISTEGO I ZIELONEGO PIARGU (TATRY WYSOKIE)

Skalnisty i Zielony Piarg, dwa stoki znajdujące się w cyrku lodowcowym Morskiego Oka zostały poddane badaniom geomorfologicznym mającym na celu określenie sposobu ich modelowania w okresie ostatnich 300 lat. Dla określenia wieku tych stoków piargowych zastosowano metodę lichenometryczną, stosując krzywą wzrostu porostów *Rhizocarpon.* Generalnie stwierdza się, że z odległością od ścian skalnych materiał budujący hałdę grawitacyjną jest starszy. Na całej długości Skalnistego Piargu występuje materiał składany przed rokiem 1880, chociaż największą jego część zajmują powierzchnie datowane na lata 1880–1900. Natomiast na stoku aluwialyjnym

Zielonego Piargu stwierdzono, że podczas końcowej fazy małej epoki lodowej miało miejsce intensywne modelowanie na całej długości, tj. od ściany do podstawy stoku, będącej równocześnie linią brzegową jeziora. Po roku 1880 rozpoczął się okres selektywnego rozcinania i nadbudowywania trwający do dzisiaj. Całkowite odmłodzenie starych powierzchni stożka obserwuje się tylko w części przyścianowej, a współczesne spływy gruzowe, powstałe w ostatnich 30 latach wykorzystują stare rynny i tylko sporadycznie dorównują swą wielkością formom utworzonym podczas małej epoki lodowej.