THE AGE OF DEBRIS SURFACES ON THE ŻÓŁTA TURNIA PEAK (THE POLISH TATRA MTS.)

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Debris cones have been the object of interest of geomorphologists for many decades. Their surface reflects in general climate changes (Baumgart-Kotarba and Kotarba 2001b, Kotarba 1995, 1996b, 2004 and 2007). Thanks to the method lichenometric dating and visual interpretation of airphotos it became possible to date the development of debris surfaces. The object of this research was a debris cone located on the western slope of the Zółta Turnia Peak in the upper section of Dolina Suchej Wody Valley in the Polish part of the High Tatra Mts. The aim of this work was to determine the age of the surface of the debris cone studied and the periods of increased activity of debris flows. The investigations were based on lichenometric dating and visual analysis of airphotos, which were systematically taken during last 50 years. The results of the investigations show that there were two stages of colluviation of studied debris flow gullies, in the last two centuries. The first stage was connected with the Little Ice Age (until the beginning of the 20th century) and with intensive precipitation mainly in the 1930s (especially 1934). In the second part of the 1940s, the stabilisation of the debris cone surface occurred which lasted until the mid 1980s. In 1986, the colluviation of the debris cone occurred again. Because of secondary generations of thalluses and their interlacing, it was impossible to determine the age of the oldest surfaces of the debris cone. Basing on the largest living thalluses, but not the oldest, it was found that the surfaces studied originated at least 200 years ago. It was also determined that the channels of debris flows which occur in the surface of the debris cone studied, were frequently, and often in different time, used for material transport.

Key words: the High Tatra Mts., debris flows, lichenometry, airphotos

INTRODUCTION

The debris slopes of the Tatra Mountains have been modelled since the last glaciation which ended in the Tatra Mts. about 12 – 13 thousand years ago. In the high located cirques, the glaciers might have preserved even until Vene-diger, i.e. 8,300 years ago (BAUMGART-KOTARBA and KOTARBA 1993, 2001a and 2001b). Since that time, the results of rapid hydrome-teorological events in form of debris flow have been uninterruptedly recorded. The periods of the increased frequency of the occurrence of rapid hydrometeorological events refer to climate changes (KOTARBA 2004 or NIEDŹWIEDŹ 2004).

Since the second part of the 1950s, the investigations on present – day morphogenetic processes have been carried out by the Research Station of Institute of Geography and Spatial Organization of Polish Academy of Sciences at the Hala Gąsienicowa (KŁAPA 1963, 1966 and 1980 or KOTARBA et al. 1983). Since 1975, detailed investigations on spatial differentiation of geomorphological processes intensity within high-mountain slopes started. Taking into consideration diversity of slope forms and covers, and their different stabilisation by vegetation, only some fragment of slopes were selected for investigations, including:

- the northern slope of the Skrajna Turnia Peak
- the western slope of the Żółta Turnia Peak
- the south-eastern slope of the Uhroć Kasprowego (from the Sucha Dolina valley to the Kopa Magury Peak)
- the south-eastern near-plateau slopes of the Kopa Królowej Małej Peak

These investigations were carried out until 1980 (KOTARBA et al. 1983 or KOTARBA 1984).

Later, in some of the mentioned above sites including also eastern slopes of the Kościelce Peak and western slopes of the Granaty Peak, only sporadic investigations of debris flows were carried out, which were concentrated to photographic monitoring of slopes and detailed measurements of newly developed debris flows (KOTARBA 1989, 1992a, 1992b, 1994, 1995, 1996a, 1997 and 2007 or KOTARBA et al. 1987). Apart from the upper part of the Hala Gąsienicowa, similar investigations, concerning among other problems also debris flows, were carried out in the area of the Morskie Oko Lake (KOTARBA and STRÖMQUIST 1984

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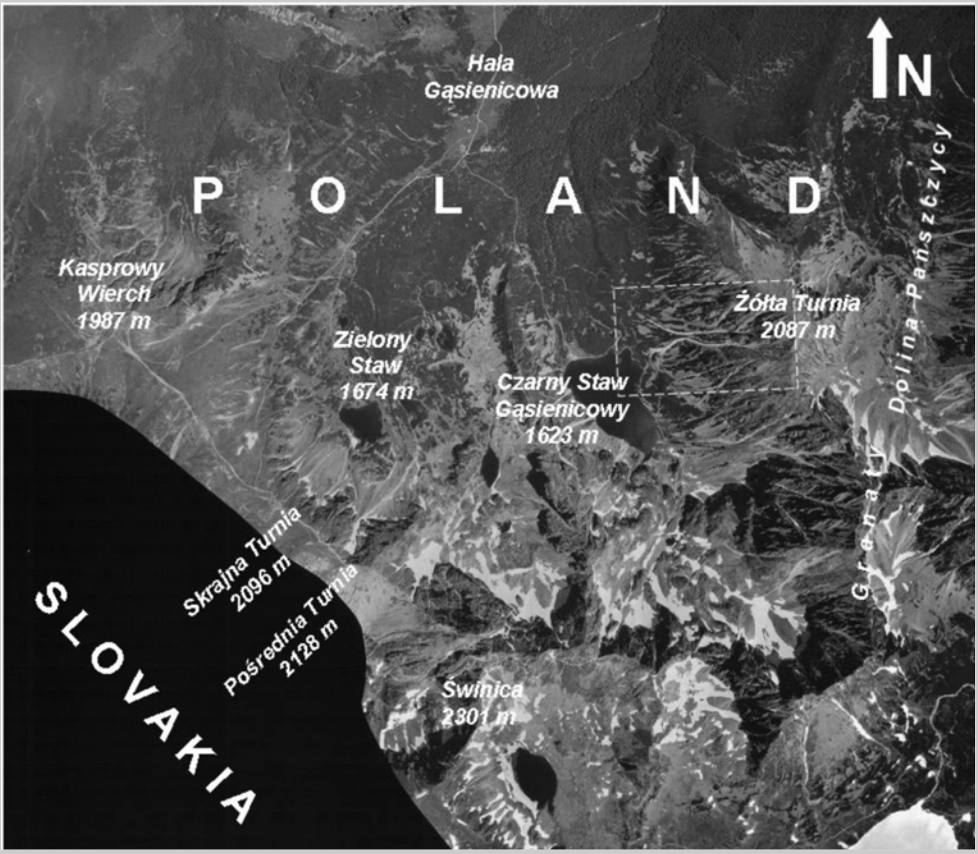

Fig. 1 The upper part of the Dolina Suchej Wody Valley with the study area

or KOTARBA 2004), Dolina Pańszczycy Valley (KOTARBA and PECH 2002), and in the Western Tatra Mts. (KOTARBA et al. 1987, KRZEMIEŃ 1988 and 1989, KOTARBA and KRZEMIEŃ 1996).

The new stage of investigations on the age of debris cones including debris flows, started when lichenometric dating method was applied and lichenometric curve for the Tatra Mts. was established (KOTARBA 1988a and 2001, JONASSON et al. 1999). This method made it possible to determine not only the age of debris cones including debris flows, but also to determine the dynamics of processes responsible for modelling of debris slopes and helped to determine their type. A close distance to meteorological stations (Hala Gąsienicowa 1520 m, Kasprowy Wierch Mt. 1991 m) made it possible to apply meteorological data (especially precipitation) and to estimate threshold values for the occurrence of debris flows (KOTARBA 1992a, 1994 and 2002).

Detailed investigations on debris flows and debris cones with the application of airphotos, lichenometric dating and geophysical studies started in selected valleys in the Tatra Mountains (including the Hala Gąsienicowa) in 2008. The aim of these investigations is to determine the character of climate changes for the last 50 years basing on the analysis of meteorological data and to link them with changes in morphological processes determined from spatial and temporal changeability of relief (erosional) forms located on the slopes above the upper tree limit in the Tatra Mts. The connections of the number and size of debris flows with climate changes have already been investigated for example by KOTARBA (1991, 1992a, 1994, 1995, 1997 and 2004 or KOTARBA and PECH 2002), nevertheless a spatial analysis of these problems (the High Tatras Mts. and Western Tatra Mts.) in different time sections including detailed analysis of meteorological data have never been carried out before. This paper shows the results of investigations on the age of the debris surface located in the western slope of the Żółta Turnia Peak (**Fig. 1**).

THE METHOD

Two methods were applied in the investigations:

a) lichenometric method – both for the debris flows and the debris surface
b) visual interpretation of airphotos which were systematically taken since the mid 1950s - only for dating the debris flows.

LICHENOMETRIC METHOD

The bases of this method were elaborated in the mid 1950s by R. E. BESCHEL (1950), who is often called „the father of lichenometry". He concluded, basing on his field observations, that fresh rocky surfaces exposed to the activity of atmospheric factors, as first become colonised by lichens. Time which passes between the moment when a fresh rocky surface is exposed to atmospheric influence and the occurrence of first lichens depends mainly on atmospheric factors (such as temperature, precipitation, duration of snow cover, insolation), type of a rock and its surface, and species of lichens colonising the rocky surface. There are many conditions which limit the application of this method e.g. a measured surface should not be shaded, it should not be moved as it caused change of the exposition, any chemical substance (e.g. mortar or paint) should not influence the surface. As the time go by, the number of thalluses and their diameter increase. The older thalluses are, the larger their diameter is. Only the largest thalluses, i.e. these which first appeared on the uncovered surface, are important for lichenometric datings.

Lichenometric dating starts from establishing a lichenometric curve, which is prepared basing on lichen thalluses growing on objects of a known age (monuments, buildings, rockfalls, etc.) called a bench mark. The older a bench mark is, the longer the curve is, and also the possibility of dating objects in longer time (i.e. very old forms) increases. The rate of thallus grow during the first 100 years is called a „lichen factor". For the Tatra Mountains, a lichenometric curve with application of lichen species *Rhizocarpon geographicum* and *Rhizocarpon alpicola* was prepared by Polish-Swedish team composed of A. KOTARBA, Ch. JONASSON and M. KOT (JONASSON et al. 1991). The team determined a lichen factor for two climatic vertical zones (according to terminology of HESS 1965) in the Tatra Mountains:

- very cool (1550-1850 m) – 38,1 mm
- temperate cold (1850-2200 m) – 32,5 mm.

For dating the debris surface and debris flows under the Żółta Turnia Peak, the lichenometric curve for very cool climatic vertical zone were applied. The lichen factor for this altitudinal belt is 38.1 mm for the first 100 years. The accuracy of lichenometric dating depends mainly on the precision of the curve establishment and the consistence of climatic conditions between a dating site and a bench mark object. It is usually in the range from one to several years. In case of dating older forms (several hundred years old) the divergences may be larger. In the final considerations, only those thalluses were included which size repeated several times in different boulders.

In the investigations under the Żółta Turnia, the measurements of thalluses, as opposite to the investigations conducted by Kotarba, were carried out along the whole surface of the cone excluded places colonised by mountain pine and high mountain grass. KOTARBA (1989) carried out his measurements along a single cross section. A method of diameter described on thalluses was applied in measurements.

AIRPHOTOS

In order to date debris flows activity for the last 50 years, also airphotos were applied. The area of the Tatra National Park was systematically photographed from space since 1955 (**Tab. 1**). Until the mid 1990s, on average one flight mission was done for 10 years, and later - one ride for 5 years. Thanks to such rich series of airphotos it is possible to date precisely (with the accuracy of frequency of missions) occurence of debris flows. **Tab. 1** shows the years when the airphotos were taken. Because of the fact that not all the airphotos had a form of an orthophotomap, only some show the study area precisely in a parallel projection. Location of study sites was determined using an orthophotomap, topographic maps at a scale 1:10 000, measuring tape and GPS Garmin with TOPO map.

MEASURING SITES

The investigations were carried out in the western slope of the Żółta Turnia Peak (2087 m a. s. l.) The Żółta Turnia Peak is located in the upper section of the Dolina Suchej Wody Valley, between the Czarny Staw Gąsienicowy Lake and the Dolina Pańszczycy Valley (**Fig. 1** and **Fig. 2**). Its pyramidal top consisting of rocky slopes and rock walls dissected by gullies is one of the most characteristic summit rising above the Dolina Suchej Wody Valley. According to the geological map of the Tatras (BAC-MOSZASZWILI et al. 1979) Żółta Turnia Peak is built of granitoides of the High Tatra Mts. The study area is included in altitude

The dates of airphotos								
1955 – 1956	1964 – 65	1974	1977	1983	1994	1999	2003 – 2004	2009

Tab. 1 Specification of airphotos applied for dating

Fig. 2 The view of the western slope of the Żółta Turnia Peak

range from 1600 m a. s. l., i. e from the level of the Czarny Staw Gąsienicowy Lake to about 1850 m a. s. l., i. e. to the foot of the steep rocky walls.

According to KOTARBA et al. (1983) the western slope of the Żółta Turnia Peak „represents as a whole a mountain slope which shows advanced development with elements of mature relief, with rocky surfaces penetrating from the slope-foot up to the higher rocky parts which are still in younger development stages". The slope studied may be divided into four parts: 1. rocky dome-like summit, 2. rocky walls with cut out gullies, 3. rocky slope covered with mantles consist of coarse debris or mixture of debris and fine materials, 4. slope foot in form of debris cones entering/overlying moraine deposits which fill valley bottom. The investigations were carried out in the two latter parts of the slope.

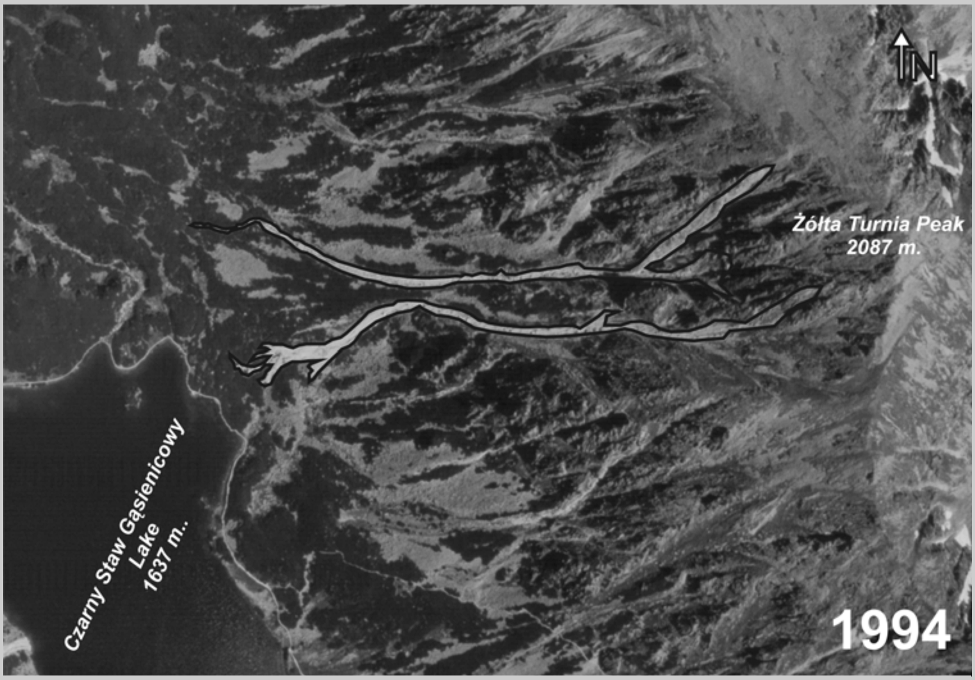

Fig. 3 Airphotos of the western slope of the Żółta Turnia Peak from 1994. A black line marks the debris flows which surface changed

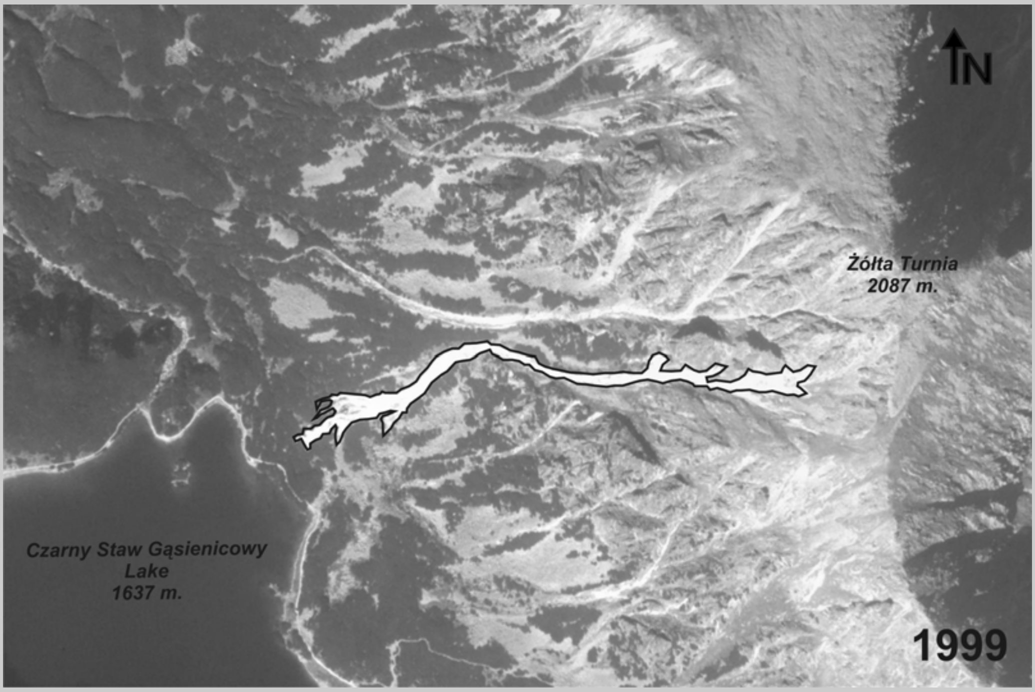

Fig. 4 Airphotos of the western slope of the Żółta Turnia Peak from 1999. A black line marks the debris flow which surface changed

According to the classification by HESS (1965) the investigation area is located within a very cool climatic vertical zone with a mean annual air temperature (MAAT) from 0 to + 2 °C and annual precipitation total of 1650 – 1700 mm. The largest monthly precipitation totals of the range 220 – 250 mm occur in June and July (HESS 1965 and 1996, NIEDŹWIEDŹ 1992).

RESULTS AND INTERPRETATION

Comparing periodically taken airphotos no changes are observed in the shape of debris flows on surfaces of the debris cone located in the western slope of the Żółta Turnia Peak since 1955 – 56 until the airphotos taken in 1983. First changes are visible on the photograph made in 1994 (**Fig. 3**). This means that these changes occurred in the period 1983 – 1994 (**Tab. 1**). According to KOTARBA (1989 and 1998) they originated on 20.06.1986 and 9.08.1991. The northern debris flow became elongated and the southern debris flow became both elongated and its lower part became considerably widen. The next photograph from 1999 (**Fig. 4**) shows successive changes in the shape of the debris flow, this time only in the southern one. Its length did not change but its shape in the lower part changed. According to KOTARBA (1998) these changes originated on 8.07.1997, when heavy rains caused floods in the whole area of the Tatra Mts. and the Western Carpathians. The described above changes in the shapes of debris flows concerned both gullies and levee. The photographs from the years 2003 – 2004 and 2009 do not show any changes in the shape of both debris flows.

Lichenometric dating which in the Tatra Mts. may reach as much as several hundred years in the past and which were made not only on debris flows but also elsewhere on debris surface, confirms the periods of the occurrence of the hydrometeorological events recorded in the airphotos. The youngest lichen thalluses measured in both debris flows gullies are dated at about 1996 (**Fig. 5**). Taking into account the accuracy of this method it may be assumed that these thalluses grew on debris which were accumulated in July 1997. The next, according to age, are the lichen thalluses dated at 1991, which correspond with the heavy rain from August 1991. According to KOTARBA (1998) this event caused triggering of debris flows is several places within the Dolina Suchej Wody Valley. The successive thalluses located in the southern debris flow gully are dated at 1988, and in the northern debris flow gully are dated at 1986. Both these dates are consistent with the occurrence of heavy rains in August 1988 and June 1986. Thus, all or almost all larger heavy rainfalls in the Tatra Mts. during the last 25 years became recorded in the material dated in both debris flow gullies. But not all the rain-

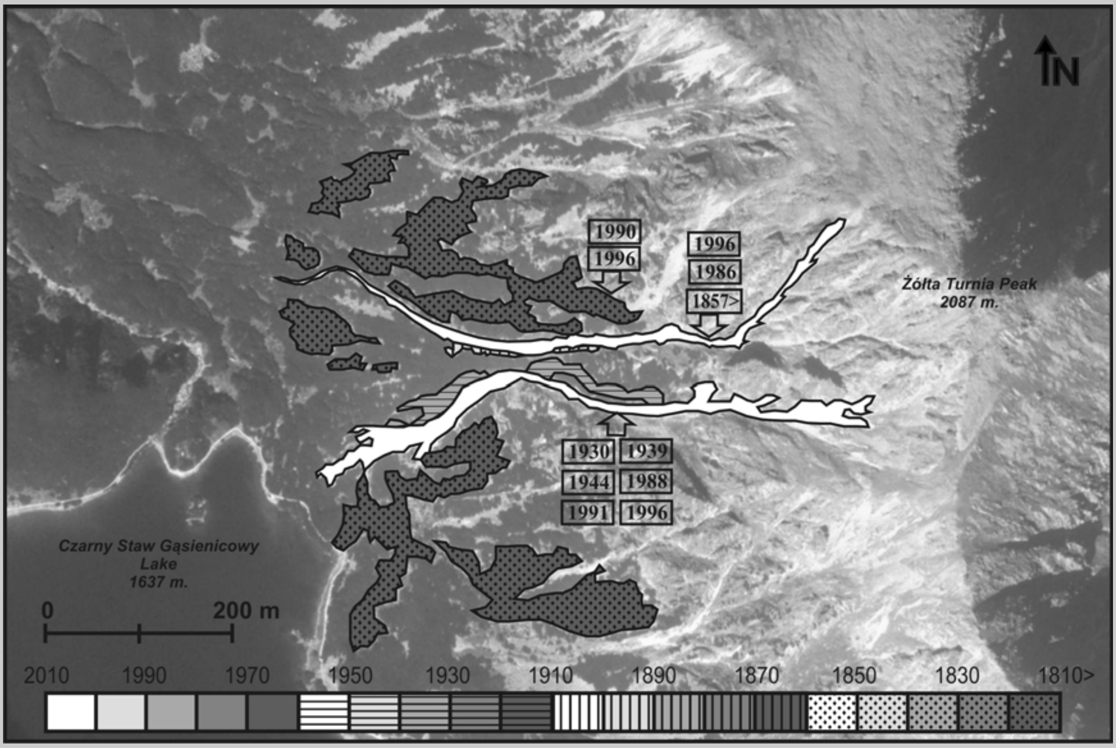

Fig. 5 The western slope of the Żółta Turnia Peak with marked areas which were dated using lichenometric method. In the bottom part of the picture there is a time scale (in years, starting from 2010) of the dated surfaces. The dates in rectangles concern the places where the date of the material is different than the date of the surface

falls were intensive enough to cause the development of debris flows visible in the airphotos. They were however intensive enough to cause movements of some material from weathering covers and small re-modelling of debris flows gullies.

According to KOTARBA (1989, 1992a, 1992b, 1997, 1998, 2002, 2004 and 2007) a debris flow is caused by precipitation which intensity exceeds 35 – 40 mm/hour or rains lasting about one hour with intensity over 1 mm/minute. Daily precipitation totals, especially in the period previous to the occurrence of precipitation, are less important than the intensity of precipitation itself, which may be larger than the threshold value. On the investigated days (20.06.1986, 9.08.1991, 8.07.1997) daily precipitation totals at the Hala Gąsienicowa were 24.3 mm, 84.6 mm and 223.5 mm. **Fig. 6** presents daily precipitation totals at the Hala Gąsienicowa, in the period 1955 – 2004. There are many days with precipitation exceeded 24.3 mm, i.e. the one which was recorded during the debris flow occurrence on 20.06.1986. However, in those days debris flows were not triggered because thresholds values of precipitation intensity were not exceeded. Even on 30.06.1973, when the precipitation total was extremely high – 300 mm, the debris flow did not origin at all, or it was such small that succeeding debris flows completely obliterated its traces.

The next date obtained on the basis of the size of thalluses was 1944. However not enough thalluses were found in both discussed debris flow gullies from the period 1945 – 1985 as to consider them for the record of a larger movements of weathering material. It is also difficult to find in precipitation series from the Hala Gąsienicowa Station any larger rainfall from that period (missing data). It is possible that it was a large summer rainfall or a spring rainfall which, together with a wet snow, caused that some material moved along the northern gully. The next date obtain from lichenometric dating the southern gully was 1930 and 1939. Probably the date 1939 reflects the period of intensive precipitation which caused large flood in the Western Carpathians in 1934, and the date from 1930 is probably the record of precipitation which caused flood in 1931. Taking into account the fact that with the age of forms the accuracy of dating decreases, such a dispersion may be assumed as admissible. On the slopes between the both debris flow gullies, in fragments without mountain-pine or alpine grass vegetation, there are many thalluses dated at the period 1930 – 1940. Most of

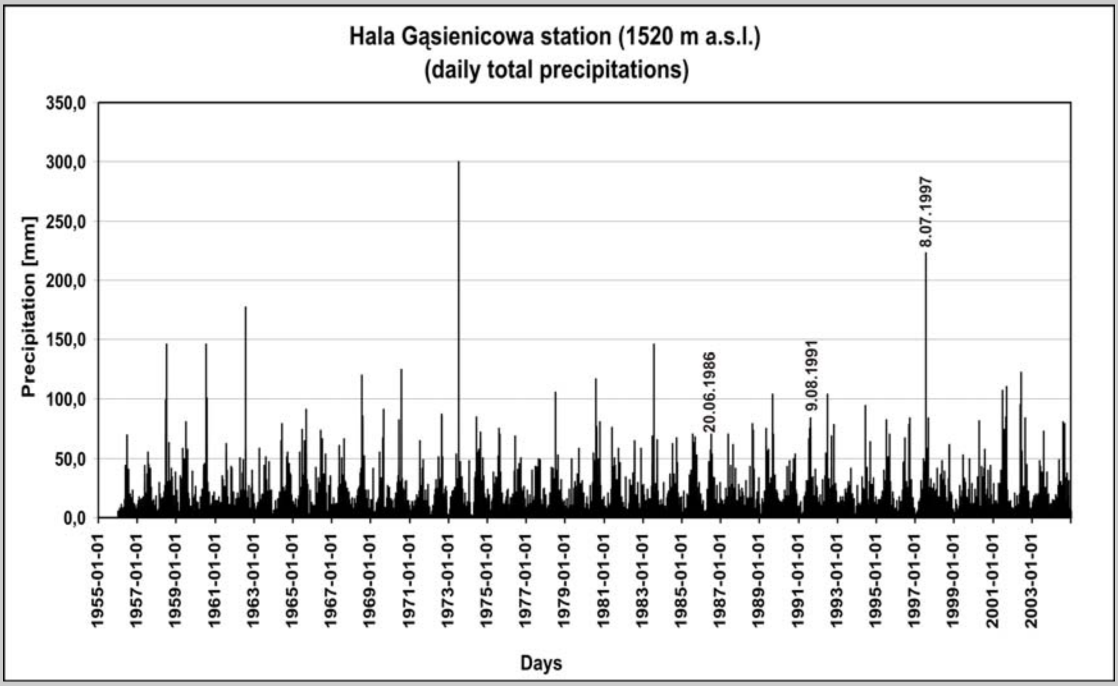

Fig. 6 Daily precipitation totals in Hala Gąsienicowa station from the period 1955-2004. Dates at the precipitation columns inform about the occurrence of debris flows under the Żółta Turnia Peak

them are from the mid 1930s. This is probably, like in the debris flow gullies, record of precipitation in 1934 and partly also in 1931. Taking into account the fact that this area is located between the gullies and a part of it is most likely covered by soil and mountain-pine vegetation (so it cannot be dated) it may be assumed that large precipitation from 1934 caused movement of much larger amounts of material than any of the succeeding extreme events.

The next dates established using lichenometry may be located in the time interval from the very beginning of the 20th century. A small part of the lateral surface of the northern gully originated in this period. In this period transgression of glaciers in the Alps was found and numerous debris surfaces in the Tatra Mts. were dated by KOTARBA (2004). It is considered as the terminal stage of the Little Ice Age. The oldest date obtained from the measurement of thalluses size is 1857. In the northern gully in several boulders deeply set in the ground, the thalluses of the first generation were found and their maximum diameter is consistent, according to the lichenometric curve, with this date. The period of around 1860 is also known from the largest glacier transgressions in the Alps (VIVIAN 1975). In the Tatra Mts. many scree surfaces come from this period (KOTARBA and PECH 2002 or KOTARBA 2004).

The large fragments of debris cone under the Żółta Turnia Peak are covered by alpine meadows and mountain-pine scurbs. There is only small bare area. An attempt to date these fragments which were not covered by vegetation was only partly successful because debris material is overgrown by successive generations of thalluses which are usually interlaced. This is why it is not possible to determine the date of the first oldest thalluses, however, basing on the measurement of the diameter of the largest thalluses it is possible to determine their minimum age. Such measurements revealed that the oldest living thalluses are at least 200 years old, but the time of their origin is still an open case. A small part of this old surface of the debris cone is covered by fresh debris material (dates 1990 and 1996) accumulated either by snow avalanches or transported by rolling and saltation on the surface of snow cover. The further the old surface is located from the rocky walls and the more tightly separated from them by mountain-pine vegetation, the smaller the delivery of fresh material occurs.

CONCLUSION

The results of investigations carried out in the debris cone located on the western slope of the Żółta Turnia Peak confirm the occurrence of the intensive colluviation of the slopes in the

Tatra Mts. In the period of the little Ice Age, what was evidenced by KOTARBA (1995 and 2004). This is confirmed by existing remnants of the debris flow gullies from the beginning of the 20th century and from the 1850s. Those fragments despite of the time passage and many succeeding extreme hydrometeorological events resulting in development of new debris flows forms, have not been totally obliterated. Precipitation from the 1930s, especially 1934 considerably influenced the modelling of the studied debris cone. That colluviation finished (or at least its traces) in the 1940s. Until the mid 1980s, any essential traces suggesting the occurrence of debris flows were not found. It does not exclude the occurrence of debris flows at that time. However, even if they occurred, they must have been of small sizes because they were not recorded in landforms and by any lichenometric dates. Moreover, they were not observed by the researchers from the Research Station at Hala Gąsienicowa who carried out systematic observation at that time of slopes of the Żółta Turnia Peak (KOTARBA et al. 1983).

The intensive colluviation of the cone started again in the mid 1980s. This is evidenced by numerous dates from the 1980s and 1990s. Geomorphological effects of these flows were limited only to small re-modelling of the already existing debris flow gullies (mainly to its deepening and elongation) and formation of new debris flow levee, especially along the lower part of the southern debris flow gully. The smallest changes occurred in the upper parts of the debris flow gullies. As results of the lichenometric dating show, the both gullies were used for transport of debris and fine material, many times and in different periods. The obtained results concerning the periods of the increased occurrence of debris flows are consistent with the earlier investigations of KOTARBA (1989, 1992a, 1992b and 2007) carried out in the upper section of the Dolina Suchej Wody valley.

Because of the fact that a large fragment of the debris cone surface is covered by vegetation, its lichen thalusses on its bare fragments are interlaced and it is not possible to date all the cone's surface. But certainly, basing on the largest but not the oldest thalluses, most of the present surface of the cone originated at least 200 years ago. It probably happened at the beginning of the Little Ice Age or much earlier.

The results of the investigations carried out under the Żółta Turnia Peak confirm the earlier statement of KOTARBA (1989, 1992a, 1992b, 1997, 1998, 2002, 2004 and 2007), that precipitation intensity is the most important parameter causing debris flows. Thresholds values of precipitation determined by that author may undergo some changes according to precipitation totals and character in the period previous to debris flow occurrence, slope topography and the amount of debris material accumulated above the cone.

The obtained results concerning the increased occurrence of debris flows are also consistent with the previous investigations of KOTARBA (2002 and 2004) carried out in the upper section of the Dolina Suchej Wody valley. It is interesting that period of low activity or lack of debris flows corresponds with the stages of precipitation increase in the period 1951-1967 and large precipitation in the period 1968 – 1980, identified by NIEDŹWIEDŹ (1996). After 1980, the stage of precipitation decrease took place.

The referred above results prove that periods of colluviation of slopes in the Tatra Mts. are not necessarily connected with the periods of humid climate, as it occurred in the period of the Little Ice Age. The occurrence of debris flows is most of all influenced by heavy rains (even short) of large intensity (above the threshold value) which are typical rather for a climate with the predominance of continental features over oceanic ones. Undoubtedly, in further investigations concerning the frequency of debris flow occurrence, other parameters of climate should also be taken into consideration.

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REFERENCES

BAC-MOSZASZWILI, M., BURCHART, J., GŁAZEK, J., IWANOW, A., JAROSZEWSKI, W., KOTAŃSKI, Z., LEFELD, J., MASTELLA, L., ZIOMKOWSKI, W., RONIEWICZ, P., SKUPIŃSKI, A., WESTWALEWICZ-MOGILSKA, E. (1979). *Mapa geolo-*

giczna Tatr polskich. Wydawnictwo Geologiczne, Warszawa.

BAUMGART-KOTARBA, M., KOTARBA, A. (1993). Późnoglacjalne i holoceńskie osady z Czarnego Stawu Gąsienicowego w Tatrach. *Dokumentacja Geograficzna.* 4 – 5, 9 – 30.

BAUMGART-KOTARBA, M., KOTARBA, A. (2001a). Deglacjacja Doliny Suchej Wody w Tatrach Wysokich. In *Funkcjonowanie geosystemów w zróżnicowanych warunkach morfoklimatycznych – monitoring, ochrona, edukacja.* Stowarzyszenie Geomorfologów Polskich, Poznań, 73 – 84.

BAUMGART-KOTARBA, M., KOTARBA, A. (2001b). Deglaciation in the Sucha Woda and Pańszczyca Valleys in the Polish High Tatras. *Studia Geomorphologica Carpatho-Balcanica*, 35, 7 – 38.

BESCHEL, R. E. (1950). Flechen als Alters mastab prezenter Moränen. *Zeitschrift für Gletscherkunde und Glazialgeologie*, 1, 152 – 161.

HESS, M. (1965). Piętra klimatyczne w polskich Karpatach Zachodnich. *Zeszyty Naukowe Uniwersytetu Jagielońskiego*, *Prace Geograficzne*, 11, 268 p.

HESS, M. (1996). Klimat. In Mirek, Z., ed. *Przyroda Tatrzańskiego Parku Narodowego*. TPN, Kraków-Zakopane, 53 – 69.

JONASSON, C., KOT, M., KOTARBA, A. (1991). Lichenometrical studies and dating of derbis flow deposits in the High Tatra Mountains, Poland. *Geografiska Annaler*, 73A, 3 – 4, 141 – 146.

KŁAPA, M. (1963). Prace Stacji Badawczej Instytutu Geografii PAN na Hali Gąsienicowej w latach 1960 – 1961. *Przegląd Geograficzny*, 35, 2, 221 – 237.

KŁAPA, M. (1966). Prace Stacji Badawczej Instytutu Geografii PAN na Hali Gąsienicowej w latach 1962 – 1964. *Przegląd Geograficzny*, 38, 2, 253 – 268.

KŁAPA, M. (1980). *Procesy morfogenetyczne i ich związek z sezonowymi zmianami pogody w otoczeniu Hali Gąsienicowej w Tatrach*. Dokumentacja Geograficzna, 4, 56 p.

KOTARBA, A. (1984). Elevational differentiation of slope geomorphic processes in the Polish Tatra Mts. *Studia Geomorphologica Carpatho-Balcanica*, 18, 117 – 133.

KOTARBA, A. (1988a). Lichenometria i jej zastosowanie w badaniach geomorfologicznych w Tatrach. *Wszechświat,* 89, 1, 13 – 15.

KOTARBA, A. (1988b). Tendencies of debris slope evolution in the High Tatra Mountains. *Geographia Polonica*, 55, 83 – 90.

KOTARBA, A. (1989). On the age of debris flows in the Tatra Mountains. *Studia Geomorphologica Carpatho-Balcanica*, 23, 139 – 152.

KOTARBA, A. (1991). On the ages and magnitude of Derbis flows In the Polish Tatra Mountains. *Bulletin of the Polish Academy of Sciences*, 39, 2, 129 – 135.

KOTARBA, A. (1992a). Denudacja mechaniczna Tatr Wysokich pod wpływem opadów ulewnych. System denudacyjny Polski. *Prace Geograficzne*, 155, 191 – 208.

KOTARBA, A. (1992b). Natural environment and landform dynamics of the Tatra Mountains. *Mountain Research and Development*, 12, 2, 105 – 129.

KOTARBA, A. (1994). Geomorfologiczne skutki katastrofalnych letnich ulew w Tatrach Wysokich. *Acta Universitatis Nicolai Copernici, Geografia XXVII, Nauki Matematyczno-Przyrodnicze*, 92, 21 – 34.

KOTARBA, A. (1995). Rapid mass wasting over the last 500 years in the High Tatra Mountains. *Quaestiones Geographicae*, Special Issue 4, 177 – 183.

KOTARBA, A. (1996a). Współczesne procesy rzeźbotwórcze. In Mirek, Z., ed. *Przyroda Tatrzańskiego Parku Narodowego*. TPN, Kraków-Zakopane, 125 – 138.

KOTARBA, A. (1996b). Sedimentation rates in the High Tatra lakes during the holocene – geomorphic interpretation. *Studia Geomorphologica Carpatho-Balcanica*, 30, 51 – 61.

KOTARBA, A. (1997). Formation of High-Mountain Talus Slopes Related to Debris-Flow Activity in the High Tatra Mountains. *Permafrost and Periglacial Processes*, 8, 2, 191 – 204.

KOTARBA, A. (1998). Morfogenetyczna rola opadów deszczowych w modelowaniu rzeźby Tatr podczas letniej powodzi w roku 1997. *Dokumentacja Geograficzna*, 12, 9 – 23.

KOTARBA, A. (2001). Lichenometryczne oznaczanie wieku formy rzeźby wysokogórskiej. *Prace Geograficzne IGiPZ PAN*, 179, 197 – 208.

KOTARBA, A. (2002). Współczesne przemiany przyrody nieożywionej w Tatrzańskim Parku Narodowym. In Borowiec, W., Kotarba, A., Kownacki, A., Krzan, Z., Mirek, Z., eds. *Prze-*

miany środowiska przyrodniczego Tatr. TPN, PTPNoZ Oddz. Kraków, Kraków - Zakopane, 13 – 19.

KOTARBA, A. (2004). Zdarzenia geomorfologiczne w Tatrach Wysokich podczas małej epoki lodowej. *Prace Geograficzne IGiPZ PAN*, 197, 9 – 55.

KOTARBA, A. (2005). Współczesne przemiany rzeźby Tatr i innych wysokich gór Europy pod wpływem spływów gruzowych. In *Przyroda Tatrzańskiego Parku Narodowego a Człowiek, Nauki o Ziemi*, Zakopane, 35 – 41.

KOTARBA, A. (2007). Geomorphic activity of derbis flows in the Tatra Mts. and in other european mountains. *Geographia Polonica* 80, 2, 137 – 150.

KOTARBA, A., KŁAPA, M., RĄCZKOWSKA, Z. (1983). *Procesy morfogenetyczne kształtujące stoki Tatr Wysokich*. Dokumentacja Geograficzna, 1, 84 p.

KOTARBA, A., KASZOWSKI, L., KRZEMIEŃ, K. (1987). *High-mountain denudation system of the polish Tatra Mountains*. Geographical Studies, Special Issue 3, 106 p.

KOTARBA, A., KRZEMIEŃ, K. (1996). Rzeźba Tatr oraz jej postglacjalna ewolucja - stan perspektywy badań geomorfologicznych. In *Przyroda Tatrzańskiego Parku Narodowego a Człowiek, 1, Nauki o Ziemi,* Kraków – Zakopane, 45 – 56.

KOTARBA, A., PECH, P. (2002). The recent evolution of talus slopes in the High Tatra Mountains (with the Pańszczyca Valley as example). *Studia Geomorphologica Carpatho-Balcanica*, 36, 69 – 76.

KOTARBA, A., STRÖMQUIST, L. (1984). Transport, sorting and deposition processes of alpine debris slope deposits in the polish Tatra Mountain. *Geografiska Annaler*, 66A, 4, 285 – 294.

KRZEMIEŃ, K. (1988). The dynamics of debris flows in the upper part of the Starorobociańska Valley (Western Tatra Mts). *Studia Geomorphologica Carpatho-Balcanica*, 22, 123 – 144.

KRZEMIEŃ, K. (1989). Struktura i dynamika spływów gruzowych w krystalicznej części Tatr Zachodnich. *Zeszyty Naukowe Uniwersytetu Jagiellońskiego*, *Prace Geograficzne*, 73, 149 – 169.

NIEDŹWIEDŹ, T. (1992). Climate of the Tatra Mountains. *Mountain Research and Development*, 12, 2, 131 – 146.

NIEDŹWIEDŹ, T. (1996). Wieloletnia zmienność temperatury powietrza i opadów w Tatrach In *Przyroda Tatrzańskiego Parku Narodowego a Człowiek, 1, Nauki o Ziemi,* Kraków – Zakopane, 161 – 167.

NIEDŹWIEDŹ, T. (2004). Rekonstrukcja warunków termicznych lata w Tatrach od 1550 roku. *Prace Geograficzne IGiPZ PAN*, 197, 57 – 88.

VIVIAN, R. (1975). *Les glaciers des Aloes Occidentales*. Imprimerie Allier, Grenoble, 513 p.