GEOGRAFICKÝ ČASOPIS

56 2004 4

Małgorzata Bajgier-Kowalska[*]

THE APPLICATION OF LICHENOMETRY IN DATING LANDSLIDE SLOPES IN THE POLISH FLYSCH CARPATHIANS

M. Bajgier-Kowalska: The application of lichenometry in dating landslide slopes in the Polish flysh Carpathians. Geografický časopis, 56, 2004, 4, 12 figs., 59 refs.

Lichenometry uses lichen thallus increment as a time measure. Since the 1950s, it has been considered a useful method for dating rocky landforms developed over the past 500 years, as other methods are not suitable for such timescales. Rock walls and colluvial blocks are the basic elements in the morphology of rock landslides, which are colonized by the *Rhizocarpon* lichens. This paper shows the assumptions of lichenometry as well as its applications in geomorphological research in Poland and worldwide. The results of lichenometric datings of landslide-bouldery walls and colluvial blocks are presented. This study helps identify the landslide episodes instigated in historical time. The obtained results show that several generations of landslide-rockfall forms old as well as apparently new and active ones occur on the investigated slopes.

Key words: lichenometric dating, landslide, upper Holocene, Polish flysch Carpathians

INTRODUCTION

As a dating technique, lichenometry is alternative to dendrochronology, radiocarbon and TL-dating. It is most useful for dating rock surfaces exposed over the past 500 years (Innes 1990), since many other techniques are not suitable for such timescales. This method uses thallus size increment as time measurement.

---

[*] Institute of Geography, Pedagogical University of Cracow, Podchorążych 2, 30-084 Kraków, Poland

Lichens occur in all climatic zones. They are thallus organisms that is they do not have roots, stems and other organs, and are associations of algal and fungal cells. The body of a lichen consists of fungal hyphae joined by algal cells, constituting an entity in terms of both physiology and anatomy. Lichens are pioneer plants, settling in places which provide no habitats for other organisms, especially on rockwalls, boulders and bare rock surfaces inaccessible to vascular plants. Such features constitute elementary units in the morphology of slopes subject to mass wasting and thus are common in landslide-controlled areas. Lichens colonize places with access to light and water contained in the air. Commonly, lichens are the only autotrophs for hundreds of years (Bystrek 1997). Insoluble in water, lichens create a coating on a rock surfaces protecting it from the action of the elements. The lichens of the *Rhizocarpon* genus are characterized by a very low growth-rate which allows dating rock surfaces over time-scales of hundreds and, in case of cold environments, thousands of years from the present (Innes 1983 and 1990). The thalli of *Rhizocarpon geographicum* live between 4000 and 4500 years, though the age of some thalli of *Rhizocarpon* genus has been estimated to 9000 years (Lipnicki and Wójciak 1995).

Lichenometry is based on the knowledge of the relationship between the size of the lichen thallus and its age. Once such relationship has been established the age of a rock surface can be derived from the size of the lichen thalli covering it. This technique has been employed in various fields, but its application has become common in geomorphology and archaeology. Beschel (1950) was the first to state, on the basis of the observations of tombstones and moraine boulders of known age, that the lichen thallus size indicates the length of time a given surface has been exposed to subaerial conditions. Beschel (1950) identified three stages of lichen ontogeny:

(a) juvenile stage: symbiotic recombination of alga and fungus,

(b) a short stage of rapid growth and habitat expansion, when a lichen attaches to the surface and shows the fastest growth rate continuing until the maturity stage is attained,

(c) maturity stage characterized by slow growth rate and aging.

At the same time Beschel did not exclude linear growth, however, in this case the above-mentioned stages cannot be distinguished. Quantification of the relationship between lithology and climatic conditions on the one side and lichen type and its growth rate on the other is the basic premise in lichenometry. In cold climate areas, juvenile thalli on fresh rock faces are discernible as soon as two or three years after their occurrence (Kiszka 1964). The length of this period amounts to eight – ten years in the High Tatra Mountains, reaching tens of years in more severe environments (Lewkowicz and Hartshorn 1998). The relative age of rock surfaces can be estimated from the extent of lichen coverage. Their absolute age can be derived from lichen growth-rate curve, computed on the basis of annual growth rate of the thalli present on the surfaces of 'known age'. The lichen thallus growth-rate curve represents a functional relationship between maximum thallus diameters and their ages, measured in years (marked on y-axis and x-axis respectively). Initially, the relationship is logarithmic, further changing into an almost linear one.

Geomorphological literature abounds in lichen growth-rate curves, plotted for various areas located in different climatic zones and indicating growth rate in milimeters per 100 years. The thalli growth rate for montane areas in temperate climates ranges from 20 to 50 mm per 100 years.

Over the past 50 years, several lichenometric techniques have been developed, relating mostly to the selection of taxa for dating, measurement methods and the number of samples. Innes (1990) presented a list of taxa used for dating, which are characterized by low growth-rate. The species used for dating rock surfaces are *Rhizocarpon*, a distinctive yellow or yellow-green-coloured crustose lichen growing on siliceous rocks and the orange-coloured *Xantoria*, which colonizes calcareous rocks. This author also describes various techniques for measuring lichen size, recommending the use of the longest axis as the size indicator, which is the most common technique used nowadays. The majority of authors also derive the age of rock surface on the basis of the mean size of the five largest uncoalesced thalli found at the site (Lock et al. 1979, Innes 1990).

THE APPLICATION OF LICHENOMETRY IN PALAEOGEOGRAPHICAL STUDIES

Geologists and geomorphologists worldwide have found lichenometry a useful method for dating rock features, particularly in the reconstruction of deglaciation phases in high-mountain areas (Beschel 1950, Benedict 1967, Andersen and Sollid 1971, Burrows 1971, Luckman 1977, Kotarba 2000 and 2001), in arctic areas (Denton and Karlén 1973, Birkenmajer 1979a, 1979b); in the studies of landform dynamics in glaciated and non-glaciated areas under periglacial morphogenesis (Ballantyne 1982, Dyke 1990), in the studies of high-mountain and arctic valley floors and transformation of talus cones by catastrophic geomorphic processes (Innes 1983, André 1986 and 1990, Kotarba 1988, 1989 and 1992, Luckman 1995, Hietaranta and Liira 1995), Blijenberg 1998, Ferber 2002); in determining talus accretion rates (Luckman 1995, Kotarba 1988) as well as determining the retreat rates of rock glaciers that is forms diagnostic for permafrost occurrence (Holzhausner 1984, Haeberli 1985); for the reconstruction of the extent of snow cover in the Japanese Alps (Iwafune 1997); for dating rockwalls and colluvium in the Beskid Śląski and the Beskid Żywiecki Mountains (Bajgier 1992, Bajgier-Kowalska 2001a, 2001b, 2002) and in various archaeological studies.

Kotarba was the first to use lichenometry in Poland (1988, 1989, 1992 and 1997) in order to reconstruct the phases of intensified slope transformation by mass movements, particularly debris flows. The author observed that over the last 300 years there had been phases of accelerated activity of storm waters on the talus slopes during heavy rainfalls. Dating debris-flow tracks provides evidence for the intensification of slope alluviation which occurred in the years 1810-1835, 1843-1852, 1860-1880 and at the beginning of the 20th century (1900-1905). A distinct climate humidification and weather instability were connected with marked advance of Alpine glaciers during the Little Ice Age, particularly in its final stage dated to the years 1790-1860. Lichenometric dating conducted at the foot of the Skalnisty Piarg talus located by Lake Morskie Oko showed that the largest rockfalls from the slopes of Mieguszowiecki Szczyt took place at the beginning of the 18th century and in the first half of the 20th century. The method has also been applied in geomorphological research in the

Écrins Massif in the French Alps (Kotarba 2000 and 2001), where glacier recession phases (from the maximum extent of the Little Ice Age to the present) were dated in some valleys. At the same time, the papers fully deal with the methodology of lichenometric dating.

Lichenometric dating is based on the assumption that the thalli of the largest lichens indicate the age of the surface which they colonize as the first and fastest-growing individuals. Since lichen growth is mostly dependent on lithology and climatic conditions of the habitat, growth-rate curve and thallus growth rate [mm/year] ought to be computed for each study area. In the Polish Tatra Mountains, it has been estimated at 38,1 mm/100 years for the very cool climatic belt (1550-1850 m asl) and 32,5 mm/100 years in the moderately cold climatic belt (1850-2000 m asl) (Kotarba 1988 and 1989), while in the Beskidy the rates are 42,8 mm/100 years (cool climatic belt: 980-1390 m asl) and 39,6 mm/100 years (very cool climatic belt: 1390-1650 m asl) (Bajgier 1992, Bajgier-Kowalska 2001a, 2001b).

LICHENOMETRIC DATING OF LANDSLIDE SLOPES

In the Polish flysch Carpathians, mass movements are widespread and are usually related to favourable lithologic and tectonic as well as climatic conditions. Mass movements play an important role in the transformation of slope and valley-side relief. Landsliding is the most common process, characterized by a long development cycle. Landslide-related slope deformations proceed in stages, resulting from overlapping different-age movements. The majority of contemporary landslides develop within the extensive old forms as a result of their repeated reactivation (Ziętara 1964, Jakubowski 1974, Alexandrowicz 1978 and 1996, Kotarba 1986, Starkel 1991, Margielewski 1994 and 2001, Alexandrowicz and Alexandrowicz 1998).

The phasal development of landsliding makes dating landslide forms exceedingly difficult. Constituent sections of the large old deep-seated forms are in different stages of development. Landslide features preserved on slopes resulted from multiple dislocations of colluvium over the same surface. It is then difficult to ascertain whether the dated feature of a landslide started as an initial form or represents a phase in its development. However, such questions become irrelevant if the frequency of mass movements related to extreme climatic conditions is to be defined. In a given period of time, parts of old forms may be activated as well as new movements can be triggered enlarging the area of landslide-affected slopes.

The radiocarbon dating and biostratigraphic methods (Mollusca, pollen and plant macrofossil analyses) as well as lichenometry, dendrochoronology and historical data provided means for dating several landslides, rockfalls and debris flows, which had occurred or been reactivated during the Vistulian and the Holocene (Gil et al. 1974, Alexandrowicz 1984, 1985 and 1996, Kotarba 1988 and 1989, Krąpiec and Margielewski 1991, Bajgier 1992, Margielewski 1994, 1997 and 2001, Wójcik 1996, Alexandrowicz and Alexandrowicz 1998). On the basis of the age distribution of the dated forms, Alexandrowicz (1996 and 1998) distinguished phases of increased magnitude of slope processes in the Polish Carpathians. These phases, associated with climate change, are reflected in accelerated activity of fluvial processes (Starkel 1986). The youngest phase of increased mass-movement activity corresponds to climate changes occurring during the Little Ice Age (Alexandrowicz 1996).

Rockwall, rock masses and colluvial blocks, covered with *Rhizocarpon* thalli, constitute elementary features of rock landslides. The lichenometric method, as the most useful in dating substrate exposed over the last 500 years (Innes 1990), was employed to date stages in the development of selected landslide surfaces in the youngest Holocene.

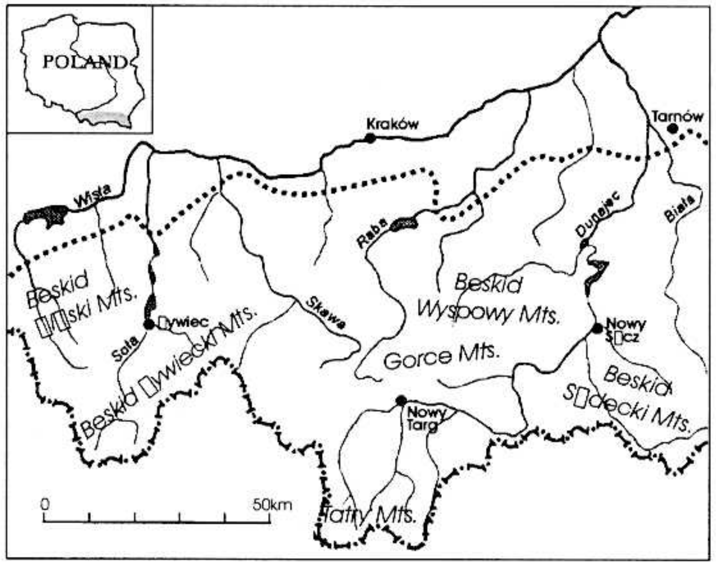

Fig. 1. Location map of the study area

In the Beskid Śląski Mountains (Fig. 1), deep-seated landslides with distinct scarps occur; reaching dozens of metres in depth. These landforms are most commonly built of thick-bedded Godula sandstones (Bajgier 1989 and 1992) which are colonized by *Rhizocarpon* lichens. On the basis of precisely dated rock surfaces with *Rhizocarpon* thalli, a lichen growth-rate curve for the cool belt was plotted (Fig. 2). The mean annual temperature in this zone (980-1390 m asl) ranges from +2 to +4°C, mean annual precipitation is 1590 mm and mean annual duration of snow cover reaches 180 days (Hess 1965). The *Rhizocarpon* thalli growth rate computed for the cool belt averages 42,8 mm/100 years (Bajgier 1992). Lichenometric dating of rockwalls and crevices of the studied landslides on the eastern and southern slopes of Skrzyczne (Fig. 3), on the eastern slopes of Malinowska Skała and the south-eastern slopes of Barania Góra indicate that they were generated between 100-250 years ago. Periods with a considerable frequency of landslide occurrence can be distinguished (1770-1775, 1813-1815, 1861-1870, and 1884-1885). These periods overlap with large floods occurring in the Carpathians as well as with climate humidification towards the close of the Little Ice Age.

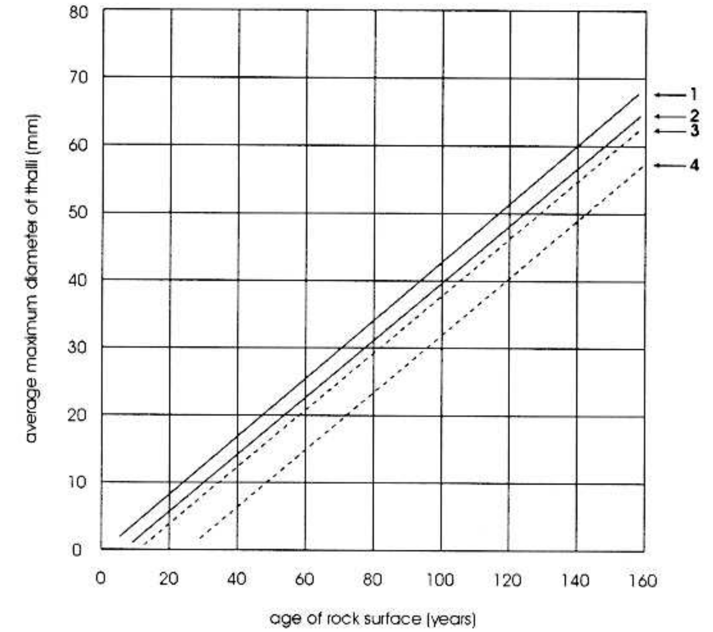

Fig. 2. Growth curves of *Rhizocarpon* lichen in the Carpathians

1 – cool belt in the Beskid Śląski (Bajgier 1992), 2 – very cool belt in the Beskid Żywiecki (Bajgier-Kowalska 2002), 3 – very cool belt in the Tatra Mts (Kotarba 1988), 4 – moderate cold belt in the Tatra Mts (Kotarba 1988)

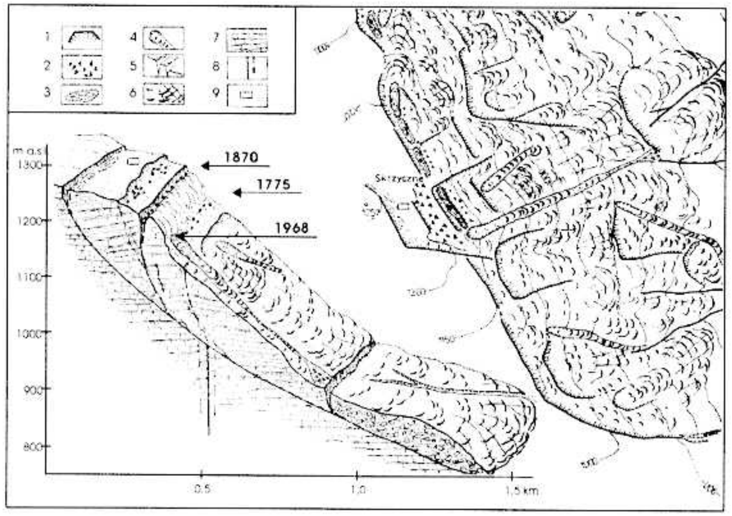

Fig. 3. Plan and cross-section of landslide complex on the eastern slope of Skrzyczne (Beskid Śląski Mts.). Stages of landslide development on the basis of lichenometric dating

1 – landslide niches, 2 – blocky slopes (blocks and rocky debris), 3 – rocky-landslide packs, 4 – tunnel landslides, 5 – cracks and fissures, 6 – clear landslide ramparts, 7 – sandstones series, 8 – dislocations, 9 – hostel

The Beskid Żywiecki Mountains, located within the Magura Nappe, does not constitute a uniform massif, but consists of several ranges extending in a latitudinal direction. Furthest to the south is the Wielka Racza range, and the main ridge stretches from Wielka Racza (1236 m asl), Jaworzyna (1176 m asl), Wielka Rycerzowa (1226 m asl) to Oszast (1152 m asl). In the north-east direction, there is the massive Pilsko range, dissected radially by deep valleys with large landslides in headwater areas. Pilsko (1557 m asl), Lipowska (1324 m asl), Romanka (1366 m asl) and Boraczy Wierch (1144 m asl) are the highest peaks in this mountain group. With the exception of Pilsko, the remaining ridges are located in the cool belt.

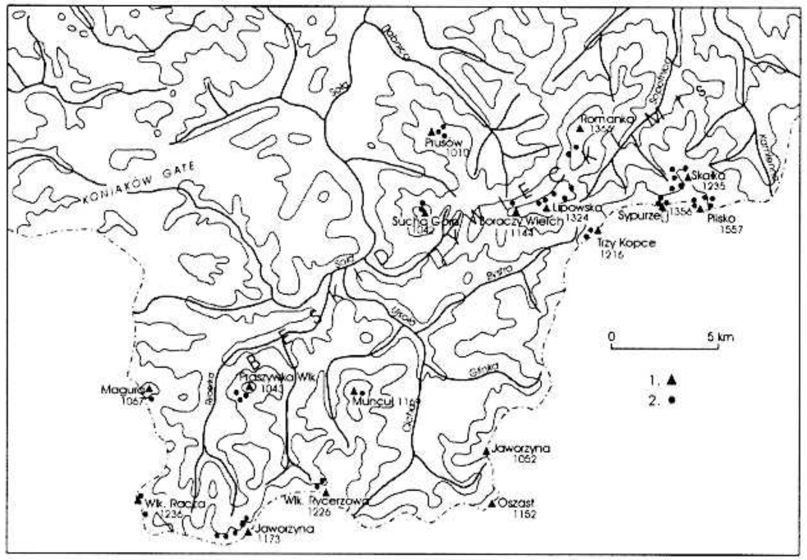

Fig. 4. Distribution of *Rhizocarpon* lichen posts around landslide rock walls in the Beskid Żywiecki according to Nowak (1998)

1 – important peaks, 2 – lichen sites

The *Rhizocarpon* lichens occur on rockwalls, mostly within landslide scarps, and on dislocated blocks found in colluvial deposits (Nowak 1998, Fig. 4). Lichen thalli were measured on five landslide scarps and at eight sites located in block-debris colluvium on the slopes of Romanka, Rysianka, Lipowska and Boraczy Wierch in the cool belt (above 980 m asl). The rockwalls of these landslides are composed of the Magura sandstones. Below the rockwalls, block fields resulting from rockfall occur or alternatively, there are ridges composed of rock particles and separated by crevices or furrows (Figs. 5 and 6).

Results of the analyses of thalli diameters from the Lipowska-Romanka range demonstrate that the oldest thalli occur on colluvial boulders, whilst the youngest individuals are present on the landslide scarp. This indicates that the studied landslide forms developed in separate stages, dated to 1610, 1705-1720, 1802, 1934-1935, 1960 when the largest, regular in shape and uncoalesced thalli were first established on freshly exposed rock surfaces. These dates mark the stages in landslide evolution and correspond to wet periods in the younger Holocene.

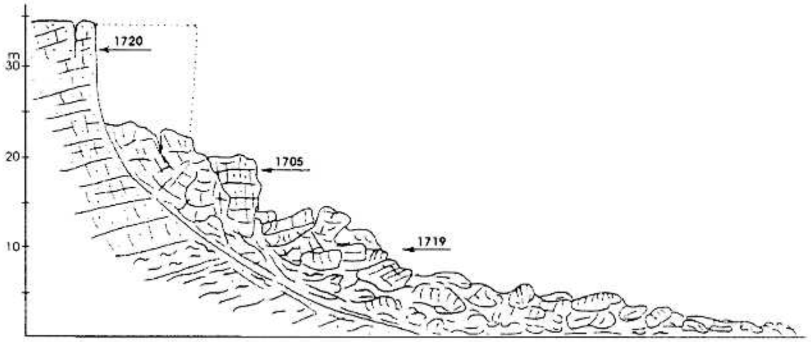

Fig. 5. Stages of landslide development on the western slope of Rysianka on the basis of lichenometric dating

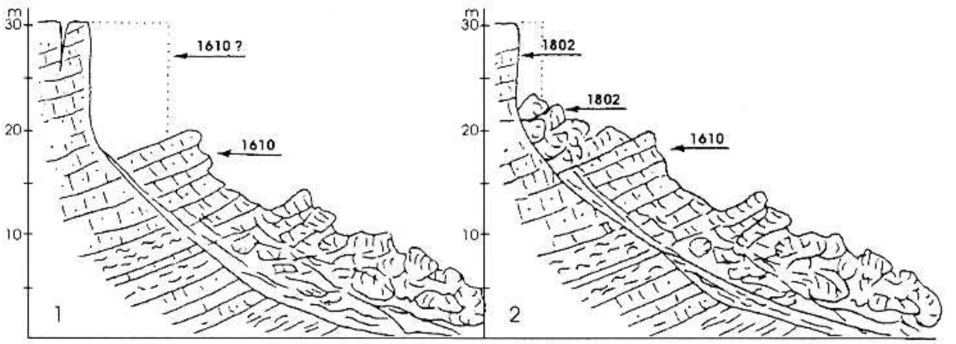

Fig. 6. Stages of landslide development on SW slope of Romanka on the basis of lichenometric dating

1 – the landslide originating from 1610, 2 – the reactivation of the landslide by the boulder in 1802

During heavy-rainfall events, middle and low sections of the landslides were transformed by debris-mud flows, which destroyed lichen thalli. Linear flow of rock debris within a landslide form results in debris-creep valleys. In the juvenile stage they are shallow with narrow floor and gentle sides. At a successive stage, the valley floor is widened while its sides become steeper through undercutting by repeated debris-flows. The last episode of landslide remobilization and dissection of colluvium by debris-mud flows occurred during the floods of 1996 and 1997.

Babia Góra (1725 m asl) is the highest peak in the Polish flysch Carpathians, and its isolated massif stretches for about 10 km in the east-west direction. The massif constitutes a large asymmetrical syncline filled with the Magura sandstone dipping south at the angle of 15-25° and underlain by the Hieroglyph layers with a predominance of shales. The low inclination of rock beds caused the asymmetry of relief of Babia Góra. The northern slope, developed on the fronts of the Magura sandstone beds, is markedly steep with numerous rockwalls reaching inclinations of 70°. This slope can be regarded as a major landslide feature, the size of which is unprecedented in the Carpathians (Alexandrowicz 1978). The rear scarp of an extensive rock slump, which originated in late Pleistocene, comprises numerous large landslides (Ziętara and Ziętara 1958, Ziętara 1962). The uppermost sections are covered with compact rock rubble descending to 1600 m asl. Accordant to the dip of rock beds, the southern slope is characterized by a somewhat monotonous relief, with consequent-structural landslides and block fields covering considerably smaller area. The step-like longitudinal profile of the ridge features classic cryoplanation terraces (Ziętara 1989). Two features are typical of Babia Góra: considerable elevation and isolation. These two factors influence the climate, which is characterized by distinct altitudinal variability; its severity in the uppermost sections of the massif makes Babia Góra similar to high-mountain areas.

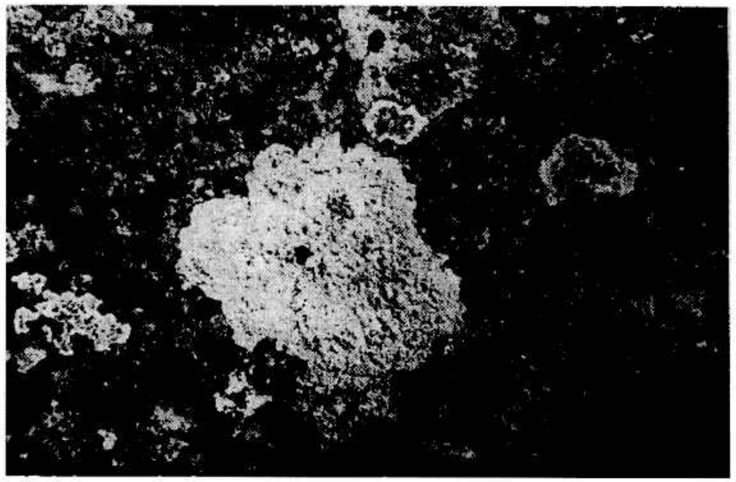

Fig. 7. *Rhizocarpon* lichen with thalli diameter of 150 millimeters, located on the wall of the landslide scarp of Babia Góra (Izdebczyska)

The rockwalls of Babia Góra are colonized by lichens of the *Rhizocarpon* genus (Figs. 7 and 8). The research was conducted between the years 1999-2000, at 24 sites located on rockfall-rock slide faces of the northern slopes of Babia Góra (Fig. 9), belonging to the very cool belt (1390-1650 m asl). The mean annual temperature in this zone ranges from +2 to 0°C, mean annual precipitation is 1750 mm and snow cover duration averages 215 days (Hess 1965, Obrębska-Starklowa 1983). The analysis of thalli diameters shows that the largest and uncoalesced individuals started to develop around the year 1560 – rockwall at Sokolica, in 1609 and 1715 (Izdebczyska), 1748 (the rockwall of Filar) and in the second half of the 18th century. Thalli sizes also point to the reactivation of mass-wasting processes in the 19th century (the years: 1829-1833, 1844-1848, 1861-1869, 1881-1884) and at the beginning of the 20th century. These periods coincide with the wet climatic phase associated with the Little Ice Age, and the following years characterized by increased precipitation which produced severe landsliding on the slopes and flooding of valley floors. The number of dated rockwalls for the given age intervals shows that the increase in age corresponds to the decrease in the number of preserved rockwalls. This points to the high intensity of mass wasting.

Fig. 8. Fragment of the landslide blocks on the slope of Babia Góra overgrown with *Rhizocarpon* thalli

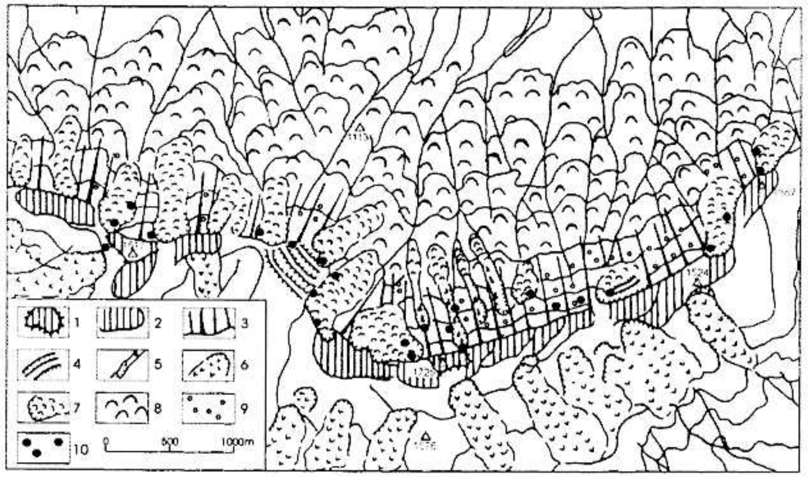

Fig. 9. Distribution of *Rhizocarpon* lichen posts around landslide rocky walls on the slope of Babia Góra

1 – frost residual, 2 – flattenings in the longitudinal profile of the ridge, 3 – wall of the big rocky slump, 4 – cracks, 5 – rocky gullies filled with debris tongues, 6 – landslide niches with a small number of rocky forms, 7 – walls of landslide niches with high rocky forms, 8 – landslide-debris slopes, 9 – rocky fields and debris, 10 – lichen sites

According to the lichenometric dating employed on the northern slopes of Babia Góra as well as on the western and eastern slopes of Pilsko, at sites located above the timberline and in the very cool belt, there are several generations of landslide forms, both old and apparently young active ones (Figs. 10 and 11). The morphology of the slopes developed under the influence of repeated mass-wasting events spaced in time and occurring in different sections of the slope. Landslide-related slope dislocations proceeded in stages and reflect subsequent generations of overriding rockfall-landslide movements.

Fig. 10. Fragment of landslide scarp on the northern slope of Babia Góra (Kępa) dated by lichenometry

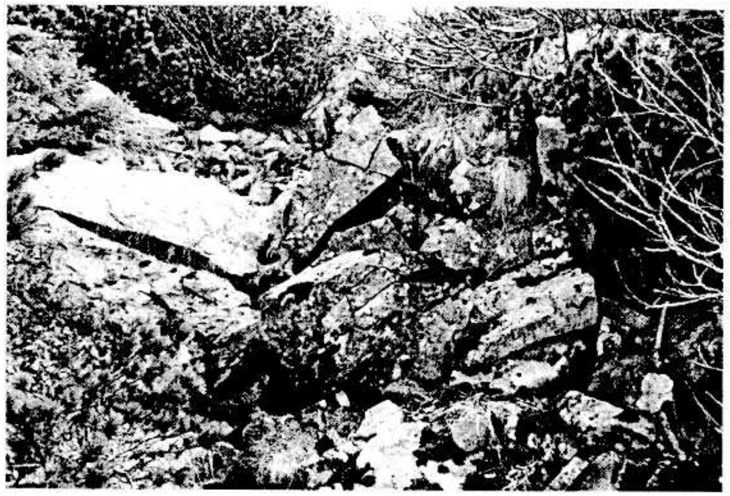

Fig. 11. Fragment of landslide crack on the western slope of Pilsko dated by lichenometry

FINAL REMARKS

Lichenometric dating of slide-and rockwalls, boulders and colluvium suggests that the slopes experience a sequence of development through secondary landslide episodes overlapping with the new rockfall and landsliding movements. Slopes in the Beskidy develop in successive stages. This is shown by the remnants of extensive old scarps on the slopes of Babia Góra, Pilsko, Romanka and Lipowska in the Beskid Żywiecki, as well as on Skrzyczne, Malinowska Skała and Barania Góra in the Beskid Śląski. "Fresh" distinct landslides are the result of yet another phase in the evolution of landslide-controlled slopes. The majority of the large, contemporary landslide forms present on the slopes of the flysch Carpathians are located within the older forms of the same origin. As such they should be considered as a manifestation of successive phases in the development of the landslide slope.

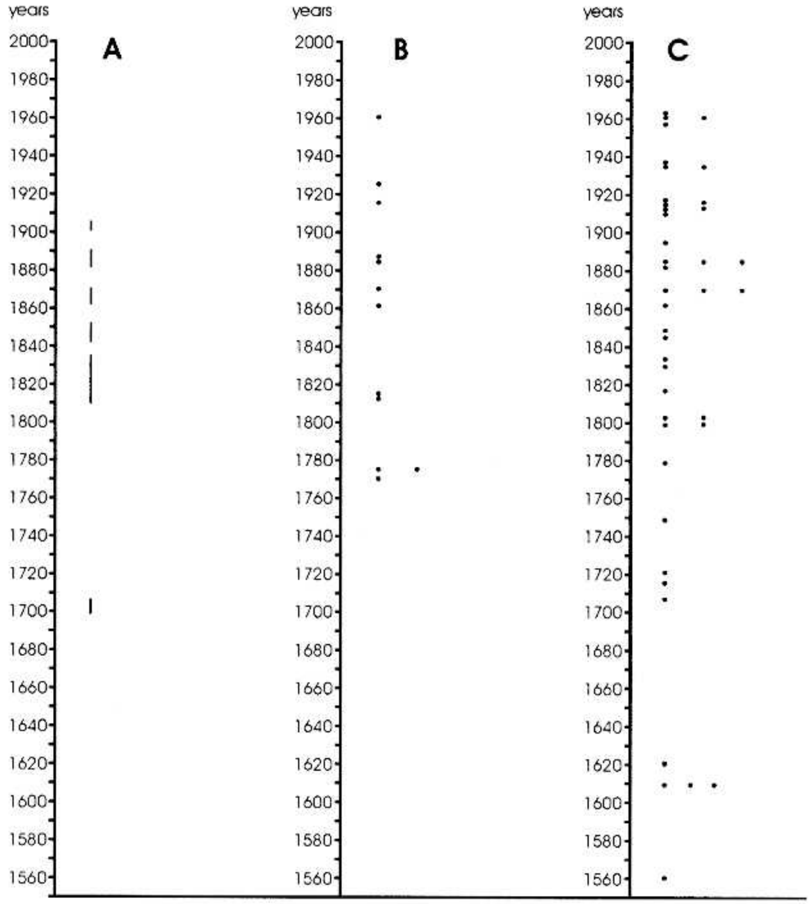

Fig. 8. The dating results with lichenometric method of debris flow and landslide rocky walls in the Carpathians

A – the periods of debris flow formation in the Tatra Mountains (Kotarba 1988 and 1997), B – the age of landslide rocky walls in the Beskid Śląski (Bajgier 1992), C – the age of landslide rocky walls in the Beskid Żywiecki

This attempt at dating landslide rockwalls and colluvia by means of lichenometry helped identify the landslide episodes instigated in historical time (Fig. 12). The results obtained show that both reactivation and triggering of landslide movements in the Beskidy Mountains should be attributed to extreme climatic conditions. According to the research findings, such conditions occurred in the following years: 1560, 1609-1610, 1705-1720, 1748, 1798, 1829-33, 1861-1869, 1881-1884, 1910-1916, 1934-35 and 1959-1960. However, the earlier landslide episodes are less easily recognizable, as their traces are preserved only when the subsequent stage was smaller in extent. The lichenometric dating discussed above has allowed us to reconstruct the history of landslide episodes over the last 500 years. Earlier phases of mass movement are evident but were considered impossible to date with this technique as the lichen thalli found on the rockwalls were coalesced.

Apart from secondary dislocations within landslides, slopes undergo considerable transformation by denudation, especially rockfall, sheetwash and dissection by debris-mud flows. These processes were active on deep-seated rock landslides in the years 1958, 1996, 1997 and 2001. The magnitude and activity of such processes depends on landslide morphology as well as on the intensity and pattern of precipitation. The studies on landslide slopes and their development may be useful for prediction purposes, especially in view of recent settlement development on old landslide forms. Their remobilization caused damage and serious economic and moral loss.

REFERENCES

ALEXANDREWICZ, S. W. (1978). The northern slope of Babia Góra Mt. as a huge rock slump. *Studia Geomorphologica Carpatho-Balcanica*, 12, 133-148.

ALEXANDREWICZ, S. W. (1984). *Środkowoholoceńskie osuwisko w dolinie Harcgrundu (Pieniny)*. Sprawozdania z Posiedzeń Komisji Naukowych Polskiej Akademii Nauk. Kraków (PWN).

ALEXANDREWICZ, S. W. (1985). Subfosylna malakofauna z osuwiska w Piwnicznej (Polskie Karpaty fliszowe). *Folia Quaternaria*, 56, 5-18.

ALEXANDREWICZ, S. W. (1996). Holoceńskie fazy intensyfikacji procesów osuwiskowych w Karpatach. *Geologia*, 22, 223-262.

ALEXANDREWICZ, S. W., ALEXANDREWICZ, Z. (1998). Osuwisko na Górze Parkowej w Krynicy – osady malakofauna i fazy rozwoju. *Geologia*, 24, 302-320.

ANDERSEN, J. L., SOLLID J. L. (1971). Glacial chronology and glacial geomorphology in the margin zone of the glaciers, Midtdalsbreen and Nigardsbreen, south Norway. *Norsk Geography*, 25, 1-38.

ANDRÉ, M.-F. (1986). Dating slope deposits and estimating rates of rock wall retreat in northern Spitsbergen by lichenometry. *Geografiska Annaler*, 68A, 65-75.

ANDRÉ, M.-F. (1990). Frequency of debris flows and slush avalanches in Spitsbergen: a tentative evaluation from lichenometry. *Polish Polar Research*, 11, 345-363.

BAJGIER, M. (1989). Wpływ morfostruktury na rozwój głębokich osuwisk na stokach Skrzycznego w Beskidzie Śląskim. *Folia Geographica, Seria Geographica Physica*, 21, 61-77.

BAJGIER, M. (1992). Zastosowanie lichenometrii w datowaniu osuwisk w Beskidzie Śląskim. *Annales Societatis Geologorum Poloniae*, 62, 339-346.

BAJGIER-KOWALSKA, M. (2001a). Lichenometryczne datowanie pokryw koluwialnych na stokach Lipowskiej-Romanki w Beskidzie Żywieckim. In Klimek, K., Kocel, K., eds. *Pokrywy stokowe jako zapis zmian klimatycznych w późnym vistulianie i holocenie*. Sosnowiec (Wy-dawnictwo Uniwersytetu Śląskiego), pp. 5-9.

BAJGIER-KOWALSKA, M. (2001b). Etapy intensyfikacji ruchów osuwiskowych w młodszym holocenie w Beskidzie Śląskim i Żywieckim. In Kostrzewski, A., ed. *Funkcjonowanie geoekosystemów w zróżnicowanych warunkach morfoklimatycznych. Monitoring, ochrona, edukacja.* Poznań (Wydawnictwo Uniwersytetu im. Adama Mickiewicza), pp. 9-11.

BAJGIER-KOWALSKA, M. (2002). Zastosowanie lichenometrii w datowaniu stoków osuwiskowo-obrywowych w Beskidzie Żywieckim (Karpaty fliszowe). *Czasopismo Geograficzne*, 73, 215-230.

BALLANTYNE, C. K. (1982). The development of sorted circles on recently deglaciated terrain, Jotunheimen, Norway. *Arctic and Alpine Research*, 14, 341-354.

BENEDICT, J. B. (1967). Recent glacial history of an alpine in the Colorado Front Range, USA I: establishing a lichen growth curve. *Journal of Glaciology*, 6, 817-832.

BESCHEL, R. E. (1950). Flechen als Altersmasstab rezenter Moränen. *Zeitschrift für Gletscherkunde und Glazialgeologie*, 1, 152-161.

BIRKENMAJER, K. (1979a). Age of the Penguin Island Volcano, South Shetland Island (West Antarctica), by the lichenometric method. *Bulletin of the Polish Academy of Sciences*, 27, 87-98.

BIRKENMAJER, K. (1979b). Lichenometric dating of Raised Marine Beaches at Admiralty Bay, King George Island (South Shetland Island, West Antarctica). *Bulletin of the Polish Academy of Sciences*, 29, (2), 119-127.

BLIJENBERG, H. (1998). *Rolling stones? Triggering and frequency of hillslope debris flows in the Bachelard valley, Southern French Alps.* Utrecht (Universiteit Utrech, Faculteit Ruimtelijke Wetenschappen).

BURROWS, C. (1971). Studies on some glacial moraines in New Zealand. The establishment of lichen-growth curves in the Mount Cook area. *New Zealand Academy of Sciences*, 14, 327-335.

BYSTREK, J. (1997). *Podstawy lichenologii.* Lublin (Wydawnictwo Uniwersytetu Marii Curie Skłodowskiej).

DENTON, G. H., KARLÉN, W. (1973). Lichenometry: its application to Holocene moraine studies in southern Alaska and Swedish Lapland. *Arctic and Alpine Research*, 5, 347-372.

DYKE, A. S. (1990). A lichenometric study of Holocene rock glaciers and Neoglacial moraines, Frances Lake map area, Southeastern Yukon Territory and Northwest Territories. *Geological Survey of Canada, Bulletin*, 394.

FERBER, T. (2002). The age and origin of talus cones in the light of lichenometric research. The Skalnisty and Zielony Talus cones, High Tatra Mountains, Poland. *Studia Geomorphologica Carpatho-Balcanica*, 36, 77-90.

GIL, E., GILOT, E., KOTARBA, A., STARKEL, L., SZCZEPANEK, K. (1974). An early holocene landslide in the Niski Beskid and its significance for paleogeographical reconstructions. *Studia Geomorphologica Carpatho-Balcanica*, 8, 139-152.

HAEBERLI, W. (1985). Creep of mountain permafrost: internal structure and flow of alpine rock glaciers. *Mitteilungen der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie*, 77, 144.

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

HIETARANTA, J., LIIRA, T. (1995). Lichenometry: dating the weathering processes in the Kevojoki River Valley, Northern Finland. *Zeszyty Naukowe Uniwersytetu Jagiellońskiego, Prace Geograficzne*, 98, 111-121.

HOLZHAUSER, H. (1984). *Zur Geschichte der Aletschgletscher und des Fieschergletschers.* Zürich (Gebo Druck).

INNES, J. L., 1983, Lichenometric dating of debris flow deposits in the Scottish Highlands. *Earth Surface Processes and Landforms*, 8, 579-588.

INNES, J. L. (1990). The use of lichens in dating. In Galun, M., ed. *CRC Handbook of Lichenology, 3*, Boca Raton (CRC Press), pp. 75-91.

IWAFUNE, M. (1997). Application of lichenometry to the changing snow patch extent during the last several decades at Karasawa Cirque in Mt. Hotakadake, the Northern Japanese Alps. *Science Reports of the Tohoku University, 7th Series Geography*, 47 (1-2), 17-33.

JAKUBOWSKI, K. (1974). Współczesne tendencje przekształceń form osuwiskowych w holoceńskim cyklu rozwojowym osuwisk na obszarze Karpat fliszowych. *Prace Muzeum Ziemi*, 22, 169-191.

KISZKA, J. (1964). Porosty Beskidu Śląskiego. *Rocznik Naukowo-Dydaktyczny Wyższej Szkoły Pedagogicznej w Krakowie, Prace z Botaniki*, 28, 1-62.

KOTARBA, A. (1986). Rola osuwisk w modelowaniu rzeźby beskidzkiej i pogórskiej. *Przegląd Geograficzny*, 63, 119-129.

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

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

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

KOTARBA, A. (1997). Formation of high-mountain talus slopes related to debris-flow activity in the High Tatra Mountains. *Permafrost and Periglacial Processes*, 8, 191-204.

KOTARBA, A. (2000). Datowanie form rzeźby wysokogórskiej przy pomocy lichenometrii. *Sprawozdania z Posiedzeń Komisji Naukowych Polskiej Akademii Nauk*, 44 (1), 203-205.

KOTARBA, A. (2001). Lichenometryczne oznaczanie wieku form rzeźby wysokogórskiej. *Prace Geograficzne Instytutu Geografii i Przestrzennego Zagospodarowania Polskiej Akademii Nauk*, 179, 197-208.

KRĄPIEC, M., MARGIELEWSKI, W. (1991). Zastosowanie analizy dendrogeomorfologicznej w datowaniu powierzchniowych ruchów masowych. *Kwartalnik Akademii Górniczo-Hutniczej, Geologia*, 17, 22-36.

LEWKOWICZ, A. G., HARTSHORN, J. (1998). Terrestrial record of rapid mass movements in the Sawtooth Range, Ellesmere Island, Northwest Territories, Canada. *Canadian Journal of Earth Sciences*, 35, 55-64.

LIPNICKI, L., WÓJCIAK, H. (1995). *Porosty. Klucz-atlas do oznaczania najpospolitszych gatunków.*Warszawa (Wydawnictwa Szkolne i Pedagogiczne).

LOCK, W. W., ANDREWS J. T., WEBBER P. J. (1979). *A manual for lichenometry.* Technical Bulletin, 26. London (British Geomorphological Research Group).

LUCKMAN, B. H. (1977). Lichenometric dating of holocene moraines at Mount Edith Cavell, Jasper, Alberta. *Canadian Journal of Earth Sciences*, 14, 1809-1822.

LUCKMAN, B. H. (1995). Estimating long-term rockfall accretion rates by lichenometry. In Slaymaker, O., ed. *Steepland geomorphology.* New York (Wiley), pp. 233-255.

MARGIELEWSKI, W. (1994). Typy sukcesji ruchów masowych na przykładzie osuwisk pasma Jaworzyny Krynickiej. *Sprawozdania z Czynności i Posiedzeń Polskiej Akademii Umiejętności, Oddział Kraków*, 58, 110-114.

MARGIELEWSKI, W. (1997). Dated landslides of the Jaworzyna Krynicka Range (Polish Outer Carpathians) and their relation to climatic phases of the Holocene. *Annales Societatis Geologorum Poloniae*, 67, 83-92.

MARGIELEWSKI, W. (2001). O strukturalnych uwarunkowaniach rozwoju głębokich osuwisk – implikacje dla Karpat fliszowych. *Przegląd Geologiczny*, 49, 515-524.

NOWAK, J. (1998). Porosty Beskidów Wyspowego i Żywieckiego, Pasma Jałowca i Masywu Babiej Góry. *Monografie Botaniczne*, 83, 1-131.

OBRĘBSKA-STARKLOWA, B. (1983). Stosunki klimatyczne w rejonie Babiej Góry. Park Narodowy na Babiej Górze. *Studia Naturae*, 29, 41-62.

STARKEL, L. (1986). Holocene climatic changes reflected in the slope and valley floor evolution in European Mountains. *Studia Geomorphologica Carpatho-Balcanica*, 20, 9-57.

STARKEL, L. (1991). *Geografia Polski – środowisko przyrodnicze*. Warszawa (PWN).

WÓJCIK, A. (1996). Osuwiska Beskidu Żywieckiego w dorzeczu Koszarawy. *Sprawozdania z Czynności i Posiedzeń Polskiej Akademii Umiejętności*, 60, 85-87.

ZIĘTARA, K., ZIĘTARA, T. (1958). O rzekomo glacjalnej rzeźbie Babiej Góry. *Rocznik Naukowo-Dydaktyczny Wyższej Szkoły Pedagogicznej w Krakowie, Prace Geograficzne*, 8, 55-77.

ZIĘTARA, T. (1962). O pseudoglacjalnej rzeźbie Beskidów Zachodnich. *Rocznik Naukowo-Dydaktyczny Wyższej Szkoły Pedagogicznej, Prace Geograficzne*, 10, 69-87.

ZIĘTARA, T. (1964). O odmładzaniu osuwisk w Beskidach Zachodnich. *Rocznik Naukowo-Dydaktyczny Wyższej Szkoły Pedagogicznej w Krakowie, Prace Geograficzne*, 22, 7-23.

ZIĘTARA, T. (1989). Rozwój teras krioplanacyjnych w obrębie wierzchowiny Babiej Góry w Beskidzie Wysokim. *Folia Geographica, Seria Geographica-Physica*, 21, 79-92.

Małgorzata Bajgier–Kowalska

VYUŽITIE LICHENOMETRIE PRI DATOVANÍ ZOSUVNÝCH SVAHOV VO FLYŠOVÝCH KARPATOCH

Lichenometrické datovanie reliéfu použili mnohí geológovia a geomorfológovia v rôznych regiónoch: Alpy, Švédsko, Nórsko, Kanada, arktické oblasti (Beschel 1950, Andersen a Sollid 1971, Denton a Karlén 1973, Luckman 1977 a 1995, Birkenmajer 1979a, b, Ballantyne 1982, Innes 1983 a 1990, André 1986 a 1990, Dyke 1990, Hietaranta a Liira 1995, Blijenberg 1998, Kotarba 2000 a 2001), ako aj v Tatrách (Kotarba 1988, 1989, 1992 a 1997, Ferber 2002) a Beskydách (Bajgier 1992, Bajgier-Kowalska 2001a, 2001b, 2002) v Poľsku. Lichenometria sa zakladá na tom, že stielky lišajníkov s najväčším priemerom naznačujú vek povrchu, ktorý obrastajú ako prvý a že intenzita ich rastu bola optimálna. Druh *Rhizocarpon*, ktorý sa vyvíja pomaly, sa bežne používa na datovanie skalnatého povrchu. Rýchlosť vývoja lišajníkov je rôzna v rôznych klimatických zónach a pásmach. Preto je potrebné vypracovať vývojovú krivku stielky lišajníka a koeficient vývoja lišajníka a zhodnotiť takzvaný lichenometrický model. V Poľsku (obr. 2) bol zhodnotený pre veľmi chladné pásmo (38,1 mm/100 rokov) a stredne studené pásmo (32,5 mm/100 rokov) v Tatrách (Kotarba 1988 a 1989), pre chladné pásmo (42,8 mm/100 rokov) a veľmi studené pásmo (39,6 mm/100 rokov) v Beskydách (Bajgier 1992, Bajgier-Kowalska 2001a, b).

Lišajník *Rhizocarpon* kolonizuje strmé skalné steny na zosunutých hlbinných horninách, čo je bežný reliéf flyšových Karpát. Krivky intenzity rastu lišajníka *Rhizocarpon*, zostavené pre chladné a veľmi chladné klimatické pásma, sa použili na určenie fáz vývoja svahov postihnutých masovým zvetrávaním. Najväčšie stielky nájdené na skalných stenách a puklinách skúmaných foriem zosuvného reliéfu na svahoch Skrzyczne (obr. 3), Malinowska Skała a Barania Góra v Beskydách mali 100-250 rokov.

Výsledky rozborov priemerov stielky z oblasti Lipowska-Romanka (Beskid Żywiecki) dokazujú, že najstaršie z nich sa vyskytujú na koluviálnych balvanoch a najmladšie indivíduá sa nachádzajú na zosuvných skalných stenách (obr. 5 a 6). To naznačuje, že študované zosuvné formy sa vyvíjali v oddelených fázach a sú datované do rokov 1610, 1705-1720, 1802, 1934-1935, 1958-1960, keď sa najväčšie stielky s pravidelným tvarom a nezrastené po prvý raz usídlili na „čerstvo“ odkrytom skalnom povrchu. Tieto dátumy označujú fázy vývoja zosuvov a zodpovedajú vlhkým obdobiam v mladšom holocéne.

Lichenometrický výskum sa realizoval v rokoch 1999-2000 na najvyššom masíve poľských flyšových Karpát, čo je Babia Góra (1725 m), Beskid Żywiecki, kde sa na skalných svahoch nachádza množstvo lišajníkov druhu *Rhizocarpon*. Rozbor priemerov stielok meraných na 24 stanovištiach na severných svahoch Babej Góry (obr. 7) ukázal, že najväčšie a nezrastené indivíduá sa vyvíjali približne v rokoch 1560 (Sokolica), 1609 a 1715 (Izdebczyska), 1748 (Filar) a v druhej polovici 18. storočia. Veľkosti stielok tiež poukazujú na oživenie procesov masového zvetrávania v 19. storočí (1829-1833, 1844-1848, 1861-1869, 1881-1884) a na začiatku 20. storočia. Tieto obdobia sa kryjú s vlhkou klimatickou fázou spojenou s malou ľadovou dobou a nasledujúcimi rokmi, ktoré charakterizuje zvýšený výskyt zrážok, ktoré zapríčinili silné zosuvy na svahoch a zaplavené dná dolín. Lichenometrické datovanie na skalných stenách, balvanoch a kolúviu (obr. 8) ukázalo, že svahy prekonali vývoj cez druhotné epizodické zosuvy, ktoré sa prekrývajú s novými.

Preložila H. Contrerasová