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LANDFORM EVOLUTION IN EUROPEAN MOUNTAINS ISBN 83-88549-40-5

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THE RECENT EVOLUTION OF TALUS SLOPES IN THE HIGH TATRA MOUNTAINS (WITH THE PAŃSZCZYCA VALLEY AS EXAMPLE)

Abstract. Lichenometry provides a suitable means of dating of recent evolution of high-mountain talus slopes due to gravitation processes, debris flows and snow avalanches. The distribution of these deposits and dated along slope transect 676 m long documents 250 years period of activity. Convective summer storms were more pronounced during the final phase of the Little Ice Age, and during the last 300 years. The most frequently debris flows were triggered between 1860 and 1910, while the period of more intensive physical weathering and rock fall is related to 1810–1910 (peak activity 1840–1890).

Key words: rockfall/rockslide, debris flows, snow avalanching, talus slope, lichenometry, Little Ice Age, High Tatra Mountains

INTRODUCTION

Present-day geomorphic process activity on high-mountains slopes of the Tatra Mountains is documented by numerous works (Kotarba 1992; Kotarba et al. 1987; Krzemień 1988; Midriak 1985). Our knowledge of high-energy, rapid mass wasting over the last 500 years, is based on lichenometric dating and lacustrine deposits analysis in the lakes being in close connection to the slopes (Kotarba 1995). Sedimentological properties of lacustrine deposits dated by ^{14}C make it possible to reconstruct Lateglacial and Holocene slope process activity (Baumgart-Kotarba and Kotarba 1993, 1995; Kotarba 1996). As a result of these studies the phases of slope destabilization were distinguished. Holocene phases of high-energy geomorphic events are characterized by inorganic layers, while a quiet periods by organic gyttja. A whole Late Glacial and Holocene sequence of the sediments documents that four periods of large scale activation of slope processes, manifested by sedimentological properties and the sedimentation rates could be distinguished: 1) Younger Dryas — period of paraglacial activity, 2) alpine Venediger stage, 3) the first half of Subboreal, and 4) the Little Ice Age. Paleolimnological studies lead to the conclusion that the most significant component of sedimentation in Tatra lakes was debris flow activity on slopes (Baumgart-Kotarba et al. 1990).

Paleolimnological studies make it possible to record high-energy geomorphic events which reached valley bottom filled with lake. But it is well known that only the largest debris flows reach valley bottom. Depending on severity of storms, debris flows are triggered in apex and middle section of talus slope, and only the most intense storms are able to trigger debris flows reaching valley floor. It means that lake sediments record signal of the most extreme slope events. On the slopes, the variable morphodynamic activities are responsible of complex and different landforms. Looking for better knowledge on slope process activity during the last centuries geomorphologic and lichenometric studied were conducted in the Pańszczyca valley — tributary valley to the Sucha Woda valley. Research Station of the Institute of Geography and Spatial Organization, Polish Academy of Sciences at Hala Gąsienicowa, realize geomorphologic monitoring of slope landforms produced in these valleys since 1975. The main aim of this study is to analyse: (1) all landforms created at least in mid-section of talus slopes during last centuries, (2) to find spatial extension of essential slope categories: debris flow slopes (alluvial talus slopes), rock falls and rockslides, and avalanche slopes, and finally (3) to distinguish specific periods of activity of rapid mass wasting, in particular to identify if there is a recent increase of such processes. To solve these questions we concentrated in this paper on geomorphology and lichenometry of chosen talus slope in the Pańszczyca valley. It might be anticipated that there would be significant differences in the rates of debris flows, rockfall/rockslide and avalanche activity in this area over the last few centuries.

GEOGRAPHIC SETTING AND METHODS

Glacial system of the uppermost part of the Pańszczyca and Sucha Woda valley represents N-facing glacial cirques. Main watershed is developed as sharp-edged ridge crest, 2,000–2,100 m in elevation, with two highest summits of Skrajny Granat (2,224 m) and Wielka Buczynowa Turnia (2,183 m). Alpine cliff consists in granitoids with pegmatite and aplite zones. Local relief ranges from a maximum of about 300 m to 150 m at the cols separating North and South facing slopes of the ridge. Talus slopes flanking this valley show a variety of forms reflecting the legacy of deglaciation and the interaction of various rapid mass movements during the Holocene. Three main slope categories of high mountain landforms below cliff have been distinguished: rockfall/rockslide slopes, alluvial talus slopes, and slopes which constitute transition between these two categories; when first two categories are strongly remodelled by dirty snow avalanches, in some localities, they are classified as avalanche slopes. Slope base is elevated at ca 1,800 m. Talus slopes have been built up during

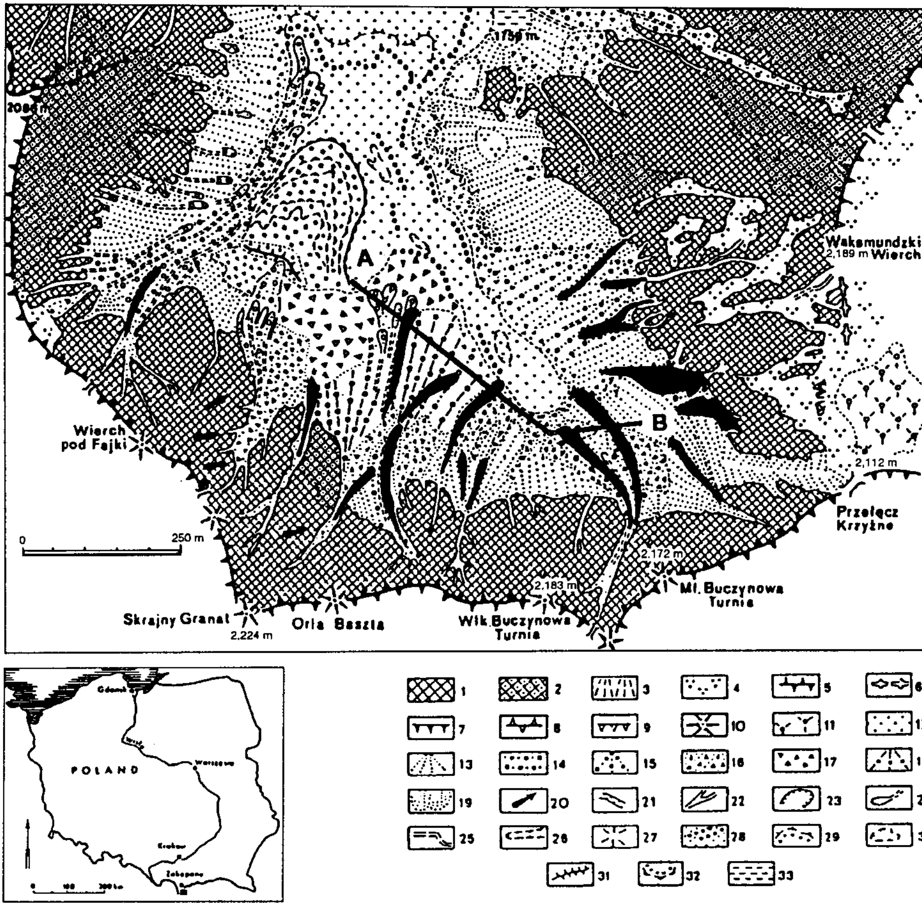

Fig. 1. Detailed geomorphological map of the uppermost part of the Pańszczyca Valley (after A. Kotarba 1992). Debris flow tracks triggered from 1980 to 1998 are marked in black. 1 — rockwall or rocky slope, 2 — debris-mantled slope, 3 — Richter-denudation slope stabilized by vegetation, 4 — block slope, 5 — sharp, rocky ridge, 6 — rounded, ridge crest, 7 — convex break on rockwall or rocky slope, 8 — narrow rocky ridge partly covered by debris and alpine vegetation, 9 — convex rounded break above rockwall or rocky slope, 10 — sharp rocky summit, 11 — mountaintop detritus with sorted polygons, 12 — rockfall gravity-sorted talus slope, 13 — rockfall gravity-sorted talus cone, 14 — alluvial talus slope, 15 — alluvial cone, 16 — rockfall/rockslide slope (Holocene), 17 — rockfall/rockslide slope (early Holocene), 18 — avalanche slope, 19 — talus slope with relict sorted stripes, 20 — source area of rockfall, 21 — rocky gorge, 22 — chute cut in solid rock, 23 — nivation niche cut in solid rock, 24 — debris flow tracks (with levée and lobe), 25 — stream, 26 — slush avalanche gully, 27 — roche moutonnée, 28 — glacial drift deposits roaming distinct morainic ridge, 29 — steep front of recessional moraine, 30 — undrained depression within glacial drift deposits, 31 — protalus rampart, 32 — relict rock glacier, 33 — glaciofluvial river-built plain

the Holocene. The last remnants of glaciers melted in the cirque during Venediger Alpine Stage (8.7–8.4 ka BP) and are marked in the valley by recessional moraines of Zadnie Usypy — 1,810 m (Baumgart-Kotarba and Kotarba 2001) (Fig. 1). Since that time, talus slope have been formed in the valley. Climatically, study area is located within temperate cold altitudinal belt of climate limited by mean annual air temperatures (MAATs) from 0°C to –2°C and precipitation of about 1,800 mm/yr (Hess 1965). The area is located within alpine meadow altitudinal belt.

Detailed geomorphologic mapping in Pańszczyca glacial cirque was done in the scale 1 : 5,000 (Kotarba 1992). Traditional mapping, even of small-scale features was supplemented with aerial photo interpretation. Field investigations and analysis of repeated air-photos (Photo 1) are summarized in Figures 1 and 2, and revealed extensive pattern of recent debris flow deposits (lichen free and not modified by avalanches). During the last ca 20 years sets of debris flows shown in Photo 1 are attributed to single summer storm events. Significant debris flow activity has occurred on talus slopes in the past. Their levées and lobes are lichen covered and partly well vegetated. Aerial photographs taken in 1983 and 1994 were used to recognize recent debris flow tracks. Similar methodology was used recently in the French Alps (Pech and Jomelli 2001). In order to obtain an evaluation of the morphodynamic activity, we did field measurements on a transect. Transect across talus slopes installed in the field and shown on Figure 1 is located in the middle part of talus slopes. This transversal profile follows more or less a level curve, in the median part of the hillslopes, because it may give us the highest probability to cross the greatest number of geomorphologic traces. It cuts a mosaic of various slope units, and is 676 m long. For each slope unit recognized on the transect largest lichens were measured (genus *Rhizocarpon*) on 600 boulders sampled systematically. Mean maximum thalli diameters were used as the data for calculation of absolute age of the unit. In this study, the lichenometric dating curve proposed by A. Kotarba (1988) is used. Lichen growth curve is based on a sequence of dated grave stones, walls of ruined chalets, and other objects built of local granodiorite boulders which have been exposed during a known period of time and located in this geoecological belt (Jonasson et al. 1991).

RESULTS

Of all the processes that have modified the form of talus slopes in glacial cirque of the Pańszczyca valley, by far the most widespread has been debris flow activity. As they differ greatly from those deposited by rockfalls, rockslides and snow avalanches, it is very easy to recognize zones of net erosion and deposition. Transect was installed in transition zone between those two zones, where both shallow gullies cut in talus, and marginal levees and terminal lobes

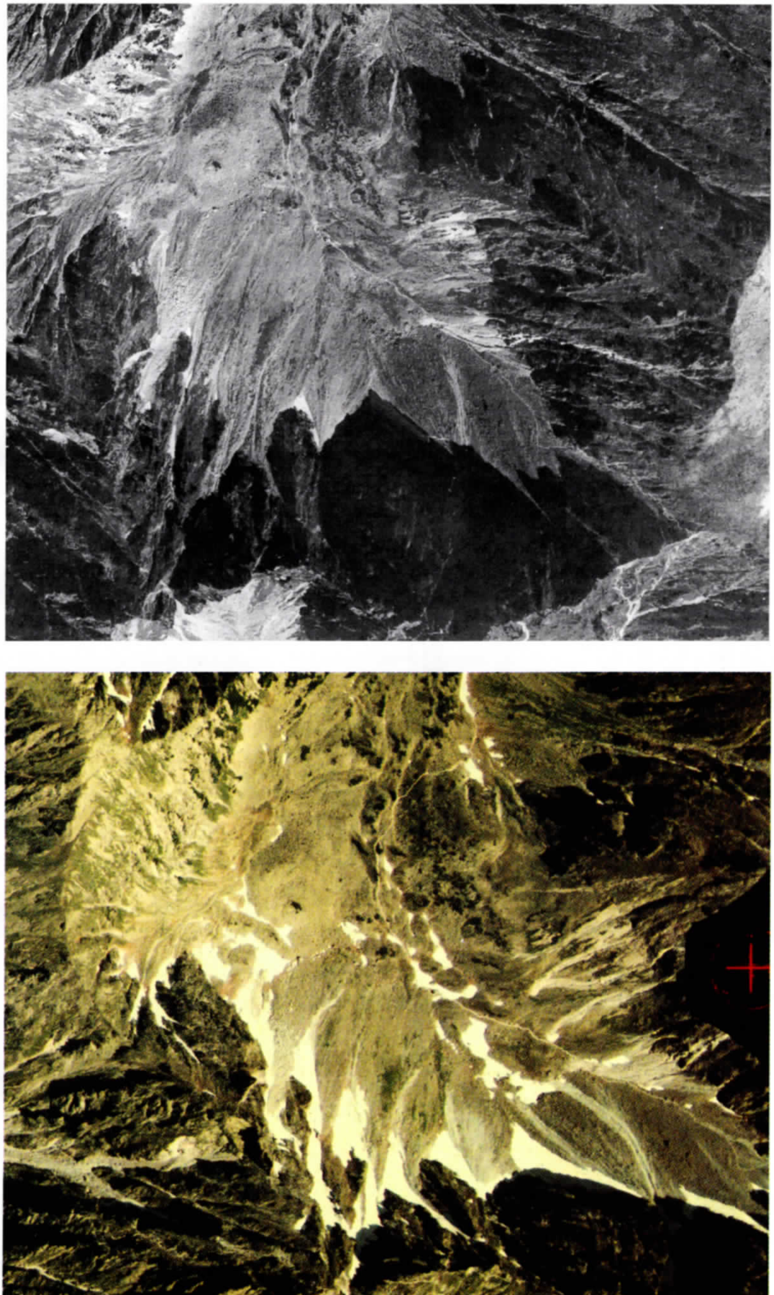

Photo 1. Aerial photographs centred on glacial cirque of the Pańszczyca Valley, taken in 1983 and 1994, courtesy Centralny Ośrodek Dokumentacji Geodezyjnej i Kartograficznej, Warsaw

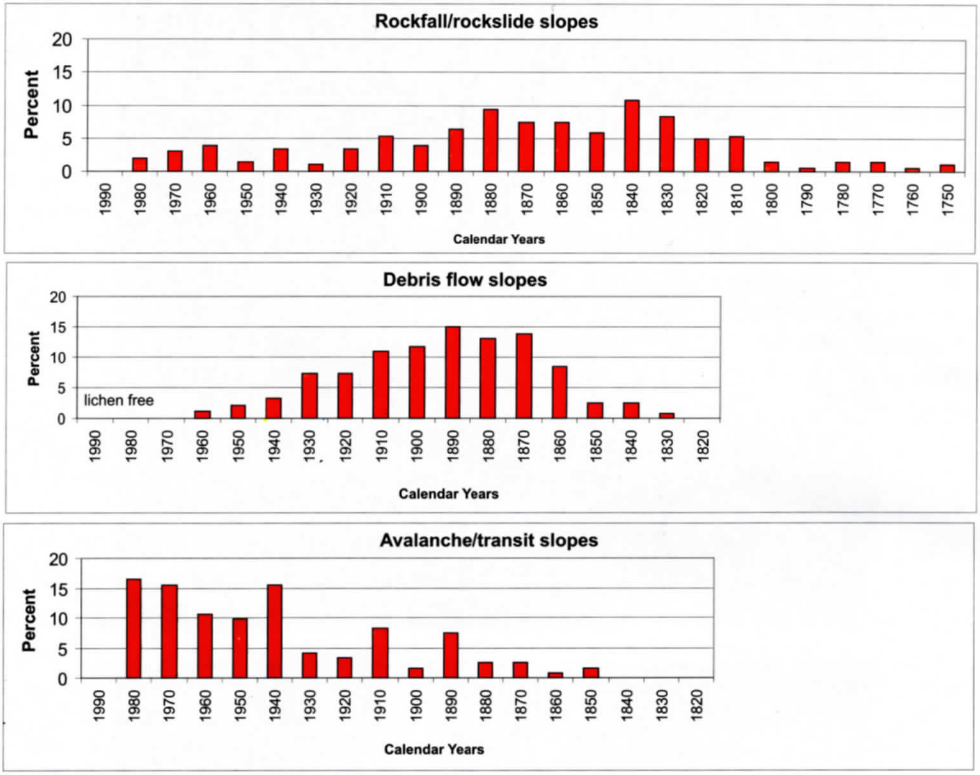

Fig. 2. Age of lichenometric dated deposit (rockfall/rockslide, debris flow and avalanche)

exist. 46.14 per cent of a whole transect is classified as alluvial talus. Old and new debris flow tracks were produced after AD 1820. Older debris flow deposits were not found, even if lichenometric method make it possible to date material 300 years old. Rockfall/rockslide talus slopes are much older. The oldest superficial material dated by lichenometry was deposited ca AD 1750 (Fig. 2).

Avalanche/transitional talus slopes, are those which were intensively modelled by dirty snow avalanches. They are smoothed and free of microforms diagnostic for other slope categories, and cover only 13.6 per cent of total length of the transect. All slope categories which were recognized on talus slopes were modelled during last 250 years. For alluvial talus slopes and avalanche slopes only 180 years series of measurements have been obtained. Rockfall/rockslide activity was going continuously, but one can distinguish the period of more intensive physical weathering and rockwall retreat between 1810 and 1910, with peak activity between 1840 and 1890. Peak activity of debris flows on alluvial talus slopes was shifted in time to 1860–1910. It means that most frequent debris flows were triggered between 1870–1910, after the coldest phase of the Little Ice Age. In contrary to that, rockfalls and rockslides were generated at various parts of steep alpine cliffs. Less steep and more dissected cliffs are developed as regolith-filled gullies separated by degraded bedrock outcrops are source areas for debris flows and avalanche starting zones. Talus cones have been developed at the outlets of the gullies. Debris flows initiated on the apex sections of coalescing cones represent hillside debris flows, and only sporadically may occur in the same tracks during particular events. They provide a dramatic illustration of the importance of intense, short--lasting local storms, and therefore are diagnostic features for reconstruction of climatically controlled geomorphic processes during last 250 years.

Separate field research in the neighbouring valley (Sucha Woda valley, next to the west from Pańszczyca valley) was focused on debris flows only (Kotarba 1995). 95 tracks, both hillslope and valley-confined type, were identified and dated by lichenometry. Analysis of lichen sizes on the upper surfaces and sides of the boulders sampled on the largest levées and lobes reveal that the most substantial tracks, 20 m wide and at least 500 m long, were triggered during the final phase of the Little Ice Age (AD 1860–1870). Number of flow tracks identified between 1820 and 1870 was relatively high (0.54 per year). Another important period of debris flows formation was identified at the beginning of 20th century (AD 1900–1910). In contrary to that, number of flow tracks between 1920–1970 was low (0.30 per year). Comparison between debris flows activity reconstructed according to lichenometric dating in these two valleys shows that time spans of intense modelling are similar. In the Pańszczyca valley one can observe (Fig. 2) continuous decrease in debris flow frequency per year from 1910 to 1930, and low frequency events till 1970.

Quite different course of geomorphic process activity was recorded on avalanche slope. Generally, we observe nearly continuous existence and growth of dirty snow avalanche activity since 1850 up to present. But these last data cannot be interpreted as proxy data for avalanche activity reconstruction as result of climate change. The frequency of avalanching and the rate of debris supply depend on rockwall topography. Source areas of avalanche tracks formation were located always in the same position, i.e. in front of gullies within strongly fragmented cliff. Dirty snow avalanches always follow the same tracks. Higher frequency of avalanche slope deposits, recorded and dated by lichenometry, should be explained by the fact, that avalanche slope units are built up by successive events, each supplying new material which obscures the previous surface. Thus, very old avalanche material was built and buried. Recent events are represented by a greater number of boulders than an older events of the same magnitude. Such mechanism of snow-avalanche activity is well documented in western Norway by D. Mc Carroll (1993) and in Scotland (Ballantyne 1989; Luckman 1992). Diagram for avalanche slope activity suggests only, that 150 year period is long enough to cover a whole slope by younger material and fossilize older avalanche deposits. Snow avalanches generate very high stresses and produce poorly sorted or non-sorted, loosely packed debris.

CONCLUDING REMARKS

Geomorphologic and lichenometric studies supplemented by repeated aerial photographs conducted in two valleys in high-mountain environment of the High Tatra Mountains make it possible to formulate following conclusions:

1) processes of rockfall and rockslide are documented for the last 250 years. Lichenometric data from avalanche slopes led to the conclusion that snow avalanching and process of rockfall has continuous character;

2) convective summer storms were undoubtedly more pronounced during the final phase of the Little Ice Age. During the present climate, i.e. since ca 1975 many substantial debris flows were recorded by eye-witness accounts and on repeated aerial photographs. Thus, we can formulate view point that precipitation regime at present is changing. Higher frequency of extreme storms, with daily rainfall greater than 100 mm, and intensity of the order of 40 mm $\cdot$ hour^{-1} triggered many fresh, lichen free, debris flow tracks. This statement is documented by rainfall data collected at Research Station at Hala Gąsienicowa. The threshold values determined by N. Caine (1980) and J. L. Innes (1983) have been exceeded several times during last 20 years. Sporadic, extreme processes produce important modification in slope morphology;

3) talus slope development during last 250 years was controlled both by continuous and sporadic processes. Diagnostic landforms of past geomorphologic processes are well preserved on investigated talus slopes.

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STRESZCZENIE

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WSPÓŁCZESNA EWOLUCJA STOKÓW PIARGOWYCH W TATRACH WYSOKICH (NA PRZYKŁADZIE DOLINY PAŃSZCZYCY)

Współczesna ewolucja wysokogórskich stoków piargowych w dolinie Pańszczycy jest przedstawiona na podstawie szczegółowego kartowania geomorfologicznego wykonanego w terenie we wczesnych latach dziewięćdziesiątych, a następnie uzupełnionego i uaktualnionego przez interpretację zdjęć lotniczych wykonanych w latach 1983 i 1994. W roku 2000 wykonano terenowe badania mające na celu przedstawienie dynamiki współczesnych zmian morfologii stoków wskutek działania szybkich ruchów masowych; odpadania i obrywania oraz grawitacyjnego przemieszczania gruzu, działania spływów gruzowych i lawin śnieżnych.

W środkowej części stoku piargowego wyznaczono transekt o długości 676 m. Przemieszczając się od zachodu (A) ku wschodowi (B) (ryc. 1) określono genezę przekraczanych odcinków na transekcie, a następnie wykonano pomiary plech porostów *Rhizocarpon.* W sumie pomierzono 600 plech, a dla wyróżnionych 3 typów stoku (grawitacyjny, aluwiacyjny, lawinowy) określono wiek stosując krzywą kalibracyjną wieku porostów określoną przez A. Kotarbę (1988). Średnie maksymalne średnice plech zostały przeliczone na lata kalendarzowe. Wiek wszystkich pomierzonych plech mieści się w przedziale czasowym ostatnich 250 lat, a więc najstarszy datowany materiał skalny odpadający ze ścian pochodzi z około 1750 roku. W przypadku stoków aluwiacyjnych i lawinowych wiek najstarszych okruchów sięga tylko roku 1820. Materiał z odpadania i materiał budujący szlaki spływów gruzowych przedstawiony na ryc. 2 pozwala wydzielić okresy wzmożonej działalności procesów związanych ze zmianami reżimu termiczno-wilgotnościowego w schyłkowej fazie małej epoki lodowej. Od roku 1975 stwierdzono wybitne zwiększenie aluwiacji stoków przejawiające się w utworzeniu wielu szlaków spływów gruzowych nie posiadających rozwiniętych plech porostów (fot. 1). Wyraźna tendencja przyrostu materiału na stokach lawinowych nie jest przejawem aktywności tych stoków wskutek uwarunkowania klimatycznego. Oznacza tylko, że na tych stokach następowało „ciągłe" nadbudowywanie powierzchni i zasypywanie materiału starszego. Lawiny zawsze nadbudowują te same fragmenty stoków piargowych, gdyż ich przebieg, a tym samym lokalizacja przemieszczonego materiału, zachodzi w tych samych miejscach. W przeciwieństwie do omówionych procesów, pozostałe procesy (spływ gruzowy, obryw) zachodzą w różnych miejscach i są rozmieszczone mozaikowo, a więc pozwalają na dokonanie prób określenia zmian reżimu termicznego (obrywy) i opadowego (spływy gruzowe).