STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
ISBN 83-88549-56-1 VOL. XL, 2006: 7–19 PL ISSN 0081-6434
LANDFORM EVOLUTION IN MOUNTAIN AREAS
Recent geomorphological hazards in Carpatho-Balcan-Dinaric region

LESZEK STARKEL (KRAKÓW)

GEOMORPHIC HAZARDS IN THE POLISH FLYSCH CARPATHIANS

Abstract. Among main factors causing geomorphic hazards in the Flysch Carpathians of Poland are various types of heavy rainfalls, rapid snowmelts and strong winds. This paper characterises the effects of heavy downpours, continuous rains and rainy seasons. During superposition of extremes, simultaneous transformation of slope and floodplain systems is likely to follow. Special attention is paid to the clustering of extreme events, particularly well visible in the last decade.

Key words: clustering of extreme, geomorphic hazards, Flysch Carpathians, Poland

INTRODUCTION

Relief-forming processes include those of various duration and intensity. Some of them are secular or continuous (like leaching and fluvial transport), some periodic — seasonal (like creeping, piping), or episodic ones (like debris flows, landsliding, river bedload, etc.). We can talk about two types of thresholds. The first one is connected with initiation of the process, like overland flow, soil throughflow, creeping or when the soil is saturated, the ground passes the plasticity limit or exceeds the internal friction and cohesion. The second type of thresholds is connected with the beginning of transformation of slopes and river channels by intensive slope wash and gulling, mud- and debris-flows, landslides, rockfalls, intensive fluvial erosion and aggradation during passing of bankfull discharges, etc. (cf. Selby 1974).

In the present-day Carpathian environment, among the main factors leading to geomorphic hazards, for instance passing the thresholds in transformation of slopes and valley floors and causing catastrophic effects (cf. Rosenfeld 2003), we can distinguish various types of heavy rainfalls, rapid snowmelts and strong winds (Starkel 1972, 1980, 1996). After the calculations made by K. Wit-Jóźwik (1978) for Szymbark station during the summer season (V–X) in years 1969–73, only during 5–10% of time it was raining, and at Łazy station in years 1971–2000 between

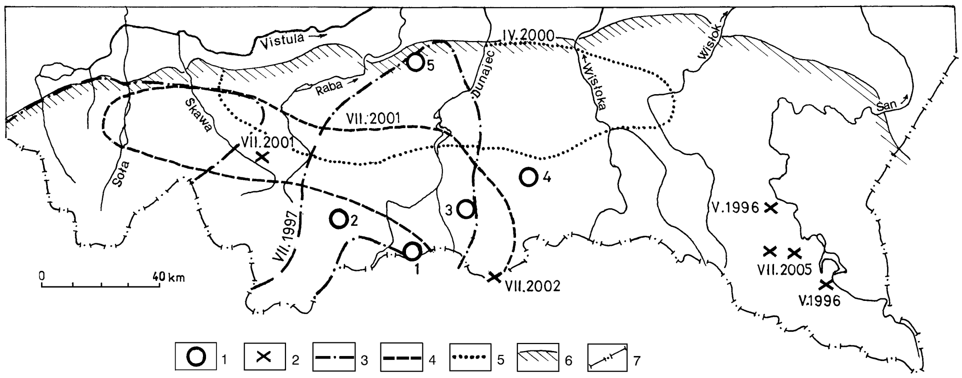

Fig. 1. Research stations and areas of selected extreme events in last decade in the Polish Flysch Carpathians. 1 — Research stations with continuous monitoring: 1. Jaworki (in 1950 and 1960-ties), 2. Ochotnica Górna (in 1960-ties), 3. Homerka (since 1970), 4. Szymbark (since 1967), 5. Łazy (since 1986); 2 — lokalities with heavy downpours; 3 — extend of continuous rain in July 1997; 4 — extend of continuous rain in July 2001; 5 — extend of rain in spring 2000; 6 — northern limit of the Carpathians; 7 — state boundary

April and October rain was falling during 3–13% of time (Saramak 2005). Especially differentiated are extreme rainfalls, depending on their totals, intensity and duration. These include: a) local heavy downpours causing intensive slope wash, gulling, earth and debris flows, b) continuous rains leading to landsliding and floods on a regional scale, and c) rainy seasons reactivating deep rocky landslides.

The observations on geomorphic hazards were initiated after the appearance of great landslides at Duszatyn in 1907 (Zuber and Blaut 1907; Schramm 1925) and at Szymbark in 1913 (Sawicki 1917) and heavy flood in 1934 (Klimaszewski 1935). In the 1950s and 1960s, continuous monitoring of secular and extreme processes at field stations was initiated, first at Jaworki and Ochotnica Górna (Gerlach 1976), then at Szymbark (Słupik 1973; Gil 1976; Gil and Kotarba 1977), later in Homerka (Froehlich 1975, 1982), and finally at Łazy (Święchowicz 2003). These measurements were supplemented by observations on the effects of extreme events in different parts of the Carpathians in 1960, 1970, 1997, 2001, 2002 (cf. Fig. 1, Ziętara 1968; Rączkowski and Mrozek 2002; Starkel and Grela 1998 and others).

REGIONAL DIFFERENTIATION OF LANDSCAPE AND PROCESSES

The geology and relief of the Polish Flysch Carpathians show differences in N–S and W–E transects. The higher ridges are located in headwater areas of rivers draining the northern slope of the Carpathians. Farther downstream the foothill zone occurs, showing relative heights of 100–200 m, and becoming wider towards the east. Much more contrasting are the lithology and geomorphic style of mountains. In the west compact massifs dominate, built up of more resistant sandstones and rising up to 1,200–1,700 m a.s.l. (Klimaszewski 1946; Starkel 1972). East of the Dunajec River valley, less resistant flysch strata prevail (Klimaszewski 1946; Starkel 1972), with foothill landscapes and isolated parallel ridges. Variable structural style of the Carpathian flysch nappes is reflected in great differences in landslide activity.

Moreover, the pattern of rainfalls shows great contrasts in their totals and intensity. In the western part, the mean annual rainfall varies between 800 and 1,500 mm, whereas in the east it does not exceed 1,000 mm. The daily maximum rainfall fluctuates between 40 and 60 mm, its 1% probability reaching 250 mm in the west (Cebulak 1992). The western part is affected much more frequently by continuous rains (which in the east are rare) reflected in frequent summer floods. During the last century, at least 8 continuous rains covered large areas causing regional floods (Starkel 1996). On the contrary, the eastern part is characterised by winter snowmelt floods (Ziemońska 1973), which are facilitated by simultaneous melting on the extensive foothill areas confined to one vertical belt.

TYPES OF RAINFALLS AND THEIR GEOMORPHIC EFFECTS

Several decades ago three main types of rainfalls and their combinations were distinguished in the Carpathians (Starkel 1972, 1976, 1980): local downpours, continuous rains, and rainy seasons (Fig. 2).

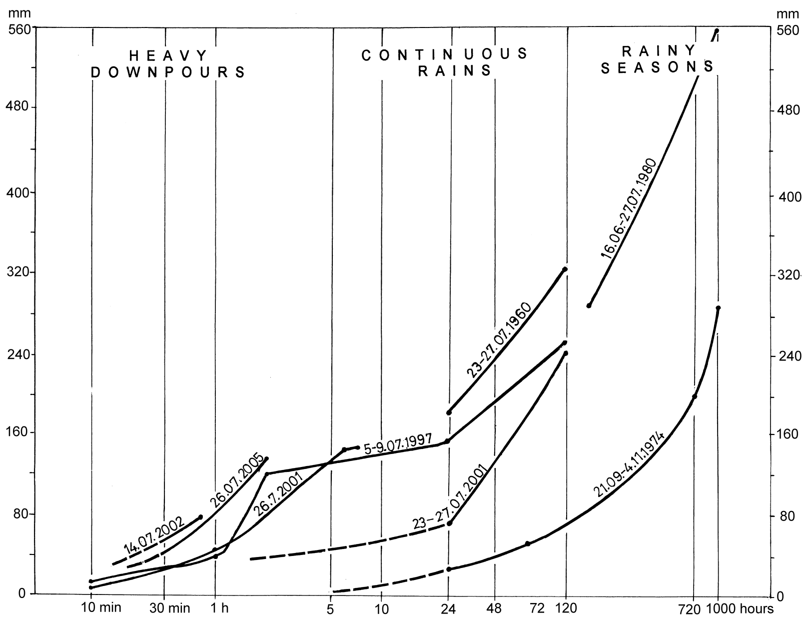

Fig. 2. Duration, rainfall totals and intensity of selected heavy downpours, continuous rains and rainy seasons during last decades in the Carpathians. Please turn your attention to complex events like continuous rains with heavy rainfalls (based on various records — mentioned in references)

Local heavy downpours, usually of short duration between 0.5 to 2 hours, are characteristic for spring–summer transition (V–VII) and reach 50–100 mm of rainfall totals and intensity of up to 1–3 mm · min^{-1}. During such a rain described by E. Gil and J. Słupik (1972), the infiltration of water reached only 20 cm depth, and 25% of 40 mm rain flowed down on the ground surface causing heavy slope wash. On cultivated fields dozens of tons of material can be washed from 1 ha (Gerlach 1976; Gil 1976, 1999), as compared to kilograms in the forests. Sometime, the whole arable layer flows down after liquefaction (Figuła 1960), and on scarps of terraced fields the slumps are common (Gerlach 1976). Runoff is concentrated along cart-roads (Froehlich 1982), and specific runoff in small catchments may exceed 10 $m^3 \cdot s^{-1} \cdot km^{-1}$ (Soja 1981).

The effects of such heavy rains include rapid rises of the water level in small creeks, reaching the stage of hyperconcentrated flow, being also combined with formation of local debris flows carrying boulders 0.6–0.8 m in diameter at a distance of 280–500 m and transforming river channels even 10–20 km downstream of the rainfall area (Froehlich 1998). Such effects I observed last year (July 2005) in the tributary catchments after 130 mm of rain in two hours (Photo 1 and 2). The effects of these downpours also depend on the land use and channel pattern. After heavy rainfall in the Gorce Mts., the channel erosion in two parallel catchments reached 103 and 517 m^3 (Niemirowski 1974).

On the regional scale, much more effective are continuous rains, covering areas of several thousand square kilometres and usually at least the catchments of 2–3 tributaries of the Vistula River (Photo 3 and 4). These rainfalls may reach 150–400 mm in 2–5 days and are usually connected with shifting of cyclone systems (Cebulak 1992). The highest daily rainfall can reach 100–250 m, but the rainfall intensity does not usually exceed 5–10 mm · h^{-1}. During the 20th century, 17 such events were registered in the Polish Carpathians (Cebulak 1992). For these continuous rains saturation of soil and the entire regolith is characteristic, being followed by formation of various landslides, intensive linear erosion, and piping (Ziętara 1968; Gil 1976; Froehlich 1982). In the Beskid Śląski Mts., during such a rain in 1970 the number of episodic springs reached 600 per 1 km^2 (Brykowicz et al. 1973). Simultaneously, floods in river valleys, after passing the specific runoff of 1 $m^3 \cdot s^{-1} \cdot km^{-2}$, carried high-suspended load and bedload. For instance, the flood in 1970 in the Kamienica Nawojowska River valley carried 92% of the total annual load (Froehlich 1975). The 1970 flood in smaller catchments exceeded 3 $m^3 \cdot s^{-1}$ of specific runoff (Soja 1977). Floods in 1958 and 1960 in the Soła River catchment caused intensive deep and lateral erosion as well as aggradation of coarse material (Ziętara 1968), leading to the rise of the channel bottom by 10 cm during one event and deposition in the water reservoir of 2,800 m^3 of material shed from 1 km^2 of the catchment area (Prochal 1968).

Photo 1. Lateral erosion during heavy downpour in the tributary valley of the Hoczewka river at Cisowiec on 26 July 2005 (Photo by L. Starkel)

Photo 2. Earthflows on the valley side of Bereźnica creek during downpour at 26 July 2005 (Photo by L. Starkel)

Photo 3. Reactivated landslide after continuous rainfall at Falkowa near Nowy Sącz in July 2001 (Photo by L. Starkel)

Photo 4. Channel of the Budzów creek (tributary of the Skawa river) totally transformed during flood in July 2001 (Photo by L. Starkel)

The Białka Tatrzańska River in the Tatra foreland (203 km^2), transforms their bars, pools and riffles every 5 years, after passing specific runoff of 1 $m^3 \cdot s^{-1}$, and after passing the double value every 50 years the entire braided channel undergoes transformation (Baumgart-Kotarba 1983).

The long-lasting rainy seasons were well recognised in autumn 1974 at Szymbark station, where after rainy summer only in October about 200 mm of rain fell (Gil and Starkel 1979). The saturated regolith facilitated a continuous subsurface flow and reached a threshold of plasticity and even liquefaction. In such a case, every additional slight impulse, like 10–20 mm rainfall, may trigger a movement on the slope (the throughflow exceeded 5,000 litre $\cdot$ h^{-1} $\cdot$ ha^{-1}). Other studies carried at the experimental slope in Szymbark (Thiel 1989; Gil 1997) showed that three times in 1974, 1980 and 1985 the reactivation of slope masses followed, when the total rainfall exceeded 250 mm and lasted several weeks. In June–July 1980, after 718 mm of rainfall at Terka (upper San River catchment) similar landslide activity was registered.

Moist years are responsible for formation of the largest recorded landslides in the flysch Carpathians. The rockslide at Duszatyn in April 1907, replacing 10 million m^3 of material, was formed after wet year 1906 (1,474 mm), being followed by 371 mm of rainfall during the first months of 1907 (Schramm 1925). Another landslide at Szymbark in summer 1913 replaced 3.5 million m^3 after 500–600 mm of rainfall in two summer months (Sawicki 1917).

SUPERPOSITION OF SLOPE AND FLUVIAL PROCESSES

The types of rain, relief energy and size of the catchment are reflected in the relationship between intensity of slope and fluvial processes (Fig. 3). The studies at Szymbark station have shown i.a. that during heavy downpours of 42 mm, soil erosion on the cultivated field reached 40 t $\cdot$ ha^{-1} and simultaneously the suspended load in a small Bystrzyca creek did not exceed 0.1 t $\cdot$ ha^{-1} (Gil 1976; Słupik 1973). This means that most of the washed material was deposited at the foot of the slope. During continuous rains the situation in the same foothill catchment was opposite: the sediment yield in the creek, calculated for unit area was 160 times higher than that from the cultivated experimental plot. This is partly the effect of linear erosion along cart-roads (Froehlich 1982). However, in the mountain headwaters the continuous rains provoke a simultaneous passing of thresholds on the slopes and in river channels, both due to direct contact of river channels with steep slopes and due to superimposed downpours in a later phase of continuous rains (Ziętara 1968, 2002).

Moreover, during heavy downpour exceeding 100 mm in small catchments, not only slopes but also channels may pass the thresholds of both gravitational and fluvial processes, as it was recorded in 1998 near Krynica (Dziewański et al. 2004) or in 2001 at Maków Podhalański (Ziętara 2002).

A specific type represent continuously active landslides, being undermined by fluvial erosion; in such a case the landsliding is a secular, continuous process (Gil and Kotarba 1977).

Nevertheless, the most common case of simultaneous transformation of slopes and valley floor, typical for the tropical and monsoons areas (cf. Starkel 1976; Froehlich and Starkel 1991), are continuous rains later supported by heavy downpours. This was the case in the Beskid Wyspowy Mts. in 1997, when the landslide slopes and river channels were active at the same time and undermining of slopes by flood waters accelerated the formation of deep landslides and mudflows (Ziętara 2002; Gorczyca 2004). The same applied to the Beskid Żywiecki Mts. in 1960 (Ziętara 1968).

SNOWMELTS

Due to high percentage of forest cover in the mountains, rapid overland flow and snowmelt floods are only recorded in the deforested foothill zone, where snowmelt partly supported by rain extends over large areas (Ziemońska 1973; Słupik 1973). In case of frozen soil, the erosional effects on cultivated fields may be dramatic (Starkel 1960; Gil and Słupik 1972). In other cases meltwaters may infiltrate in the ground and with additional heavy rain cause the reactivation of landslides on a regional scale, as happened in April 2000 (Rączkowski and Mrozek 2002; Gorczyca 2004).

CLUSTERINGS OF EXTREMES

The clustering of events passing the thresholds play probably a leading role in the transformation of landscape in the temperate zone (Starkel 2002). Among these clusters, we should distinguish events of same type, following during consecutive days, or events occurring during consecutive years and series of extreme events of different types.

A good example of the first type is provided by heavy downpours repeated every day on the eastern side of the cyclone system located in the Eastern Sudetes and Western Carpathians between 4 and 10 July 1997 (Grela et al. 1999; Niedźwiedź 1999). In the Raba and Dunajec river catchment basins, especially at 7, 8 and 9 July evenings (every day) their followed heavy downpours with rainfall totals between 40 and 120 mm, with recorded intensity of up to 2 mm $\cdot$ min^{-1} (Froehlich 1998; Cebulak 1998; Gorczyca 2004, and others). Every day various types of landslides were expanding and river channels were eroded more intensively. The progressing saturation of slope deposits and re-bedding of bedload caused that during the final accord these creeks passed not only the barrier of hyperconcentrated flow but also of debris flow, as was exactly recorded at

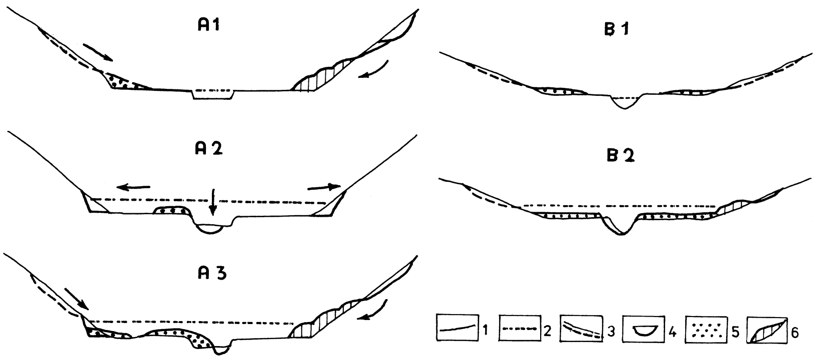

Fig. 3. Trends of transformation of slopes and valley floors in the mountains (A) and in the foothills (B) during heavy downpours (A1, B1), during continuous rain (A2, B2) and during coincidence of continuous rain with downpour causing simultaneous transformation of slopes and valley floors (A3). Signs: 1 — former cross-section, 2 — high water level, 3 — soil erosion, 4 — channel erosion, 5 — fluvial deposits, 6 — colluvia (landslides)

Homerka station in the Beskid Sądecki Mts. (Froehlich 1999). In the Uszwica River valley, the three flood waves totally transformed the channel with local incision in the bedrock up to 2 m (Patkowski 1999). A similar sequence of days with heavy downpours repeated between 23 and 27 July 2001 in the eastern part of the Beskid Sądecki Mts. (Lach and Lewik 2002).

Extreme floods during consecutive years were frequent in the last century (Cebulak 1998; Starkel 1996). The effects of such continuous rains from 1958 to 1960, causing landslides and floods in the Soła River catchment, were described by T. Ziętara (1968), leading finally to total transformation of river channels. A similar sequence of floods in the Ropa River valley in 1970, 1972, 1973 and 1974 caused at first the removal of gravels from the channel, and then incision in the solid rock and channel stabilisation (Soja 1977).

In the last decade we observed a very spectacular sequence of extreme events of various types, which are leading both to great differentiation on the local scale (role of local heavy downpours) and to stabilisation of a new trend in the relief evolution on larger areas (Fig. 1).

The July 1997 continuous rain with superimposed many local downpours was preceded at many localities by heavy downpours in 1996 (Cebulak and Niedźwiedź 1998), and followed later by similar downpours in 1998 (Ziętara 2002) and snowmelt combined with spring rainfall in 2000. Their total effect was evaluated in a part of the Beskid Wyspowy Mts. by E. Gorczyca (2004). Regular monitoring of landslides has been continuing since 1997 by the Carpathian Branch of the Polish Geological Institute (Poprawa and Rączkowski 1998; Mrozek et al. 2000; Rączkowski and Mrozek 2002). These studies recognised extensive areas affected by different types of landslides, among them: in July 1997, during spring 2000, in July 2001, and in 2002 (Photo 3). Some areas have been permanently active since 1997, some extended, while others have shown secondary cracks or slumps. We may talk about the landslide phase; continuation of landslide activity is not only triggered by repeated rainfalls but also by human activity, including undercutting of slopes during road or building constructions, as well by foundation of much heavier houses built upon old landslides which remained stable in the last centuries.

STRONG WINDS

Among geomorphic hazards, strong winds play a less important role. These winds are recorded mainly on mountain ridges. Winter deflation is a common phenomenon on cultivated fields. It is only the transversal depression of the Carpathian range in the Beskid Niski Mts. and their foreland, i.e. the Jasło–Sanok Depression, where very strong and frequent southern winds do prevail, which during some winters play a leading role in slope transformation (Gerlach and Koszarski 1968; Gerlach 1976). These winds, of velocities exceeding 10–15 $m \cdot s^{-1}$, remove snow and soil aggregates from the S-facing slopes to the opposite ones. During a windy winter, T. Gerlach measured the removal of up to 200 m^3 from 1 ha, and deposition up to 10–50 mm on the N-facing slope during one season.

CONCLUSIONS

Among geomorphic hazards in the Flysch Carpathians, different types of extreme rainfalls give the most spectacular effects. However, distinct geomorphological changes in the relief of slopes and floodplains with river channels follow when the thresholds of extreme processes are passed in both systems simultaneously. This happens either during heavy downpours on the local scale or during superposition of high intensity rain over continuous rainfall in larger catchments. The change of tendency in the evolution of slopes or river channels (frequently opposite to the previous one) is the effect of clustering of extreme events in several years, when there is no time for relaxation (Starkel 2002). We should turn our attention to such a cluster during the last decade, which seems to be common throughout Central Europe and coincident with a global warming. It is also coeval with the changes in land use and infrastructure, reduction of arable lands, expansion of forests and entering of various constructions over mountain slopes. Therefore, we observe both a distinct reduction in sediment load and incision of river channels, as well as higher flood discharges and reactivation of many old landslides.

ACKNOWLEDGEMENT

This paper has been prepared partly in the framework of the KBN project PBZ-086/PO4/2003. The author express thanks to Professor Witold Zuchiewicz for the correction of my English manuscript.

Institute of Geography and Spatial Organisation PAS
Department of Geomorphology and Hydrology of Mountains and Uplands
ul. św. Jana 22, 31-018 Kraków, Poland
e-mail: starkel@zg.pan.krakow.pl

REFERENCES

Baumgart-Kotarba M.,1983. *Kształtowanie koryt i teras rzecznych w warunkach zróżnicowanych ruchów tektonicznych (na przykładzie wschodniego Podhala).* Prace Geograficzne IG i PZ PAN 145, 145 pp.

Brykowicz K., Rotter A., Waksmundzki K., 1973. *Hydrograficzne i morfologiczne skutki katastrofalnego opadu i wezbrania w lipcu 1970 roku w źródłowej części Wisły.* Folia Geographica, ser. Geogr.-Phys. 7, 115–129.

Cebulak E., 1992. *Maksymalne opady dobowe w dorzeczu górnej Wisły.* Zeszyty Naukowe UJ, Prace Geograficzne 90, 79–96.

Cebulak E., 1998. *Przegląd wyjątkowych opadów ekstremalnych, które wywołały powodzie w XX wieku w dorzeczu górnej Wisły,* [in:] *Powódź w dorzeczu górnej Wisły w lipcu 1997 r.* Konferencja naukowa, Kraków 7–9 maja 1998, Wyd. Oddział PAN Kraków, 21–37.

Cebulak E., Niedźwiedź T., 1998. *Ekstremalne zjawiska opadowe w dorzeczu górnej Wisły w latach 1995–1996.* Dokumentacja Geograficzna IG i PZ PAN 11, 11–30.

Dziewański J., Wota A., Limanówka D., Cebulak E., Michalik S., 2004. *Katastrofalny spływ wodno-gliniasty w Muszynie w lipcu 2000 roku.* Studia, Rozprawy, Monografie 118, Instytut Gospodarki Surowcami Mineralnymi i Energią PAN, 32 pp.

Figuła K., 1960. *Erozja w terenach górskich.* Wiadomości IMUZ 1, 4.

Froehlich W., 1975. *Dynamika transportu fluwialnego Kamienicy Nawojowskiej.* Prace Geograficzne IG i PZ PAN 114, 122 pp.

Froehlich W., 1982. *Mechanizm transportu fluwialnego i dostawy zwietrzelin do koryta w górskiej zlewni fliszowej.* Prace Geograficzne IG i PZ PAN 143, 133 pp.

Froehlich W., 1998. *Transport rumowiska i erozja koryt potoków beskidzkich podczas powodzi w lipcu 1997 roku*, [in:] *Powódź w dorzeczu górnej Wisły w lipcu 1997 r.* Konferencja naukowa, Kraków 7–9 maja 1998, Wyd. Oddział PAN Kraków, 133–144.

Froehlich W., 1999. *Mechanizm i natężenie erozji, transportu i sedymentacji powodziowej w świetle badań metodami klasycznymi, radioizotopowymi i magnetycznymi*, [in:] *Funkcjonowanie geoekosystemów zlewni rzecznych*, ed. A. Kostrzewski, UAM Poznań, Wyd. Naukowe Bogucki, 33–41.

Froehlich W., Starkel L., 1991. *Wartości progowe w ewolucji rzeźby fliszowych Karpat i Dardżylińskich Himalajów.* Conference Papers IG i PZ PAN 14, 49–58.

Gerlach T., 1976. *Współczesny rozwój stoków w Polskich Karpatach fliszowych.* Prace Geograficzne IG i PZ PAN 122, 116 pp.

Gerlach T., Koszarski L., 1968. *Współczesna rola morfogenetyczna wiatru na przedpolu Beskidu Niskiego.* Studia Geomorphologica Carpatho-Balcanica 2, 85–114.

Gil E., 1976. *Spłukiwanie gleby na stokach fliszowych w rejonie Szymbarku.* Dokumentacja Geograficzna IG PAN, 65 pp.

Gil E., 1997. *Meteorological and hydrological conditions of landslides, Polish Flysch Carpathians.* Studia Geomorphologica Carpatho-Balcanica 31, 143–158.

Gil E., 1999. *Obieg wody i spłukiwanie na fliszowych stokach użytkowanych rolniczo w latach 1980–1990.* Zeszyty IG i PZ PAN 60, 78 pp.

Gil E., Kotarba A., 1977. *Model of slide slope evolution in flysch mountains (an example drawn from the Polish Carpathians).* Catena 4,3, 233–248.

Gil E., Słupik J., 1972. *Hydroclimatic conditions of slope wash during snowmelt in the Flysch Carpathians.* Symposium International de Geomorphologie, Universite de Liege, 67, 75–90.

Gil E., Starkel L., 1979. *Long-term extreme rainfalls and their role in the modelling of flysch slope.* Studia Geomorphologica Carpatho-Balcanica 13, 207–220.

Gorczyca E., 2004. *Przekształcanie stoków fliszowych przez procesy masowe podczas katastrofalnych opadów (dorzecze Łososiny).* Wyd. Uniwersytetu Jagiellońskiego, Kraków, 101 pp.

Grela J., Słota H., Zieliński J., (eds.), 1999. *Dorzecze Wisły, monografia powodzi, lipiec 1997.* Instytut Meteorologii i Gospodarki Wodnej, Warszawa, 199 pp.

Klimaszewski M., 1935. *Morfologiczne skutki powodzi w Małopolsce zachodniej w lipcu 1934 r.* Czasopismo Geograficzne 13, 2–4, 283–291.

Klimaszewski M., 1946. *Podział morfologiczny południowej Polski.* Czasopismo Geograficzne 17, 3–4, 215–234.

Lach J., Lewik P., 2002. *Powodź w lipcu 2001 roku na Sądecczyźnie i jej skutki*, [in:] *Geograficzne uwarunkowania rozwoju Małopolski*, ed. Z. Górka, A. Jelonek, Instytut Geografii UJ, Kraków, 199–204.

Mrozek T., Rączkowski W., Limanówka D., 2000. *Recent landslides and trigering climatic conditions in Laskowa and Pleśna regions, Polish Carpathians.* Studia Geomorphologica Carpatho-Balcanica 34, 89–112.

Niedźwiedź T., 1999. *Rainfall characteristics in Southern Poland during sever flooding event in July 1997.* Studia Geomorphologica Carpatho-Balcanica 33, 5–24.

Niemirowski M., 1974. *The dynamic of contemporary river beds in the mountain streams*. Zeszyty Naukowe UJ, Prace Geograficzne 34, 92 pp.

Patkowski B., 1999. *Skutki powodzi w dolinach rzecznych Pogórza Wielickiego,* [in:] *Dorzecze Wisły, monografia powodzi lipiec 1997*, eds. J. Grela, H. Słota, J. Zieliński, IMGW, Warszawa, 155–156.

Poprawa D., Rączkowski W., 1998. *Geologiczne skutki powodzi w 1997 roku na przykładzie osuwisk województwa nowosądeckiego*, [in:] *Powódź w dorzeczu górnej Wisły w lipcu 1997 roku*, Wyd. Oddziału PAN Kraków, 119–132.

Prochal P., 1968. *Badania nad erozją gleb w terenach górskich.* Procesy erozji i problem ochrony gleb w Polsce, Katedra Melioracji WSR, Lublin, 2, 51–92.

Rączkowski W., Mrozek T., 2002. *Activating of landsliding in the Polish Flysch Carpathians by the end of 20-th country.* Studia Geomorphologica Carpatho-Balcanica 36, 91–101.

Rosenfeld Ch. L., 2003. *Geomorphological hazards,* [in:] *Encyclopedia of geomorphology,* ed. A.S. Goudie, Routledge, 423–427.

Saramak A., 2005. *Ekstremalne opady atmosferyczne i ich potencjalny wpływ na wybrane procesy stokowe na przykładzie Gaika-Brzezowej.* (manuscript of dissertation in Climatological Section of Institute of Geography, Jagiellonian University, Kraków).

Sawicki L., 1917. *Osuwiska ziemne w Szymbarku i inne zsuwy powstałe w 1913 roku w Galicyi zachodniej.* Rozpr. Wydz. Mat.-Przyr. PAU 3, 13, A, 227–313.

Schramm W., 1925. *Zsuwiska stoków górskich w Beskidzie. Wielkie zsuwisko w lesie wsi Duszatyn ziemi sanockiej.* Kosmos 50, 4, 1355–1374.

Selby M.J., 1974. *Dominant geomorphic events in landform evolution*. Bulletin of the International Association of Engineering Geology 9, 85–89.

Słupik J., 1973. *Zróżnicowanie spływu powierzchniowego na fliszowych stokach górskich.* Dokumentacja Geograficzna IG PAN 2, 108 pp.

Soja R., 1977. *Deepening of channel in the light of the cross profile analysis.* Studia Geomorphologica Carpatho-Balcanica 11, 127–138.

S o j a R., 1981. *Analiza odpływu z fliszowych zlewni Bystrzanki i Ropy (Beskid Niski).* Dokumentacja Geograficzna IGiPZ PAN 1, 91 pp.
S t a r k e l L., 1960. *Rozwój rzeźby Polskich Karpat fliszowych w holocenie.* Prace Geograficzne IG PAN 22, 239 pp.
S t a r k e l L., 1972. *Charakterystyka rzeźby Polskich Karpat i jej znaczenie dla gospodarki ludzkiej.* Problemy Zagospodarowania Ziem Górskich 10, 75–150.
S t a r k e l L., 1976. *The role of extreme (catastrophic) meteorological events in contemporary evolution of slopes,* [in:] *Geomorphology and Climate*, ed. E. Derbyshire, Wiley, Chichester, 203–246.
S t a r k e l L., 1980. *Erozja gleb a gospodarka wodna w Karpatach.* Zesz. Probl. Podst. Nauk Rolniczych 235, 103–118.
S t a r k e l L., 1996. *Geomorphic role of extreme rainfalls in the Polish Carpathians.* Studia Geomorphologica Carpatho-Balcanica 30, 21–38.
S t a r k e l L., 2002. *Change in the frequency of extreme events as the indicator of climatic change in the Holocene (in fluvial systems).* Quaternary International 91, 25–32.
S t a r k e l L., G r e l a J. (ed.), 1998. *Powódź w dorzeczu górnej Wisły w lipcu 1997 roku.* Wyd. Oddziału PAN, Kraków.
Ś w i ę c h o w i c z J., 2003. *Współdziałanie procesów stokowych i fluwialnych w odprowadzaniu materiału rozpuszczonego i zawiesiny ze zlewni pogórskiej*, [in:] *Przemiany środowiska na Pogórzu Karpackim,* t. 3, ed. W. Chełmicki, Prace Instytutu Geografii UJ, 152 pp.
T h i e l K.(ed.), 1989. *Kształtowanie fliszowych stoków karpackich przez ruchy masowe*. Gdańsk–Kraków, 91 pp.
W i t - J ó ź w i k K., 1978. *Analiza deszczów w Szymbarku w latach 1969–73 (w okresie od maja do września).* Dokumentacja Geograficzna IG i PZ PAN 6, 23–67.
Z i e m o ń s k a Z., 1973. *Stosunki wodne w Polskich Karpatach Zachodnich.* Prace Geograficzne IG PAN 103, 125 pp.
Z i ę t a r a T., 1968. *Rola gwałtownych ulew i powodzi w modelowaniu rzeźby Beskidów*. Prace Geograficzne IG PAN 60, 116 pp.
Z i ę t a r a T., 2002. *Rola gwałtownych ulew i powodzi w modelowaniu rzeźby terenu oraz niszczeniu infrastruktury osadniczej w górnej części dorzecza Wisły,* [in:] *Geograficzne uwarunkowania rozwoju Małopolski,* eds. Z. Górka, A. Jelonek, Instytut Geografii UJ, Kraków, 37–54.
Z u b e r R., B l a u t h J., 1907. *Katastrofa w Duszatynie.* Czasopismo Techniczne 25, Lwów, 218–221.

STRESZCZENIE

L e s z e k S t a r k e l

WSPÓŁCZESNE ZAGROŻENIA GEOMORFOLOGICZNE W POLSKICH KARPATACH FLISZOWYCH

Wśród głównych czynników wywołujących groźne przekształcenia rzeźby istotne są różne typy: opady ekstremalne, gwałtowne roztopy i huraganowe wiatry. Autor zwraca szczególną uwagę na skutki krótkotrwałych ulew, opadów rozlewnych i pór deszczowych.

W czasie nakładania się różnych typów opadów dochodzi do równoczesnego przekroczenia równowagi systemów stokowych i korytowych z równinami zalewowymi. Szczególnie groźne są zgrupowania w czasie różnych zdarzeń ekstremalnych, wyraźnie zaznaczające się w ostatnim dziesięcioleciu.