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ACTIVATING OF LANDSLIDING IN THE POLISH FLYSCH CARPATHIANS BY THE END OF THE 20TH CENTURY

Abstract. The paper presents an outline of landslide movements activated in the Polish Flysch Carpathians in the recent years. This is the landslide prone region due to geological and morphological conditions and to active triggers among which precipitation is of a crucial importance. There is a good evidence of landsliding since the beginning of the 20th century. A close relationship between landslide movements and extreme precipitation manifested themselves in the number of such events and their extent in the recent years of the 20th century and at the beginning of the 21st century. The threshold precipitation values are presented against the background of the landsliding events involved.

Key words: landslides, catastrophic precipitation, Flysch Carpathians

INTRODUCTION

Summarizing the results of the studies that were carried out since the beginning of the 20th century it should be stated that the natural conditions make the area of the Polish Flysch Carpathians particularly prone to development of landslides, and landsliding is a fundamental geomorphic process, which contributes to essential transformation of relief of the area in question. The mountainous character of the relief (deep river valleys, slope gradients), geological settings in terms of both lithology (flysch rocks) and tectonics (rock formations, dislocation lines, faults and joints) favour landsliding in this area. Intensive infiltration of rainwater and, to a lesser degree, of meltwater into rock masses and slope covers is a direct factor triggering the landslides (Sawicki 1917; Starkel 1960, 1996; Ziętara 1968; Gil 1997; Mrozek et al. 2000). The development of landslides is encouraged by the presence of pliant to water soaking rock complexes, thick weathering covers and Quaternary deposits, and, in particular, the covers of the so called Carpathian variety of loesses occurring in the Carpathian foothills. Seismic quakes are important factors triggering and rejuvenating the landslides and should be mentioned for the sake of historical evidence (Pokorny 1958; Gerlach et al. 1958; Wójcik 1997; Bober and Wójcik 1977), however, this factor is not of a crucial importance in the Polish Carpathians.

L. Bober (1984) emphasizes a close relationship between lithologic development of the flysch members and occurrence of landslides, while among the regional, or so called active triggers, he points to precipitation as a next factor after river erosion. However, this relationship is not so straightforward as the works by L. Bober and A. Wójcik (1977), A. Wójcik (1997), A. Wójcik and Z. Zimnal (1996) point to significance of tectonics (arrangement of rocks within particular geologic units, pattern of main faults, joints etc.) in distribution of landslides, being maybe even more important than lithology of rocks building a given region.

The landslides occurring in the Polish Flysch Carpathians are in majority the old forms, created during the Pleistocene, Late Glacial and early and middle Holocene (according to landslide dating after Gil et al.1974; Alexandrowicz 1996, 1997; Margielewski 1991, 1997, 2001) when periods of intensification of extreme phenomena occurred cyclically. A very important aspect was the entering this region by man and his activity — deforestation and beginning of cereal growing, which resulted in conditions favouring a more intensive rain water infiltration into slope covers and substratum. It is a very difficult task to discriminate between the importance of climatic and anthropogenic factors, at least during the recent 2000 years (Starkel 1993–1994). The role of the main factor — rainfall — has been reinforced by man who by his inconsiderate activity was a cause of intensified landsliding. On the other hand, landsliding delimited human activity in certain cases and often damaged lifetime achievements of man.

K. Jakubowski (1974) and M. Bajger (1994) point to multiple rejuvenation of many old landslides. This rejuvenation takes place every few, several dozen or some tens of years, at the moment of catastrophic rainfall, when precipitation lasts during summer and autumn seasons but evapotranspiration ceases. Referring to such cases E. Gil and L. Starkel (1979) write about „landslide years" in the Carpathians. During such wet years (from May to July) apart from rejuvenation of the old forms, the so called "chronic" forms are subject to vivid activating (e.g. Zapadle landslide — Gil and Kotarba 1977, 1979; Kawiory landslide — Dauksza and Kotarba 1973).

The purpose of this paper is to present intensification of landsliding processes against the background of a radical increase in precipitation during the last years of the 20th century. The frequency of wet years increased and, therefore, the end of the last century is the period of particularly catastrophic mass movements (Zespół OK PIG 1997).

BRIEF OUTLINE OF THE STUDIES ON THE LANDSLIDES IN THE POLISH CARPATHIANS

The history of the studies on the Carpathian landslides is rich and the comprehensive account on the major landsliding events in the Polish Carpathians is given in Table 1. In the papers, which date back to the beginning of the 20th

Table 1

Listing of major years when landsliding movements were registered in the Polish Carpathians (based on the available literature and information collected by the Carpathian Branch of the Polish Geological Institute)

Year	Location where landslides formed*	Geomorphological region (after Starkel 1972)	Author of description
1850	Brzeżanka (1967, 1969, 1974, 1976)	Strzyżów Foothills	L. Bober et al. (1977); L. Bober et al. (1997)
1899	Krasny Łuh near Żabie at Czeremosz River valley	Eastern Carpathians	W. Łoziński (1909)
1908	Tymowa in Brzesko region	Wieliczka Foothills	W. Łoziński (1909)
1907	Duszatyn at Chryszczata slopes	Bieszczady Mountains	R. Zuber, J. Blauth (1907); W. Schramm (1925)
1912	Zagorzyce	Strzyżów Foothills	L. Starkel (1957)
1913	Szklarka Stream valley near Szymbark	Beskid Niski Mountains	L. Pitułko (1913); L. Sawicki (1917)
	Muszyna, Wierchomla, Grabówka	Beskid Sądecki Mountains	L. Sawicki (1917)
1927	Szybenne, Mt. Gropa slopes Mount Ćwilin slopes	Czarnohora Mts (Eastern Carpathians), Beskid Wyspowy Mountains	B. Świderski (1932); M. Klimaszewski (1978)
1933	Krasnoilia	Eastern Carpathians	H. Teisseyre (1934a i b)
1934	Zakopane, Poronin, Szaflary, Barcice, Rytro, Piwniczna, Łomnica and Wierchomla, Żegiestów, Muszyna, Bachledzki Wierch (1948) Dunajec River valley	Podhale Basin, Beskid Sądecki Mountains, Dynów Foothills, Beskid Wyspowy Mountains, Beskid Żywiecki Mountains	K. Stecki (1934); P. Śliwa (1955); M. Klimaszewski (1935); P. Śliwa (1955); K. Jakubowski (1967)
	Ruszelczyce, Mielniów		L. Bober et al. (1997)
	Wilkowisko (1975, 1997)		L. Bober et al. (1981); Zespół OK PIG (1997); L. Bober et al. (1997)
	Radziechowy near Żywiec		L. Bober et al. (1997)
	Tresna		L. Bober et al. (1997)
1940	Rożnów Foothills	Wieliczka Foothills	T. Ziętara (1974)
1942	Lipowica near Dukla	Beskid Niski Mountains	J. Badak, R. Pawłowski (1959)
1948	Kobyle Gródek (1997)	Wieliczka Foothills	B. Bargielewicz (1958); L. Bober et al. (1997); Zespół OK PIG (1997)

Table 1 contd

Year	Location where landslides formed*	Geomorphological region (after Starkel 1972)	Author of description
1949	Mount Przykrzec near Jordanów	Beskid Średni Mountains	M. Książkiewicz (1972)
1952	Bańska Wyżnia	Podhale Basin	P. Śliwa, Z. Wilk (1954); K. Jakubowski (1967)
1957	Lipowica near Dukla (Earthquake!) Lipowica (1970) anthropogenic	Beskid Niski Mountains	T. Gerlach et al. (1958); L. Bober et al. (1997)
1958	Eastern Podhale Basin – Łapsze Niżne, Kowaniec	Podhale Basin	K. Jakubowski (1968)
1959	Lipowska Range, Romanka Range and Lasek Range	Beskid Żywiecki Mountains	T. Ziętara (1968)
1960	Łaśnica at Cedron River valley	Wieliczka Foothills,	T. Ziętara (1968)
	Beskid Śląski, Soła River valley and Beskid Mały Mountains	Beskid Śląski, Mały, Żywiecki, Średni and Wyspowy Mountains, Nowy Sącz Basin	T. Ziętara (1968)
	Pcim near Myślenice Bielanka near Jordanów Wieliczka, Bochnia, Brzesko, Nowy Sącz Region		K. Jakubowski, S. Ostaficzuk (1962); K. Jakubowski (1967); M. Wrzosek-Matl (1961)
1962	Ostruszanki River valley near Ciężkowice	Ciężkowice Foothills	T. Ziętara (1968)
	Babia Góra Range Złatne near Ujsoły Tresna – Zaporze	Beskid Żywiecki Mts, Wieliczka Foothills	L. Bober et al. (1997) K. Jakubowski (1974)
	Zagórze near Rożnów (1997, 2000, 2001)		L. Bober et al. (1997); Zespół OK PIG (1997)
1964	Plebańska Góra near Myślenice		L. Bober et al. (1997)
1970	Szymbark Kotelnica w Zakopanem	Beskid Niski Mountains, Podhale Basin	L. Dauksza, A. Kotarba (1973); E. Gil, A. Kotarba (1977); L. Bober et al. (1997)
1974	Szymbark Region, e. g. Bystrzyca Łącko Foothils	Beskid Niski Mountains, Beskid Wyspowy Mts	E. Gil, L. Starkel (1979); K. Thiel (1989); L. Bober et al. (1997); S. Ziemnicki, J. Repelewska-Pękalowa (1977)

Table 1 contd

Year	Location where landslides formed*	Geomorphological region (after Starkel 1972)	Author of description
1977	Stojowice	Wieliczka Foothills	L. Bober et al. (1997)
1978	Szymbark Region, e.g. pod Kamionką	Beskid Niski Mountains	E. Gil (unpublished)
1980	Połoma Szymbark Region e.g. pod Kamionką	Bieszczady Mountains Beskid Niski Mountains	J. Dziuban (1983); W. Margielewski (1991); E. Gil (unpublished)
1985	Bystrzyca in Szymbark Łomnica	Beskid Niski, Beskid Sądecki	E. Gil (1996); L. Bober (1992)
1988	Brzezowa near Myślenice Debris-flows in Tatra Mts	Wieliczka Foothills	L. Bober et al. (1997); A. Kotarba (1994)
1996	Beskid Żywiecki Mountains	Beskid Żywiecki Mts	T. Ziętara (1999)
1997	Landslides in Nowy Sącz and Tarnów voievodships	Beskid Żywiecki, Średni, Wyspowy, Sądecki and Niski Mountains, Carpathian Foothills, Podhale Basin, Tatra Mountains	Zespół OK PIG (1997); E. Gil, W. Bochenek (1998); E Gorczyca (1998); T. Ziętara (1998, 1999); A. Kotarba (1999)
	Debris-flows and landslides in Tatra Mountains and Podhale Basin Region		
1998	Mszana Dolna and Górna Region, Laskowa, Kamionka and Sechna	Beskid Wyspowy, Wieliczka, Ciężkowice and Strzyżów Foothills, Beskid Wyspowy Mts	Zespół OK PIG (1997)
2000	Landslides in Carpathian Foothills and Beskid Wyspowy Mountains		Zespół OK PIG (1997)
2001	Lachowice, Budzów, Jachówka, Harbutowice, Przykrzec near Jordanów	Beskid Średni Mountains, Wieliczka Foothills, Nowy Sącz Basin	Zespół OK PIG (1997); T. Ziętara 2001
	Rożnów and Czchów Dam Region		Zespół OK PIG (1997)
	Landslide in Falkowa – Nowy Sącz		Zespół OK PIG (1997)
2002	Lachowice, Kamionka, Sechna, Ropa, Jachówka	Beskid Średni, Wyspowy and Niski Mountains	Zespół OK PIG (1997)

* Years in parantheses denote the reported re-activating of the landslide.

century, for the first time, the attention was drawn to landslide-induced hazard for people dwelling this region (Zuber and Blauth 1907; Łoziński 1909; Pitułko 1913; Schramm 1925). The works carried out by L. Sawicki (1917) depicted the landslide formed in the Szklarka valley near Szymbark and some other forms in the Beskid Sądecki Mts. During the 1920s–1930s numerous papers in the field of geology were published which provide description of a number of newly formed landslides and rejuvenated ones at that time (i.a. Świderski 1932; Teisseyre 1934a, b; Stecki 1934; Klimaszewski 1935). After WWII the majority of the papers in this domain deal with the formation of the landslides in relation to the catastrophic rainfall and with the rejuvenation of the old forms already existing on the slopes (Śliwa and Wilk 1954; Śliwa 1955; Bargielewicz 1958, 1961; Wrzosek-Matl 1961; Gerlach 1962; Michalik 1962; Jakubowski 1962, 1964, 1965, 1967, 1968, 1974; Jakubowski and Ostaficzuk 1962; Starkel 1960, 1996; Ziętara 1964, 1968). As early as in 1968 started a series of new studies associated with the Research Station of the Institute of Geography and Spatial Organization of the Polish Academy of Sciences, where the landslides were subject to systematic examination (detailed monitoring) and are still under investigation (Kotarba 1970, 1986; Dauksza and Kotarba 1973; Gil and Kotarba 1977, 1979; Gil 1994, 1997; Gil and Bochenek 1998).

Other studies on landslides were carried out within the framework of practical tasks such as designing of water reservoirs on the Carpathian tributaries of the Vistula River or highway projects. Moreover, a detail inventory of the landslides has been continued during the field surveying for the *Detail Geological Map of Poland 1:50,000*. The registration of the landslides in Poland performed by the end of the 1960s provided a comprehensive view on their distribution. Out of 10,860 forms recorded at that time, 8,500 occurred in the Polish Flysch Carpathians (*Katalog osuwisk...* 1975). The further geological studies allowed to increase that number to the total of 20,000 of landslide forms of various types and sizes (Rączkowski 2001). The detail registration of the landslides in the scales of 1:5,000 and 1:10,000 is being carried out for the purpose of the regional planning at the level of the smallest administrative units (gminas) in the Carpathians (Mrozek and Rączkowski 2001; Wójcik et al. 2001 — archive materials).

The spatial extent of the landsliding of 1997 and the scale of the related damages became the stimuli for further more precise examination of landsliding within the framework of natural hazard mitigation. The detail studies are being performed on the active "chronic" landslides in the vicinity of Szymbark (Kawiory, Zapadle, Taborówka) and in Laskowa, Lachowice, Falkowa, Jachówka, etc.

METEOROLOGICAL CONDITIONS IN THE 20TH CENTURY AND IN THE FIRST YEARS OF THE 21ST CENTURY AS THE BACKGROUND OF THE LANDSLIDE DEVELOPMENT

Landslides in the Polish Flysch Carpathians develop mainly in relation to the catastrophic rainfall and accompanying floods (Fig. 1). In the 20th century, 37 cases of the catastrophic rainfall with the totals above 200 mm, including 20 events whose precipitation sums exceeded 350 mm (Cebulak et al. 2000;

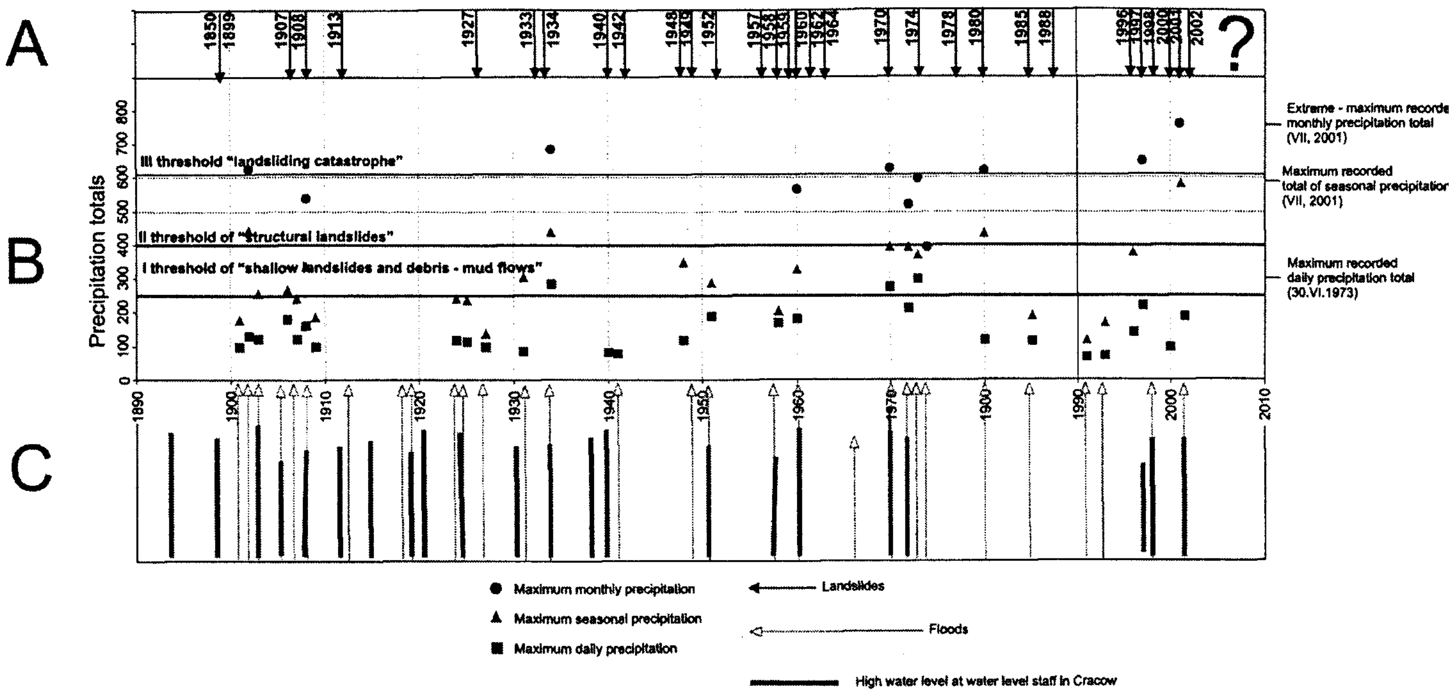


Fig. 1. Compilation of landslide movements in the Polish Flysch Carpathians according to the published literature (A) in relation to precipitation data (B) of IMGW data (Cebulak et al. 2000, 2002) and in relation to floods (C) based on IMGW data and literature (Czulak and Niedbała 2000). Bold lines denote threshold values

Cebulak et al. 2002), and 12 cases of catastrophic floods (Czulak and Niedbała 2000) were recorded.

As the catastrophic rainfalls usually occur in certain drainage basins of the Carpathians rivers, the spatial distribution of the accompanying floods and landslides is also related to these basins (1903 — Soła, Skawa; 1925 — Skawa; 1934 — Skawa, Raba, Dunajec; 1940 — Wisła, Soła, Skawa; 1948 — Skawa, Raba; 1958 — Soła, Skawa; 1960 — Skawa, Dunajec; 1970 — Wisła, Soła, Skawa, Raba, Dunajec; 1974 — Ropa, Wisłoka; 1980 — San; 1997 — Wisła, Skawa, Dunajec, San; 2001 — Skawa). The annual precipitation totals in the Carpathian region decrease eastward and the catastrophic rainfall usually occur in the western part of the Polish Carpathians, so the Biała Dunajcowa drainage basin (Cebulak et al. 2000) seems to be the delimiting zone here. In the mountainous region of the Polish Carpathians, which is the most prone to formation and rejuvenation of landslides and similar phenomena (debris flows and mud-debris flows, falls, washing), not only is the precipitation total during a rainfall period important but also the character of precipitation and its distribution in time. The papers summarizing over 30 year long period of investigations of the Research Station at Szymbark emphasize that the deep-seated landslides are formed after long-lasting precipitation, when the monthly precipitation totals of 400–550 mm cause saturation of the substratum and overloading by water infiltrating into rock masses. When rainfalls are continuous and their cumulative totals amount to 400 mm during 2–5 days, the earth slides comprising weathering covers are formed and dormant landslides are activated. Short-lasting catastrophic downpours whose daily totals exceed 100 mm and whose intensity is 1–3 mm min^{-1} cause intensive downwash, debris-mud flows (Gil and Starkel 1979; Starkel 1960, 1996; Gil 1997) and debris flows (the latter are recorded mainly in the Tatras — Kotarba 1994, 1999).

Figure 2 shows the extent of landsliding triggered during the recent years. The pattern of these phenomena coincides well with the eastward decline of precipitation. The catastrophic precipitation of summer 1997 and 2001 brought about the most spectacular mass movements in the regions of the Beskid Żywiecki, Beskid Wyspowy and Beskid Sądecki Mts. To illustrate the magnitude of the rainfalls involved it is sufficient to consider the data for July 1997 (Table 2). At some stations, the monthly precipitation totals of July 1997 were above 600 mm (Cebulak et al. 2000) while the daily precipitation totals recorded at numerous meteorological stations exceeded 200 mm. Many extraordinary values were recorded, for example, the total of 2-hour precipitation of 9 July exceeded 120 mm at the rain gauging station in Rozdziele. These rainfalls contributed to formation/rejuvenation of many landslides, especially in the middle part of the Polish Carpathians. Precipitation of the extraordinary totals and the long period of their occurrence (June-July 1997) contributed to disturbance in slope stability after an almost 15-year long dry phase. The landslides

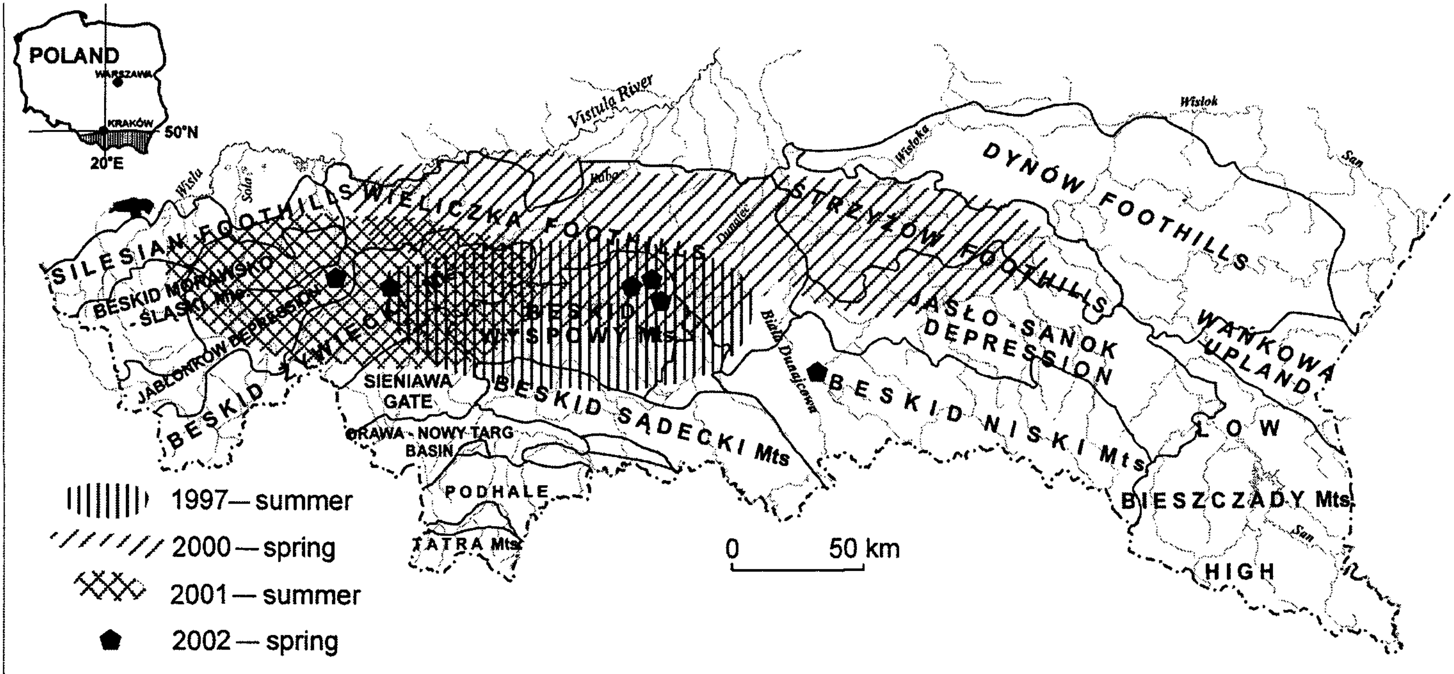


Fig. 2. Extent of landsliding in the Flysch Carpathians in the recent years of the 20th century and at the beginning of 21st century

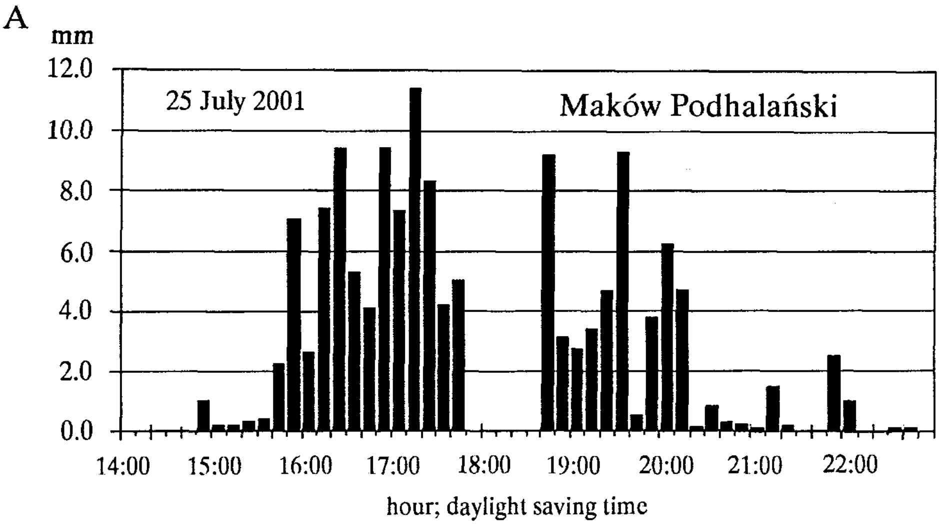
Table 2

Precipitation totals of July 1997 and 2001 and other extraordinary monthly totals at the selected Polish Carpathian stations

Station	Precipitation totals in July of 1997 [mm]	Precipitation totals in July of 2001 [mm]	Other extraordinary precipitation: Monthly totals [mm]	Other extraordinary precipitation: Month and year
Dolina Pięciu Stawów	613	788	566	July 1960
Hala Gąsienicowa	560	743	622 596	July 1980 June 1973
Kasprowy Wierch		651	588	July 1980
Równica Wieś	648			
Zwardoń			624	June 1902
Brenna Leśnica	602		540	July 1908
Szczyrk	540	375		
Maków Podhalański		521		
Poronin	386	505		
Wisła Malinka	501			
Limanowa	332	266		
Półrzeczki	185	318	352	July 1960
Zakopane	365	439	438	July 1960
Żabnica	436	421		
Wisłok Wielki	225	235	408	July 1980
Rozdziele	374	300		
Krzeczów	298	395		
Tarnów	248			

in Stańkowa or Laskowa in the Beskid Wyspowy Mts can serve here as examples (Zespół OK PIG 1997; Mrozek et al. 2000).

Precipitation of July 2001 was extremely high as well, and the monthly precipitation totals reached their record values at numerous stations. That caused a danger of floods. At all the Tatra stations the recorded precipitation of July was above 700 mm (maximum value — 788 mm at the Dolina Pięciu Stawów, in the Tatra Mts), while at numerous Beskidian stations the appropriate monthly precipitation totals exceeded 500 mm. The daily precipitation totals exceeded 150 mm, and, for example, in Maków Podhalański the hourly sums were as high as 8–10 mm as illustrates Figure 3A (Cebulak et al. 2002). The



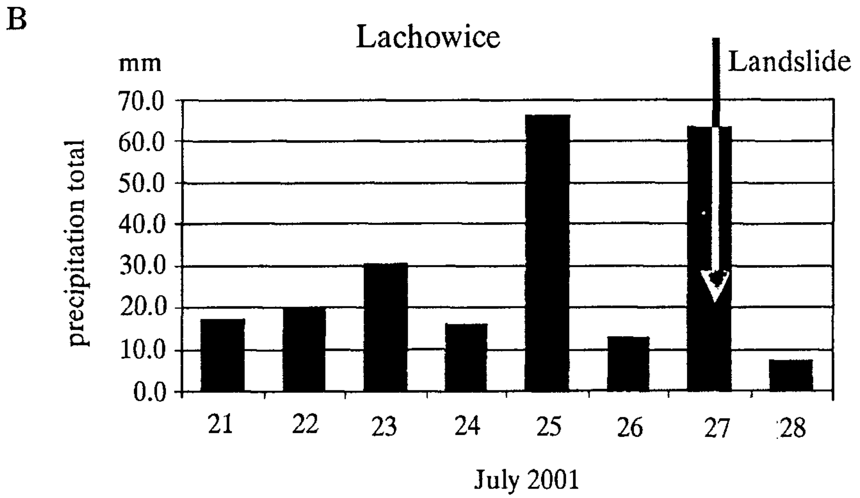


Fig. 3. A — Hourly precipitation at the station in Maków Podhalański on 25 July 2001. B — Daily precipitation preceding landslide movements on the slopes of Pierchałówka in Lachowice for 20–27 July 2001

range of daily precipitation preceding the landsliding events is shown in Figure 3B with Lachowice landslide as example.

The rainfall lasting since June brought about tremendous hazard and damages in the Carpathian river valleys (especially the Skawa drainage basin) while the landslides became activated/rejuvenated on the slopes. The major region in which the landslides were triggered is the Beskid Morawsko-Śląski, Beskid Środkowy, Beskid Wyspowy and Beskid Sądecki.

Similarly to the year of 1997, the majority of landsliding movements in 2001 took place within the area of the old landslides, already existing in a given locality for a long time. For example, the landslide in Lachowice (Fig. 4, Photo 1) of the area of ca 13 ha was formed within the old morphological form whose area is 3 times larger. The activated landslide in Falkowa near Nowy Sącz (Fig. 5, Photo 2) comprised the area of ca 10 ha and this renewed form amounted only to the 1/10 of the old landslide developed on the entire slope in Falkowa. These landslides were renewed by dislocation of the material in the upper segment of the slope, while the lower slope segments moved in reaction to pressure from the upper mass of water and material. The most spectacular effects were recoded in the niches of the old forms — a 15 m high scarp has been exposed (see Photo 2), and in the case of the landslides of Lachowice and Falkowa the damages occurred on the entire slopes.

The delapsive slope movements and related landsliding was also observed in relation to summer precipitation of 1997 and 2001. However, the channelization of the Carpathian rivers and streams reduced substantially the role of lateral erosion and downcutting of rivers and streams which

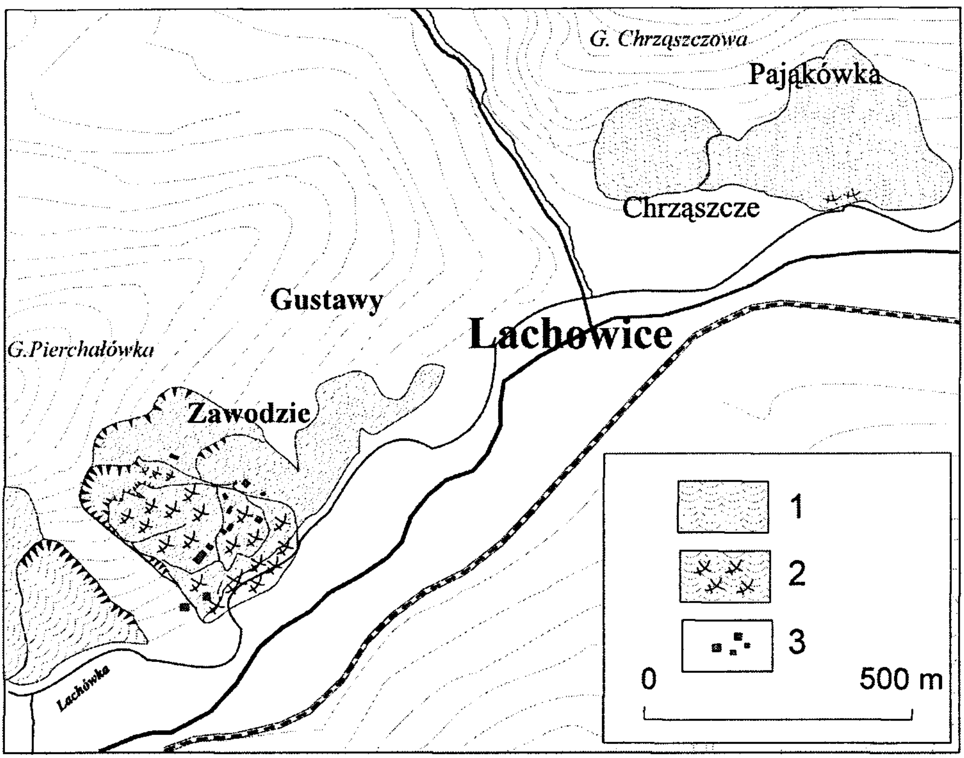


Fig. 4. Distribution of landslides in the Lachówka stream valley near Lachowice. Old landslide on the slopes of Pierchałówka Mts damaged the settlement of Zawodzie on 27 July 2001. 1 — old landslides, 2 — dislocated parts of the landslides, 3 — damaged houses

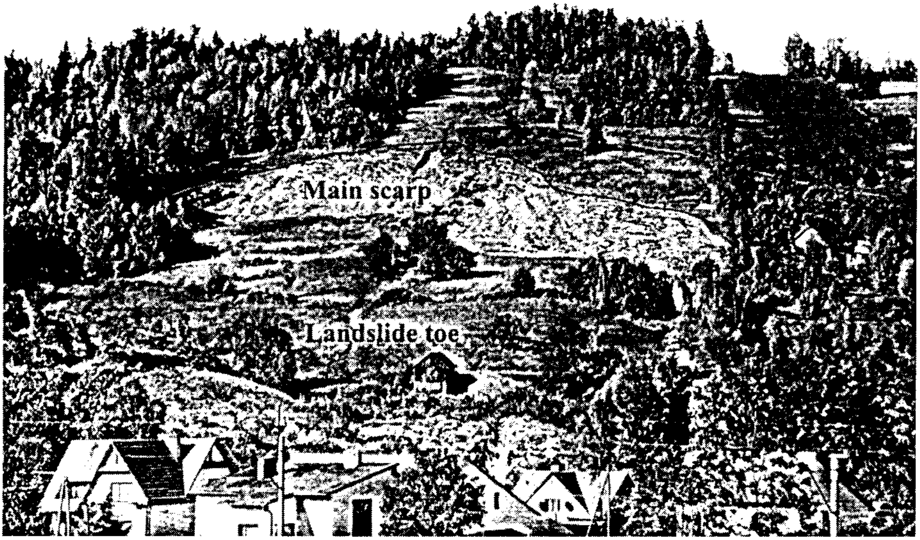


Photo 1. Landslide in Lachowice, July 2001

Photo 2. Landslide in Falkowa, July 2001

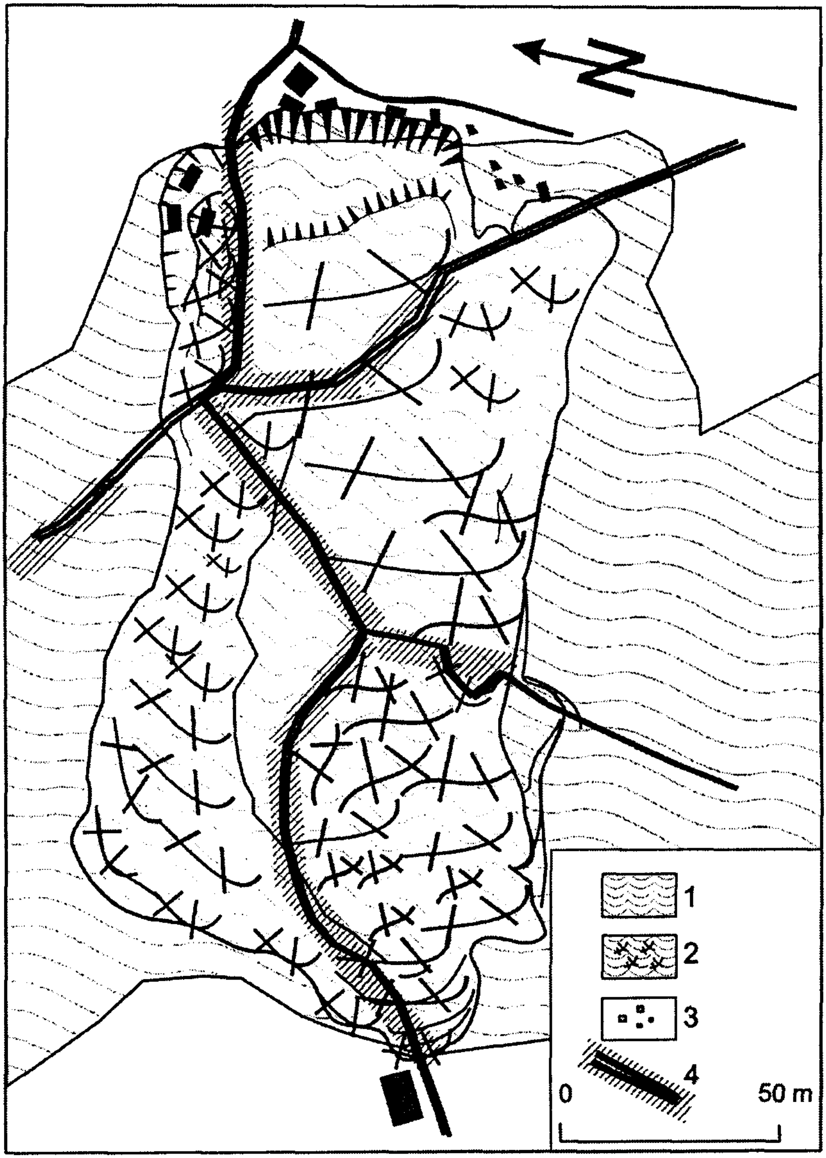


Fig. 5. Landslide in Falkowa near Nowy Sącz. 1 — old landslides, 2 — dislocated parts of the landslides, 3 — damaged or endangered houses, 4 — destroyed segments of roads — positions after landslide movement

probably belonged to major reasons of landslide triggering during the Holocene or earlier as emphasized in many publications (i.a. Dauksza and Kotarba 1973; Bober 1984).

In the period for 1998–1999 landsliding also occurred in association with precipitation, however, the latter was not so spectacular, thus the landsliding was not as extensive as in 1997 (the Beskid Wyspowy Mts, the Carpathian Foothills). Sporadically, landsliding triggered in the spring period was recorded in 1998 (e.g. region of Mszana Dolna), however, the scale of the phenomena was local.

In the Polish Flysch Carpathians and at their foothills, the region located in the temperate climate, the triggering of the landslide movements attributed to summer precipitation is apparent. However, the landsliding, which develops in spring time becomes more and more significant as, evidenced by the phenomena of recent years. The slope stability became very delicate and in certain region (especially in the Carpathian Foothills and Beskid Wyspowy Mts) a tiny rainfall or meltwater are sufficient to trigger landslide processes.

Specific weather condition of winter 1999/2000, rainfall and snowfall at the beginning of April 2000 caused the landsliding events to occur with a higher intensity, especially in the foothill parts of the Polish Carpathians (Mrozek et al. 2000). The damages due to landslides (area deteriorated and households destroyed) were even larger than in 1997.

In the sense of setting off the landslide movements spring of 2000 was to a certain extent similar to spring of 1907 when one of the larger and better known landslides — that in Duszatyn (Zuber and Blauth 1907; Schramm 1925) was formed. However, other aspects were somewhat different; the winter season of 1906/1907 was characterized by a thick and long-lasting snow cover (Zuber and Blauth 1907) and high precipitation exceeding a multi-year average (142% in November 1906 and 203% in January 1907 — Kardaszewska 1968) while the season 1999/2000 was characterized by discontinuous snow cover, mid-winter thawing, and precipitation only slightly exceeding the multi-annual average for particular months except of March when it was very high (at Limanowa 278%, Rozdziele 250% and Tarnów 240% of the average of this month for 1951–1996)

The evidences of spring landsliding are also forms and processes registered during the period of the early spring of 2002. Such landslide movements, associated with spring melting occurred in the regions of Lachowice, Jachówka, Laskowa, Sechna, Ropa and Szymbark.

THRESHOLD VALUES FOR LANDSLIDING EVENTS

W. Froehlich and L. Starkel (1991) were likely the first researchers who dealt with threshold values in the relief evolution of the Flysch Carpathians. These authors accentuated that the threshold values are usually reached locally and they almost never occur simultaneously on the slopes and in the river channels — the latter finding confirmed by earlier paper by L. Starkel (1972, 1979).

Following the above approach, the analysis of the precipitation totals in the 20th century, the threshold values when transformation of slope relief occurs due to landslide movements are suggested (Fig. 1). It seems reasonable to link the first threshold value, called "the threshold of landslide catastrophe" with monthly precipitation total above 600 mm (values for the years of 1902, 1934, 1960, 1970, 1980, 1997 and 2001) — the cumulative outcomes of landsliding in these years were catastrophic. In these years, the annual precipitation totals were also above the average and the precipitation totals of July usually amounted to 1/3 of the annual sum. During these years all types of landslide movements were recorded, namely deep-seated structural landslides, slips of weathering covers, debris and mud-debris flows. In the Carpathians, the structural landslides are formed/renewed when the slope deposits are oversaturated with water which is associated with large sums of precipitation in a given period (cf. rainy seasons — Starkel 1996) exceeding 400 mm during a given rainfall event (usually ca of the annual precipitation total — it is a "lower threshold of structural landslides") and amounting to the monthly value above 600 mm. In the case of very intensive rainfall whose daily totals exceed 250 mm ("threshold of shallow landslides and debris and debris-mud flows") in the area affected by such rainfall, the shallow, weathering cover landslides, debris flows and mud flows occur in the Polish Carpathians.

FINAL REMARKS

Catastrophic rainfalls, as all other phenomena of this type, occur in a random manner (i.a. Warakomski 1998; Walanus and Soja 1995), and cannot be assigned any regularity. Because of that the landslides cannot be forecasted with sufficient certainity, as the weather conditions cannot be precisely forecasted for longer periods — of a year, two years or more.

The inventory (registration) performed in the recent years and observations of the landslides, which have formed and are renewed contemporarily, lead to conclusion that the majority of the landslides is old, but they are subjected to multiple rejuvenation during the successive periods of particularly high precipitation — "landslide years" in the Carpathians. The landsliding occurs randomly — irregularly — and comprises only some, particularly (meteorologically) prone areas of the Carpathians as well as the regions apt due to specific geological settings (the Beskid Żywiecki Mts, Beskid Wyspowy Mts, regions of Rożnów reservoir, vicinity of Szymbark). During the periods separating the landsliding events there is a preliminary ("setting-off") time interval of a relative stability of the slopes, weathering of exposed rock formations, loosing and cracking of rock masses due to a load released etc. The landslide movement takes place as a result of external triggers, and damages are observed on the slope surface. The regions most prone to landsliding processes are mainly the areas of the old landslides where the natural rock structure has already been destructed — the colluvia are more sensitive than the terrains of undisturbed geological structures. Apart from the main trigger, which is usually precipitation water, there are many interlinked factors resulting from the geological structure.

In the case of the occurrence of the catastrophic events, the term forecasting/predicting can only denote a probability that such events will occur but it cannot indicate a specific location, timing and intensity of these events. In the Polish Flysch Carpathians the locations particularly apt to high daily precipitation (of 1% probability i.e. T= 100 years) are the northern slopes of the Tatras. In the Beskid Żywiecki Mts, Beskid Morawsko-Śląski as well as the Gorce Mts, the Beskid Wyspowy and Beskid Środkowy the precipitation whose daily total is > 150 mm can occur while in the Tatras and the Beskid Śląski it can exceed 200 mm and more. In the region of the foothills one can expect renewal/formation of the landslides when the winter seasons are mild but snowy, and spring snow melting is fast. In the eastern part of the Polish Carpathians — located in the region of a lower probability of catastrophic precipitation (although such events may happen there but with lesser effects — 1980, 1987) and of a smaller number of the old landslides occurring here — there is a lower probability of landslide movements.

The scale of the damages related to the landslides is very large and should be a warning for decision makers, local authorities and people dwelling the landslide prone regions. The assessment of a risk understood as a product of vulnerability and economic value should be considered when choosing location for new investments and remedial actions in the case of already existing structures. The best mitigation and prevention measure in the landslide affected regions seems to turn away from building on the landslide slopes as it is known that the mass movement processes will occur in these localities and the open question is only when and where particularly.

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STRESZCZENIE

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UAKTYWNIENIE PROCESÓW OSUWISKOWYCH W POLSKIEJ CZĘŚCI KARPAT FLISZOWYCH W KOŃCU XX WIEKU

Polskie Karpaty fliszowe są obszarem, gdzie procesy osuwiskowe i związane z nimi formy występują powszechnie, ze względu na specyficzną budowę geologiczną, warunki morfologiczne oraz stymulujące czynniki aktywne. Wśród czynników aktywnych dominującą rolę odgrywają opady atmosferyczne, przy czym ważna jest ich wielkość, natężenie oraz rozkład w przestrzeni i czasie. Ilustruje to dobrze literatura przedmiotu (tab. 1, ryc. 1). Poza osuwiskami rozwijającymi się w następstwie opadów letnich, obserwuje się również nasilenie procesów osuwiskowych w okresach wiosennych, jako skumulowany efekt saturacji wodami roztopowymi. W ostatnich latach poprzedniego wieku oraz na początku bieżącego można zauważyć istotną zależność pomiędzy występowaniem ekstremalnych opadów i liczebnością oraz rozprzestrzenieniem osuwisk. Wartości progowe opadów wywołujących specyficzne procesy osuwiskowe ilustruje rycina 1.