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

PIOTR MIGOŃ (WROCŁAW), MOJMÍR HRÁDEK (BRNO),
KRZYSZTOF PARZÓCH (WROCŁAW)

EXTREME EVENTS IN THE SUDETES MOUNTAINS. THEIR LONG-TERM GEOMORPHIC IMPACT AND POSSIBLE CONTROLLING FACTORS

Abstract. In the paper we review extreme geomorphological events in the Sudetes Mountains and discuss their formative role in the long-term landform evolution and factors controlling their occurrence. Extreme phenomena of significant geomorphic impact include debris flows, landslides, gully erosion and floods, all being generated by episodes of heavy rainfall in spring or summer season. Debris flows play an important part in the evolution of mountain slopes, yet they are spatially restricted to two highest mountain ranges within the Sudetes, Karkonosze and Hrubý Jesenik, both formerly glaciated and currently elevated above the timberline. Landslides are rare and disfavoured by geological structure and insufficient regolith thickness. Valley floors affected by big floods are the most dynamic environment and numerous erosional and depositional effects accompany each major flood. River behaviour during floods indicates the tendency towards re-creating braided patterns which existed prior to the onset of extensive human colonization and land use changes. However, newly created landforms are usually quickly obliterated by humans and geomorphic long-term impact of extreme events is thus considerably reduced. The primary factor controlling the occurrence and effects of extreme geomorphic events in the Sudetes appears to be human impact, chiefly extensive deforestation of mountain slopes and associated alteration of hydrological regimes. No unquestionable evidence exists to argue about increasing frequency and magnitude of extreme events in the last few decades, nor about effects of any directional climate change.

Key words: extreme events, debris flow, landslide, runoff, floods, human impact, land use, Sudetes

INTRODUCTION

Recent catastrophic floods of 1997 and 1998 in the Sudetes Mountains, unparalleled within the last fifty years or so, have generated much interest as far as their geomorphological impact is concerned. In a number of papers landscape changes resultant from accelerated runoff and flooding of valley floors have been extensively documented and patterns of erosion and deposition identified (e.g. Czerwiński and Żurawek 1999; Hrádek 1999; Żurawek 1999; Zieliński 2001). It has become immediately clear that the extent of re-modelling of valley floors has significantly surpassed any landform changes witnessed over the previous tens of years. However, given the evidence from the 1997 event alone, it would perhaps be premature to consider it as a formative event since the fate of newly created landforms is yet to be monitored. This raises an important issue whether low frequency but high magnitude events do play an important part in the recent geomorphic evolution of medium-high mountains such as the Sudetes, or are insignificant in relation to secular processes and over longer time scales.

In this paper we aim to partially address the above issue by reviewing the available evidence of geomorphic role of extreme events in the Sudetes. In particular, we consider mass movement phenomena of debris flows and landslides, erosional events on slopes resultant from accelerated surface runoff, and floods. We will discuss the reasons of extreme geomorphic events in the Sudetes, and indeed, where their fundamental controls are to be sought.

STUDY AREA

The Sudetes are the highest mountain range in Central Europe (Śnieżka, 1,603 m a.s.l.) northwards from the Alpino-Carpathian chain (Fig. 1) and although its general landscape of forested slopes and drainage divides may be considered representative to the medium-high mountains, there are also similarities with high mountains as shown by the occurrence of the timberline at ca 1,200–1,250 m a.s.l. and relict Pleistocene glacial landforms. Much of the lower slopes below 700–800 m a.s.l. were deforested in the medieval times, and arable land locally extends to 600–700 m a.s.l. nowadays.

Lithology, structure and relief of the Sudetes cannot be discussed at length here, but a few characteristics important in the context of extreme geomorphic events need to be highlighted. The Sudetes are built predominantly of igneous and metamorphic rocks, and their highest parts contain exclusively these lithologies. Regolith blanket in the form of coarse slope deposits is usually very thin, hardly exceeding a few metres, thus solid bedrock occurs very close to the surface. These circumstances apparently disfavour any more extensive landslide activity.

The gross morphology of the mountains consists of intramontane basins of various size and origin, surrounded by uplands and mountain ranges (Jahn 1980). Many of the ranges are horsts, separated from the basins through high, steep and deeply dissected marginal slopes of tectonic origin. This has important implications for runoff characteristics and rapid generation of flood wave within basins, as well as for geomorphic processes in the piedmont zone, within the alluvial fan area (Czerwiński 1991; Żurawek 1999). In the highest part of the Sudetes, in the Karkonosze massif, there exist cirques and trough valleys inherited from mountain glaciation in the Pleistocene. Their exceptionally steep

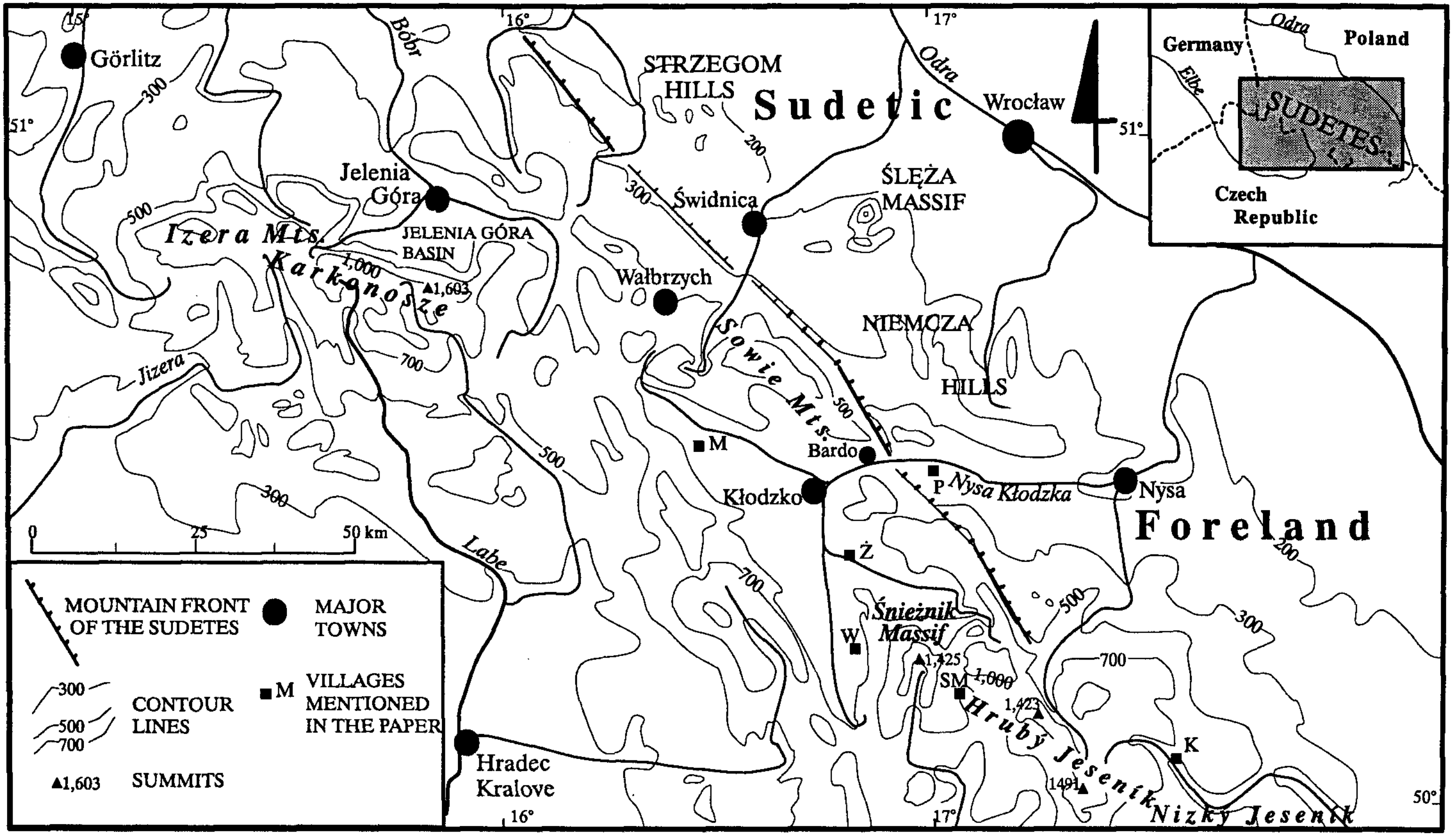

Fig. 1. Location map. K — Karlovice, M — Martinkovice, P — Pilce, SM — Stare Mesto pod Sneznikem, W — Wilkanów, Ż — Żelazno

slopes, locally by as much as 60°, and perched blankets of regolith cover above the timberline are often affected by debris flows and related mass movements (Pilous 1973). In the remaining parts of the Sudetes glacial forms are very rare (Hrubý Jeseník) or non-existent.

Abnormally high precipitation episodes are not uncommon for the Sudetes, often taking the form of a late spring or summer cloud burst and being at least partially intensified by orographic effect. They are known to generate flood waves and historical records contain frequent references to precipitation-related flood events (Trzebiński and Trzebińska 1954; Czerwiński 1991; Polách and Gába 1998). Although these records seem to show an increasing frequency of flooding episodes from late medieval towards recent times, this could be an artefact of their incompletness for the more distant past and not the reflection of an actual climatic trend. Furthermore, extensive forest die-back in the last 20–30 years, especially in the West Sudetes, has significantly changed runoff characteristics and contributed to an increasing probability of flooding although rainfall characteristics may remain constant. For example, A. Dubicki (1993) reports 10–16% increase in average yearly runoff, up to 30% increase in snowmelt runoff maximum, 40–90% increase in the height of rainfall-induced flood wave and up to 95% increase in flood discharges. Similarly, apparent clustering of major floods between 1875 and 1930 may be causally linked to extensive deforestation of the mountains. Generally, the Sudetes receive from 700–800 mm to 1,500 mm of rainfall per year, depending largely on the altitude, but with a slightly decreasing amount to the east.

DEBRIS FLOWS AND RELATED PHENOMENA

Debris flows are typical high-mountain phenomena and therefore their occurrence in the Sudetes is both infrequent and restricted in space. They are known from two highest ranges within the Sudetes only, the Karkonosze in the west (Ouvrier 1933; Pilous 1973, 1975, 1977) and the Hrubý Jeseník in the east (Sokol 1955; Gába 1992).

A detailed register of debris flows in the Karkonosze Mountains for the period until 1976, based on both field evidence and historical sources, includes references to more than 170 cases on the Czech side alone (Pilous 1973, 1975, 1977). In the subsequent years, a few new flows have been recorded (Pilous 1994). No comparable inventory has been made for the Polish side so far, yet we may safely identify at least 20 debris flow tracks (Czerwiński 1967; Pilous 1973; Parzóch 2001; Sadulski 2001).

Debris flows are concentrated in two distinct geomorphic settings, within glacial cirque walls and within steep (> 20°) slopes of deeply incised valleys, often re-modelled and deepened by valley glaciers in the Pleistocene (Fig. 2). They are generated above the timberline by moderately deep regolith slides,

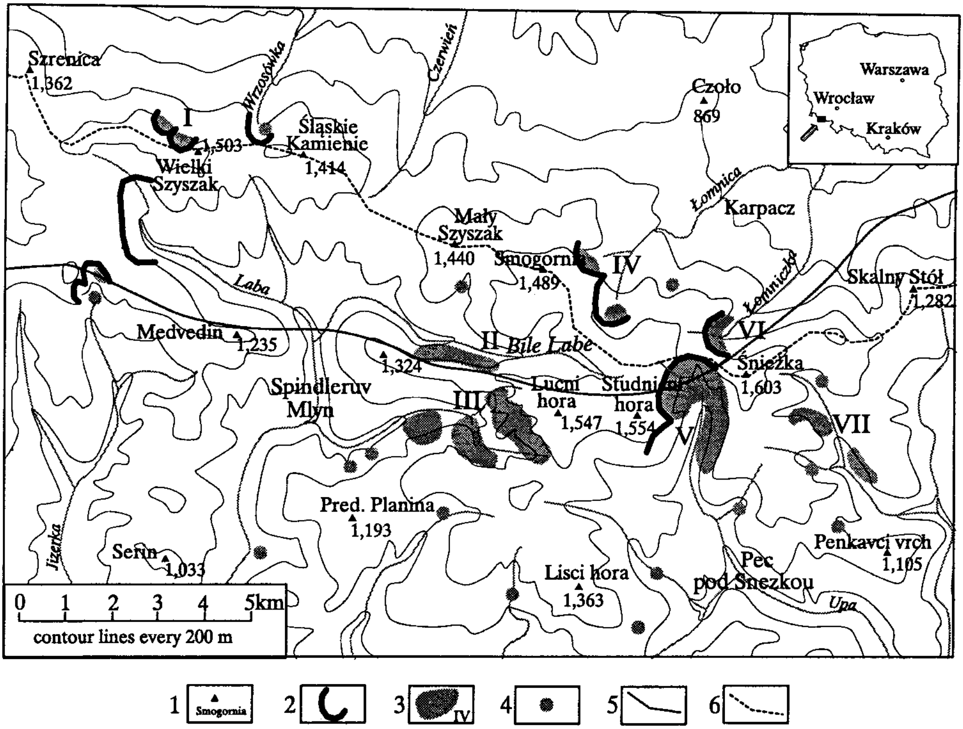

Fig. 2. Distribution of areas affected by debris flows in the Karkonosze Mountains. 1 — major summits, 2 — glacial cirque headwalls, 3 — slopes subjected to debris flow activity most frequently (I — Śnieżne Kotły, II — Dul Bilého Labe, III — Dlouhý dul, IV — Kotły Wielkiego i Małego Stawu, V — Upská jama i Obří dul, VI — Kocioł Łomniczki, VII — Jelení dul), 4 — individual debris flows, 5 — granite/country rock lithological boundary (granite area occupies the northern part), 6 — state boundary

which usually occur during thunderstorms, however preceded by longer periods of wet weather or even continuous rain. The probable role of antecedent soil moisture is shown by relatively low hourly intensities of rainfall (Table 1), which seem to be far below the threshold values of 40 mm $\cdot$ h^{-1} for debris flow initiation as established for the Tatra Mountains (Kotarba 1992). On the other hand, it is possible that short-term intensities of rainfall may have been higher than calculated from rainfall totals, although rainfall intensities in summer 1997 (Dubicki, Malinowska-Małek 1999; Table 1) are real and not calculated.

On their way downslope, debris flows may invade the upper montane forest belt and travel across it towards valley floors over distances of a few hundreds meters (Photo 1). The exact form of movement is controlled by the pre-existing topography. The existence of linear incisions within the slopes exerts an effect of channelling and typical debris flows arise, otherwise much wider debris avalanches occur. Landforms left by debris flows and avalanches vary in size. The majority of tracks, ca 60%, is small, not exceeding 200 m in

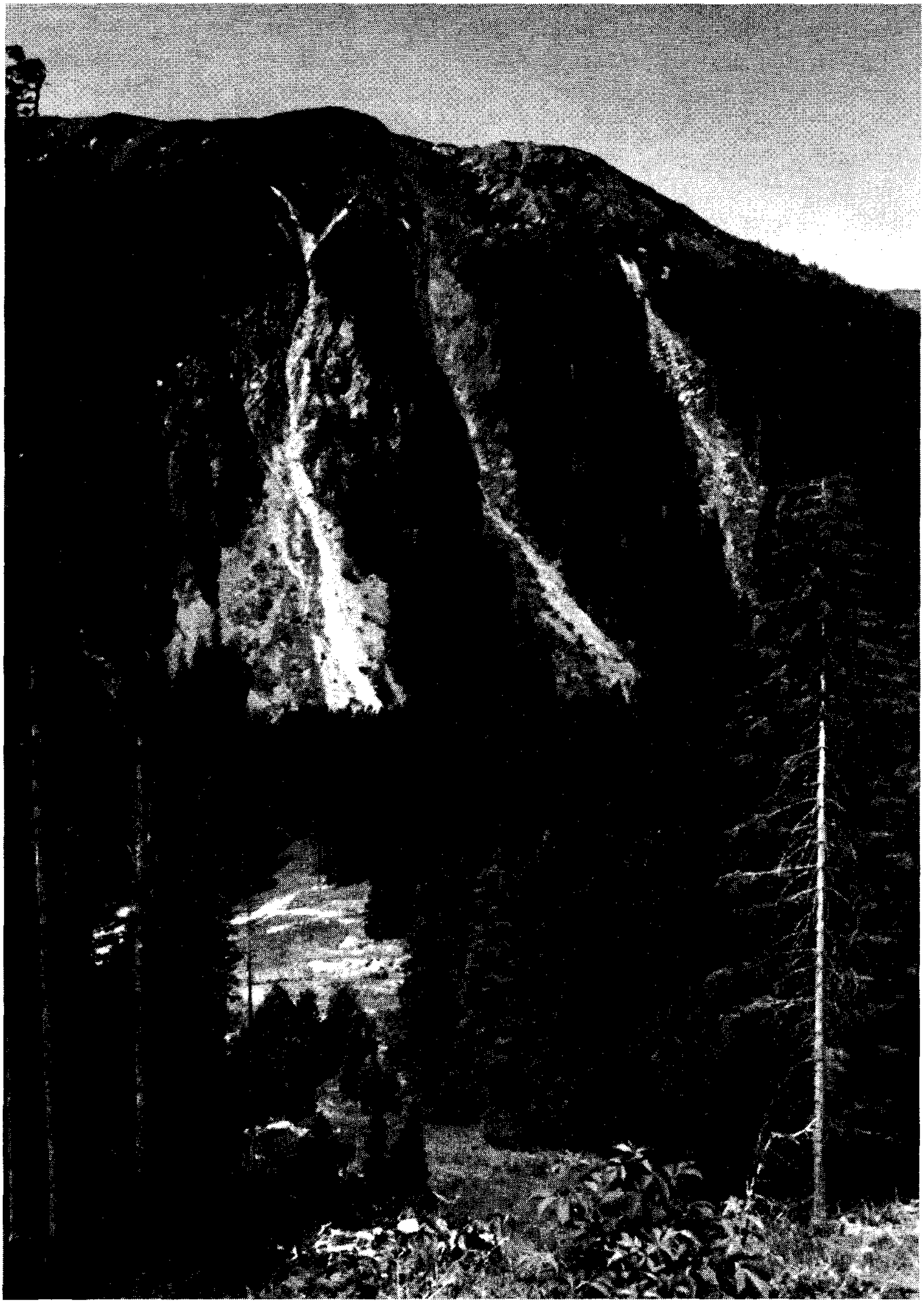

Photo 1. Three parallel debris flow tracks originating in 1974 on the steep valley side of the formerly glaciated Obří důl in the eastern part of the Karkonosze Mountains. Forest-free area in the foreground is the vestige of a big debris flow which occurred in 1897. Obří důl has hosted the largest number of debris flows recorded in the Karkonosze (photo by P. Migoń)

length and 30 m in width, although much larger examples up to 900 m long and 100 m wide have been noted (Pilous 1977). Levees usually attain 1–2 m high, the tracks themselves become 1–3 m deep. Debris cones form rather infrequently, mainly at the outlet of slope channels.

The lifetime of debris flow landforms is quite considerable and traces of the flows which occurred in July 1897 may be still identified in the landscape, although their forms are subject to continuous degradation and biological succession. Levees decline in height due to the action of needle ice and overland flow, whereas the incised tracks become partially filled by debris from both levees and upslope, especially near the toe. It is estimated that 0.5 $m^3 \cdot y^{-1}$ of mineral and organic matter is transported within a track on average (Parzóch 2001). Plant encroachment on debris flow tracks is very fast, unlike in the high mountains. In the Łomniczka valley, the site of 7 individual flows in September 1994, 50% of the debris flow surface was overgrown by moss and grass after three years from the event (Dunajski 1998) and levees have become completely vegetated by grass, heather and spruce after seven years. The process of natural degradation of debris flow--related landforms is additionally enhanced by human activity. Numerous dams to prevent further erosion have been installed within the tracks. They act as traps for fine-grained sediment washed down the slope, which in turn elevates the surface and allows for even faster vegetation succession.

There is no reason to doubt that debris flows in the Karkonosze Mountains have occurred throughout the Holocene as indicated by the sedimentary history of glacial cirques (Chmal and Traczyk 1998). However, V. Pilous (1977) suggests that the frequency of flows has increased in the last 100–200 years and seeks the explanation in deforestation and introduction of spruce mono-stands. Unfortunately, almost no data from earlier times is available to confirm or reject this hypothesis. On the other hand, the graph of debris flow frequency (Fig. 3) shows clearly that they cluster in two particular years, in which episodes of especially intense precipitation were recorded (Table 1). The general absence or scarcity of debris flows over many years after 1882 and 1897 events is striking and in recent years, 1994 and 1997, there have been only a few larger flows, although the amount and intensity of precipitation was again considerable and comparable to the years 1882 and 1897. This temporal pattern is explained by the fact, that slopes subjected to shallow mass movements are weathering-limited and regeneration of a thickness of regolith mantle sufficient for a debris flow to occur must take time, probably much longer than 100 years. Indeed, in July 1997 debris flows occurred during the first episode of rainfall and did not during the second one, although precipitation was actually higher during the latter (Table 1).

In the Hrubý Jeseník there have been recorded about 100 individual debris flows, the oldest ones dating back to the end of 18th century. Although circumstances of older flows remain obscure, it is clear that the more recent ones are causally related to episodes of extreme precipitation, as it was the case of 1921,

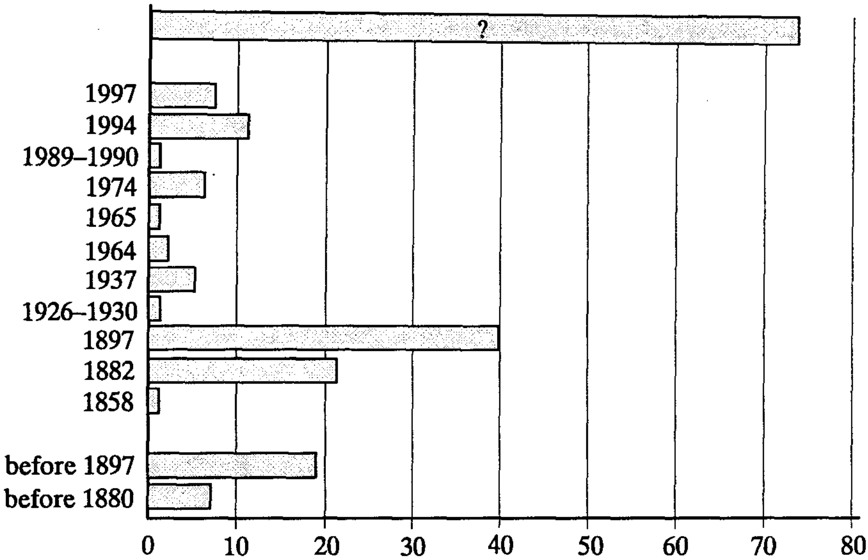

Fig. 3. The occurrence of debris flows in the Karkonosze Mountains through time. Clustering of events in 1882 and 1897 is very clear, but a large number of debris flows of unspecified age (question mark) is to be noted. However, it is certain that the vast majority of them happened prior to 1945. Debris flow ages after V. Pilous (1973, 1977) supplemented by authors' own observations

Table 1

Extreme precipitation events and debris flow occurrence in the Karkonosze Mountains

Year	Days of occurrence	Rainfall [mm]	Rainfall intensity [mm · h^{-1}]	Debris flow presence (+) or absence (–)	Data source
1882	17 VII	146–226	11.9	+	Czerwiński 1991
1897	29–30 VII	130–301	12–15	+	Czerwiński 1991
1977	31 VII–2 VIII	120–340	13.1	–	Głowicki 1979
1994	2 IX	62	13.8	+	Pilous 1994
1997	5–9 VII	66.5–207	6.5–17.7	+	Dubicki and Malinowska-Małek 1999
	18–22 VII	185–229.5	12	–	

1951 and 1991 events. On 1. 06. 1921 rainfall intensity close to the debris flow area was measured as 196.5 mm within 24 hours, yet the bulk of this rainfall occurred within less than 5 hours (Sokol 1955). On 4. 07. 1991 precipitation probably exceeded 100 mm (Gába 1992). The longest flows travelled 800–900 m and were from 10 m to, exceptionally, as much as 180 m wide.

The vast majority of debris flows in the Hrubý Jeseník has been recorded in the northern part of the massif, in the Kepmík (1,423 m a.s.l.) area, only less than 10 being known from the Praded (1,491 m a.s.l.) area. This is surprising given similar altitude, relief and vegetation in both areas. It is suspected that lithological and structural factors may play a decisive part. The Kepmík area is a structural dome (Hrádek 1984) built predominantly of mica schists which are subjected to weathering by hydration and easily disintegrate by slaking which supports creep and downslope bending. Moreover, within weathered mica schists many potential failure planes along cleavage and schistosity surfaces are offered and at least some steep slope surfaces are parallel to schistosity.

Direct impact of debris flows was usually limited to regolith removal and damage to mountain forest communities, mainly composed of spruce, along the tracks. In order to prevent further erosion, stabilization works including dam building and aforestation are carried out on the tracks shortly after flows have occurred. Landforms created by debris flows such as scars, levees and terminal lobes are small and become obliterated either in the course of engineering work or by natural erosion. One of the biggest debris flows from 1. 06. 1921 reached the valley floor and temporarily dammed the river of Hucivá Desná, resulting in a devastating flood after the dam failed, yet no traces of the dam existed a mere 26 years later (Zvejska 1947).

LANDSLIDES

Landslides, i.e. laterally extensive slope failures with a well defined shear plane, have generally been very rare in the Sudetes in historical times, and the vast majority of documented forms dates back to the Pleistocene or early Holocene (Pulinowa 1972). Slope forms in the Sudetes are largely inherited from pre-Holocene times and reflect a long-term geomorphic evolution of mountain slopes rather than any action of contemporary extreme events. Indeed, even the most efficient rainfall episodes of an order of >100 mm per day recorded in historical times have seldom caused any extensive landslide activity.

However, episodes of extreme precipitation, such as the ones in July 1997 or July 1998 in the eastern Sudetes and the middle Sudetes, respectively, have resulted in numerous shallow slides. In the Hruby Jeseník massif, 35 slides have been recorded after heavy rains in early July 1997, yet all of them have occurred within slope deposits or man-made talus, without affecting solid rock beneath (Aichler and Pecina 1998). Furthermore, most of them have been caused by direct slope undercutting by lateral erosion of rivers and have not propagated upslope. Similar characteristics show shallow landslides in the Bystrzyca Dusznicka valley, caused by intensive rainfall in July 1998 (Żurawek 1999; Zieliński 2001). Slope undercutting, whether by active lateral river erosion or road construction, has been crucial in initiating mass movements.

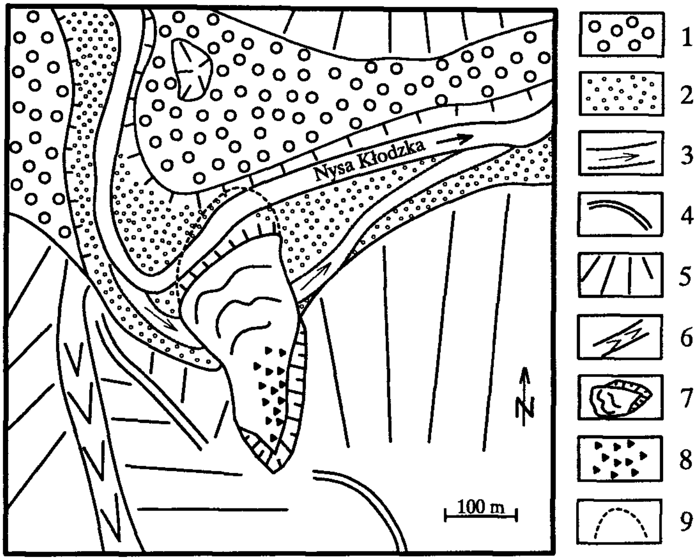

Fig. 4. Geomorphological sketch of the 1598 landslide in Bardo. 1 — higher terrace flats, 2 — alluvial valley floor, 3 — pre-1598 channel, 4 — ridges, 5 — slopes, 6 — V-shaped valleys, 7 — landslide, 8 — post-landslide debris cone, 9 — inferred maximum extent of the 1598 landslide

Dimensions of shallow slides have hardly exceeded 100 m in length or width and their lifetimes have been short.

Deep-seated slides occurred sporadically, and actually a few instances are known from the Sudetes. The largest one is located in the town of Bardo, on the steep valley side of the Nysa Kłodzka river, and dates to 24 August 1598 (Oberc 1957; Tuła 1999). Its total length from the back scarp to the toe exceeds 350 m and the height of the slope affected is 170 m (Fig. 4). It probably began as a translational rockslide along the structural boundary between Devonian shales and Carboniferous greywackes and assumed certain characteristics of an extrusion flow in the lower part, forming a 200 m wide toe, almost twice wider than the scar. Geomorphic impact of the Bardo slide has been considerable. The landslide mass filled a part of the valley, dammed the river and caused channel diversion by 100 m away from the slope. Reasons of this unusual event remain obscure. According to chronicles, the slide coincided with a period of particularly heavy rains, yet a seismic trigger has also been proposed (Ciężkowski and Koszela 1988). Whatever the actual cause, it seems clear that the Bardo slide occurred in very specific structural and external circumstances and as such it is hardly representative for the present-day evolution of the Sudetes. Significantly, no reactivation was recorded in July 1997 in spite of extensive undercutting of the toe. Yet, because of landslide scarcity, large forms which do occur have considerable lifetimes and their geomorphic effects are long-

-lived. The newly established river channel in Bardo has persisted until today and all landslide elements are clearly recognizable in the present-day landscape (Tuła 1999).

RUNOFF RELATED EROSIONAL EVENTS ON SLOPES

Heavy rains affecting the Sudetes are known to cause intensive surface erosion on slopes, although its form and extent is much controlled by local relief, underlying lithology and last but not least, land use. Therefore, patterns of erosion on forested slopes, grasslands and cultivated lands are fundamentally different in a similar way as are much slower processes of soil creep (Jahn 1989).

In the forest zone rainfall-induced surface erosion is negligible in its effect. Even extreme precipitation such as that in July 1997 hardly ever results in washing the sediment off the slope (Czerwiński and Żurawek 1999). In recent years there has been much concern about adverse effects of forest die-back, including accelerated erosion on steep slopes stripped of montane forest communities. However, immediate natural succession of grasslands has acted as an effective barrier against surface erosion. By contrast, linear erosion along numerous logging tracks, unpaved or over-used forest roads and tourist paths is usually massive and may lead to the origin of more than 4 m deep incisions in the most spectacular cases (Šilhavy 1991; Czerwiński and Żurawek 1999). Extensive studies on rill and gully erosion in the Karkonosze Mountains (Parzóch 1998, 2001) confirm the key role of man-made structures in guiding the present-day denudation on slopes. Development of rills and gullies is highly episodic and occurs under conditions of heavy rains, during which gully deepening from 0.2–0.5 m to 2 m has been recorded. Much less erosional effect is generated by snowmelt. Several generations of gullies are present in the Karkonosze, with many currently inactive, filled by fine sediment and partly vegetated. The presence or absence of culverts at road/gully intersections may assist to determine the ages and lifetimes of gullies. It is likely that during the major phase of forest road building in the late 19th century and early 20th century culverts were made in places where roads crossed active gullies whereas there was no need to construct one across a gully long inactive. If this reasoning is correct, then it would take 100–200 years to fill the gully.

The phenomenon of concentrated runoff and gully erosion on mountain slopes, although not very spectacular as far as its direct geomorphic impact is concerned, is very important for the comprehensive assessment of the role of extreme events. It is during episodes of high precipitation when gullies become active and supply abnormal quantities of both water and large debris to river channels in a short time (Photo 2). This in turn contributes to rapid generation of flood waves and increases bed load. It is likely that the existence of a dense

Photo 2. Episodic heavy gully erosion along logging tracks (seen above the gully head) on moderately steep slopes of the Karkonosze Mountains (photo by K. Parzóch)

network of gullies is the chief factor responsible for hydrological consequences of deforestation (Dubicki 1993) reported earlier in this paper.

Unlike the forest zone, slopes at lower altitude, transformed into cultivated land support active surface wash during heavy rains (cf. Demek and Seichterova 1962). Most recently, landform changes on agricultural slopes around Martinkovice in the central part of the Sudetes, resultant from a cloud burst have been reported by J. Demek and J. Kopecký (1997). They claim that the amount of both surface and linear erosion experienced during the event much surpassed any geomorphic changes in the preceding tens of years. Events such as one in Martinkovice teach us that the medieval to recent fine-grained deluvial deposit, common in the less elevated part of the Sudetes, is the effect of many punctuated erosional episodes separated by much longer periods of slope stability.

FLOODS

Floods are typical phenomena in the Sudetes and have been recorded since the late medieval times (15th century). The vast majority of them is related to cloud bursts and prolonged heavy rains in the warm season, typically from May to August, whereas floods induced by sudden snowmelt are relatively infrequent. For example, in the review for the Hrubý Jeseník Mountains 89 events are mentioned, of which a mere 8 are snowmelt floods and 66 occurred in late spring and summer

(Polách and Gába 1998). Likewise, 62 out of 92 floods recorded in the Karkonosze Mountains before the year 1900 occurred between May and August (Czerwiński 1991). Historical sources serve as a valuable data base on flood occurrences and associated property and life loss over hundreds of years, yet information about geomorphic impact of floods is scarce. The above-mentioned review by D. Polách and Z. Gába (1998) refers to landscape changes due to flooding in 9 cases only and without any greater precision. Another historical review (Czerwiński 1991) does mention the origin of several flood chutes during the flood in July 1897, but again no details are provided. Therefore, historical sources are not suitable for any comparative analysis of flood effects, nor for attempts to recognize their long-term impact.

Given the uncertainties associated with the use of historical data, the most recent floods of high magnitude in August 1977, July 1997 and July 1998 provide the most reliable data source about geomorphological consequences of extreme fluvial events (Lisowski 1979; Teisseyre 1979; Czerwiński and Żurawek 1999; Hrádek 1999; Żurawek 1999; Zieliński 2001). These geomorphic effects are erosional and depositional, depending largely on local channel slope, floodplain width, land use and the presence or absence of man-made constructions such as dikes, bridges and dams. They include increasing channel and floodplain scour, lateral erosion and channel widening, meander cut-offs and channel straightening, development of chutes and anabranching channels, whereas sedimentary effects are usually an extensive overbank deposition of gravel, sand and mud, leading to building-up of floodplains. Most extensive floodplain and channel re-shaping occurs downstream of mountain fronts, whether in intramontane basins or beyond the Sudetes, in the alluvial fan sectors, as has been convincingly shown for the 1997 flood (Czerwiński and Żurawek 1999; Żurawek 1999; Zieliński 2001). Most spectacular has been the origin of three major flood channels of the Nysa Kłodzka river around the village of Pilce, in the front of the Sudetes, of the total length of more than 4.5 km (Fig. 5A). Individual flood diversion channels on the alluvial valley floors in Wilkanów, Żelazno (Fig. 5B) and Karlovice were 1 km (Żurawek 1999), 450 m and more than 400 m long (Hrádek 1999), respectively. Similarly, geomorphic effects of floods originating in the Karkonosze Mountains were most dramatic in the adjacent Jelenia Góra Basin, and both thick overbank deposition of sand and gravel as well as development of erosional channels has been reported for several events (Czerwiński 1991).

The geomorphic impact of floods must be viewed and assessed in the long-term evolutionary context. T. Zieliński (2001) has emphasized that flood-induced changes taken together document a tendency of rivers towards braiding, especially on alluvial fans. Combined sedimentological and archaeological evidence shows that braiding patterns were typical for Sudetic rivers until the onset of extensive colonization, forest clearance and development of agriculture, which is

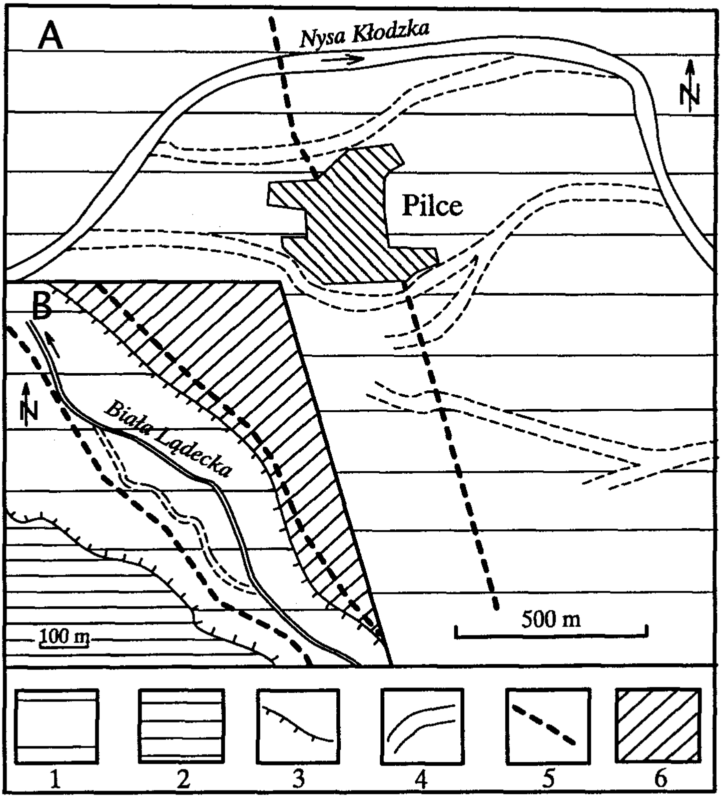

Fig. 5. Flood channels cut into alluvial valley floors of Nysa Kłodzka river in Pilce (A) and Biała Lądecka river in Żelazno (B). 1 — alluvial valley floor, 2 — higher terrace flat, 3 — scarps, 4 — flood channels, 5 — roads, 6 — bedrock slopes

generally dated for 14–17th century (Teisseyre 1985, 1991) (Photo 3). Changes in land use, almost simultaneous over large areas, resulted in increasing soil erosion, surface wash and delivery of much fine grained material to the channels. Being now dominated by suspended load, the formerly braided rivers underwent metamorphosis towards single-channel sinuous or meandering ones, a trend additionally enhanced by regulation and channelization, or towards anastomosing systems under specific topographic circumstances (Teisseyre 1991). Floodplains built of fine sediments were created at the expense of previous gravel beds and were then increasing in height by vertical accretion during numerous flood events of moderate magnitude. However, in the last 100 years or so the aggradation tendency has been replaced by one of incision and former floodplains have been subjected to dissection. A. K. Teisseyre (1977, 1985) attributes this shift in the fluvial regime, at least partially, to incorrect hydrotechnical works on many Sudetic rivers. Specifically, he names channel straightening with no simultaneous bed and bank protection, weir construction and bridge building. We also suspect that

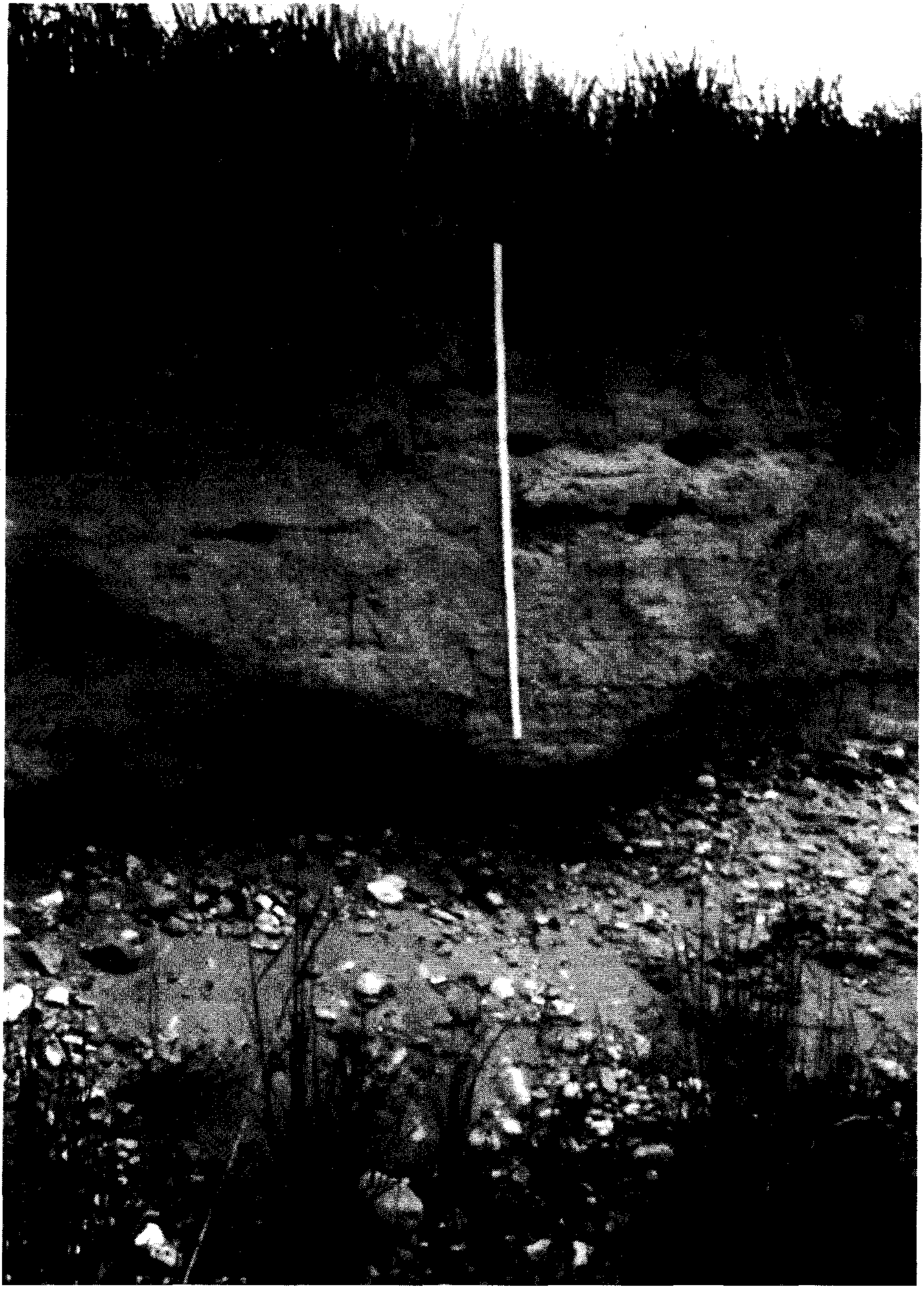

Photo 3. Fine-grained overbank deposits lying on coarse gravel document the shift of the Nysa Kłodzka river from the braided pattern towards the sinuous and meandering ones, caused by dramatic change in land use in the Sudetes in the late medieval times. Locality: near Kozielno in front of the Sudetes (photo by P. Migoń)

contemporaneous decline of mountain economy, withdrawal of agriculture and widespread return of forest and grassland may have altered load characteristics again, yet river channelization and bank maintenance prevent reduction of sinuosity and the return to braided patterns under normal conditions. High-energy flood events might provide an opportunity for channel changes, yet these become combated by humans as they provide an immediate threat to the long established settlement and land use patterns and communication lines (roads, railway tracks) within valley floors.

Spectacular geomorphic effects of the flood in July 1997 (Czerwiński and Żurawek 1999; Hrádek 1999; Żurawek 1999; Zieliński 2001) could have provided an excellent opportunity to trace the fate of newly created erosional and depositional forms and to establish their lifetimes, yet the majority of these forms has been quickly obliterated by humans. For example, a 450 m long, 10–15 m wide and 1–2 m deep chute of the Biała Lądecka river in the village of Żelazno, into which the river might have been diverted, has been blocked from upstream immediately after the flood and then subsequently filled with waste, so that very little of the flood channel can be seen today. The system of flood diversion channels in Karlovice suffered from a similar fate. The pre-flood channel of the Opava river was cleared of the log jam and their banks strengthened, new anabranching channels filled by waste and the river forced back to its previous course. However, in a few places, for instance near Staré Mesto pod Sneznikem, an anabranching system of the Krupa river, inherited from an after-flood braided system, has been preserved and its current development is being monitored. In the West Sudetes, affected by flooding in 1977, its geomorphic effects have already disappeared from the landscape.

DISCUSSION AND CONCLUSIONS

Historical records and current observations indicate that extreme meteorological and hydrological events are relatively frequent phenomena in the Sudetes, often of a regional extent. Their geomorphological significance is, however, highly variable and controlled by a number factors, of which the intensity of the event itself is not necessarily the most important one. One of these factors is lithology and structure, unfavourable to any more extensive mass movement phenomena of landslide type. Therefore, the majority of slopes in the Sudetes, especially in the forested lower montane zone (up to 800–1,000 m a.s.l.), can be considered stable under recent environmental conditions and no historical or geomorphic evidence is available to infer any role of extreme events in their contemporary modelling. Indeed, it is only the attempt to identify components of the contemporary denudational system of the Karkonosze Mountains which does give some credit to extreme geomorphic events, although no in-depth analysis is provided (Bieroński et al. 1992).

Two most dynamic geomorphic environments within the Sudetes are steep slopes of Pleistocene glacial cirques and deeply incised valleys in the most elevated parts of the mountains and valley floors/floodplains of larger rivers. The former are dominated by debris flows, whilst in the latter numerous erosional and depositional landforms form after each major flood. However, lifetimes of newly created landforms differ between these environments because human use is in each case different.

Debris flows in the Karkonosze Mountains usually affect unmanaged upper slopes within the boundaries of the National Park and therefore their traces can be left in the landscape. In a few cases only stabilization works and aforestation have been undertaken, although such remedial measures were frequent in the 19th century, when settlements were located much higher in the mountains than they are today and no legal landscape protection was enforced. By contrast, in the Hrubý Jeseník Mountains, debris flows occur within production forests and are quickly rehabilitated (Sokol and Vavřík 1971).

Flood landforms, especially if of considerable size, may have long-lasting effects for further development of river channels and valley floors, including simultaneous transformation from sinuous channel patterns to the braided ones and from floodplains to gravel beds (Teisseyre 1979; Zieliński 2001). Such changes, if allowed to proceed freely, would have obvious consequences for land use patterns within valley floors, possibly leading to the complete abandonment of the most dynamic valley reaches. On the other hand, it is the valley floors which have long attracted settlers and farmers, and have been most suitable for the development of industry and communication lines, hence they are now the most occupied and developed part of the Sudetes. Therefore, any flood-induced changes provide an immediate threat to the established pattern of land use and usually become quickly obliterated, especially flood channels become filled with waste and their entrances blocked. Floodplain vertical accretion has been an important process in the last few hundreds years and resulted in a few metres thick accumulation, but it has been recently replaced by channel downcutting (Teisseyre 1985), variously attributed to incorrect channelization or land use changes and resultant alteration of load characteristics.

Extreme events often trigger accelerated erosion on slopes, yet the location and magnitude of geomorphic change are again clearly related to various human activities. Rill and gully erosion develop along unpaved forest roads, logging routes and badly managed tourist trails, whereas on agricultural slopes linear erosion occurs together with surface wash. Extensive deforestation in the montane forest zone, by contrast, has not resulted in catastrophic erosion on slopes, largely due to development of grass cover.

The widely debated issue of a climatic change and its role in triggering landscape instability cannot be satisfactorily addressed in the Sudetes, at least in the light of currently available data. Extreme events are too much far and between, historical records too vague and human activity too intense to allow for a safe isolation of a factor of climate change. Geomorphic events of the last decade on slopes and within valley floors have not been exceptional in terms of either extent or magnitude and parallels may be found in early 20th or 19th century.

Tentative conclusions offered by this study are thus the following:

— extreme weather events, although frequent, appear not to play an important part in the contemporary geomorphological development of the Sudetes as a whole, except for specific localities;

— the primary factor controlling the occurrence and effects of extreme geomorphic events in the Sudetes is human impact rather than climate change, debatable in itself. For example, an apparently increasing frequency of floods towards recent times, if not an artefact, is causally linked to periods of extensive deforestation rather than is the reflection of a climatic trend;

— debris flows and major floods are the phenomena capable of exerting long-lasting geomorphic impact on mountain slopes and valley floors, but these are rather uncommon. By contrast, landslides, linear erosion and small to medium magnitude floods are either rare or insignificant in terms of their landscape effects;

— the occurrence of debris flows is limited to a few areas only in the most elevated parts of the Sudetes. However, their role in the recent slope evolution of glacial cirques and valleys in the Karkonosze Mountains is considerable;

— valley floors affected by big floods are the most dynamic environment and numerous erosional and depositional effects on a grand scale have accompanied each major flood. However, newly created landforms are usually quickly obliterated by humans and the natural tendency towards re-creating braided patterns cannot be sustained. Geomorphic long-term impact of extreme events is thus considerably reduced.

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Piotr Migoń, Krzysztof Parzóch
Geographical Institute
University of Wrocław
pl. Uniwersytecki 1
PL 50–137 Wrocław, Poland

Mojmír Hrádek
Institute of Geonics, Brno Branch
Academy of Sciences of the Czech Republic
Drobného 28
CZ 602 00 Brno, Czech Republic

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STRESZCZENIE

P. Migoń, M. Hrádek, K. Parzóch

ZDARZENIA EKSTREMALNE W SUDETACH. ZNACZENIE GEOMORFOLOGICZNE I UWARUNKOWANIA

Ekstremalne zdarzenia geomorfologiczne w Sudetach wywoływane są przede wszystkim przez opady o dużym natężeniu, trwające od kilku godzin do kilku dni. Zdarzenia te przybierają formę ruchów masowych, epizodów wzmożonej erozji na stokach oraz katastrofalnych wezbrań w dolinach rzecznych.

Cechy budowy geologicznej i rzeźby sudeckiej powodują, że osuwiska są nieliczne i niewielkich rozmiarów, a większość zjawisk masowych to spływy gruzowe i gruzowo-błotne (mury) ograniczone do najwyższych partii Karkonoszy i Wysokiego Jesionika. W tych dwóch obszarach odnotowano w czasach historycznych odpowiednio ponad 200 i ponad 100 pojedynczych spływów, z których największe miały zasięg do 1 km długości i 400 m szerokości. W Karkonoszach najwięcej spływów zeszło w trakcie silnych opadów w latach 1882 i 1897, natomiast w trakcie późniejszych epizodów opadowych o porównywalnej wielkości były dużo rzadsze. Wskazuje to na kluczową rolę dostępności materiału do transportu. Spływy gruzowe są ważnym czynnikiem morfogenetycznym przekształcającym ściany kotłów polodowcowych i głęboko wciętych dolin rzecznych, choć pozostawione przez nie tory i strefy akumulacji podlegają szybkiej sukcesji roślinnej, a niekiedy także pracom stabilizującym.

Geomorfologiczne konsekwencje ulewnych opadów na stokach zależą przede wszystkim od sposobu użytkowania powierzchni. W obszarach leśnych i łąkowych erozja powierzchniowa jest nieznaczna, natomiast znaczne natężenie erozji liniowej cechuje nieutwardzone drogi leśne, szlaki turystyczne, a zwłaszcza trasy zrywki drzewa. W niższych partiach Sudetów znaczenie erozji powierzchniowej wzrasta na stokach rolniczych.

Wezbrania rzek, licznie notowane w Sudetach od późnego średniowiecza, są niewątpliwie najbardziej powszechnymi zdarzeniami ekstremalnymi, często przynoszącymi znaczne straty materialne, a nawet ofiary śmiertelne, ale ich geomorfologiczne znaczenie jest zróżnicowane. Dla większości z nich brak wzmianek o istotniejszych i trwałych zmianach w rzeźbie dolin rzecznych, przykładem może być duża powódź w Sudetach Zachodnich w lecie 1977. W trakcie największych wezbrań powstają liczne formy erozyjne, w tym systemy roztokowych koryt powodziowych o długości do kilkuset metrów na równinach zalewowych oraz akumulacyjne, głównie w postaci rozległych pokryw żwirowych na terasie zalewowej. Zmiany w największej skali zachodzą u podnóża krawędzi morfologicznych, na stożkach napływowych, poniżej wylotów przełomów rzecznych oraz w miejscach malejącego spadku podłużnego, co zostało m.in. obszernie udokumentowane dla powodzi w lipcu 1997. Charakter przekształceń rzeźby den dolinnych wskazuje na tendencję powrotu do roztokowego układu koryt, jednak przeciwdziała jej ze względów gospodarczych człowiek, likwidując nowe koryta, pogłębiając i oczyszczając stare, umacniając brzegi itd. Stąd nawet zdarzenia fluwialne o znacznym natężeniu nie są w stanie pozostawić w krajobrazie nowych, trwałych form, a dna dolinne pozostają kształtowane w głównej mierze przez gospodarkę człowieka.

Dostępne dane nie pozwalają na wiarygodną ocenę znaczenia czynnika klimatycznego jako sprawczego dla zdarzeń ekstremalnych w Sudetach, a tym bardziej na ustosunkowanie się do hipotezy podnoszącej rolę współczesnych zmian klimatycznych. Zdarzenia ostatnich lat (1997, 1998) analizowane w szerszym kontekście czasowym znajdują swoje odpowiedniki pod koniec XIX w. i tracą wiele ze swojej wyjątkowości, zwłaszcza przy uwzględnieniu stale rosnącego stopnia rozwoju infrastruktury narażonej na zniszczenia i straty. Wydaje się, że głównym, choć pośrednim czynnikiem sprawczym wielu zdarzeń ekstremalnych jest człowiek i powodowane przez niego zmiany w środowisku, np. wylesienie stoków górskich. W ogólności jednak, za wyjątkiem specyficznych miejsc, ekstremalne zdarzenia pogodowe nie odgrywają kluczowej roli we współczesnej morfogenezie Sudetów.