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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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THE 2002 DEBRIS FLOW IN THE BABIA GÓRA MASSIF — IMPLICATIONS FOR THE INTERPRETATION OF MOUNTAINOUS GEOMORPHIC SYSTEMS

Abstract. In summer 2002 a debris flow of unusually large extent and dimensions occurred on the steep northern slope of the Babia Góra massif, West Carpathians. The failure zone was located above the timberline and the track continued for about 700 m down the slope, ending within the upper montane forest belt. During the last 100 years no similar event was recorded in the uppermost part of the massif. The 2002 flow prompts a modified approach to the recognition of mountain geomorphic systems. It provides clear evidence that a few years, or even a few tens of years of observations may be insufficient to record all important components of the Holocene geomorphic system. The recognition of this gap bears on approaches to hazard and risk mapping. The absence of high magnitude slope processes within the limited observation period must not be taken as the evidence that these cannot occur in the current environmental conditions, and the worst-case scenario needs therefore to be adopted.

Key words: debris flow, geomorphic systems, extreme events, natural hazards, Babia Góra

INTRODUCTION

In the recent years much emphasis has been given to the recognition of geomorphic systems of mountain areas and their changing behaviour through time (e.g. Gardner et al. 1976; Kotarba et al. 1987). The problem of proper identification and understanding of linkages within the systems becomes augmented under the current conditions of highly unstable weather and possible climate change, which are likely to have significant impact of the course and magnitude of geomorphic processes.

A typical approach to the identification of geomorphic systems is through careful measurements of a range of intimately linked processes (process cascade) and/or, increasingly, modelling the linkages. Monitored drainage basins in different mountain regions worldwide have provided useful data to reconstruct sediment budgets in different topographic and climatic conditions. If process measurements are not available or cover specific subsystems only, then mapping of landforms and deposits of different ages is used as a proxy of geomorphic systems recognition (e.g. Bieroński et al. 1992). Indeed, much of our knowledge about mountain geomorphology is actually derived from geomorphic mapping rather than from long-term process recording.

The key problem is that in either of these approaches one inevitably focuses on secular, high frequency processes and considers their average magnitudes, whereas very rare events of huge landforming potential may escape attention. Relict landforms are helpful, but if no modern analogues are observed, their interpretation is not necessarily straightforward. For example, large deep-seated landslides in the Moravian Carpathians (Moravoslezské Beskydy) of Holocene age have been identified only recently, after the re-examination of slope morphology and sandstone rock steps, previously thought of as periglacial frost-riven cliffs, and the application of radiocarbon dating (Pánek et al. 2006)

Mt Babia Góra (1,725 m a.s.l.) in the West Carpathians is an example of a mountain area, where the conceptual model of the contemporary geomorphic system is at the stage of construction. Few quantitative process data and limited accessibility of the terrain, adversely affecting field mapping, have resulted in contrasting views about the significance of different geomorphological processes. The Holocene age of massive deep-seated rotational slides involving a few cubic kilometres (!) of rock material is claimed (Alexandrowicz 1978; Ziętara 2004), but yet to be confirmed, and further controversies exist concerning glacial inheritance in the massif. Lichenometric dating of rock faces indicates their ongoing activity (Bajgier-Kowalska 2002), but the relationship to long-term trends in slope development is poorly known. Likewise, a few shallow slides turning into flows recorded in the forest belt in the recent times (Bajgier-Kowalska 2002) need to be assessed against other processes at work.

An unusual debris flow which occurred in summer 2002 on the northern slope of Mt Babia Góra, remarkable in its size (>700 m long) and unique in recent history, prompts us to look at the geomorphic system of the area from a new perspective. The role of singular but truly high magnitude events and their implications need to be carefully considered before models of geomorphic systems are built. In this paper, we briefly document the geomorphic record of this unique event and discuss its relevance to other Central European mountain areas of moderate height. In addition, we emphasize the implications of the 2002 debris flow event for hazard mapping and vulnerability assessment.

GEOMORPHIC SYSTEMS OF TRANSITIONAL MEDIUM-TO-HIGH MOUNTAINS

The Babia Góra mountain massif, rising to 1,725 m a.s.l. (Fig. 1), is a special example of mountain terrain, which hardly fits simple classification schemes. Usually considered as one of many medium-high mountain ranges

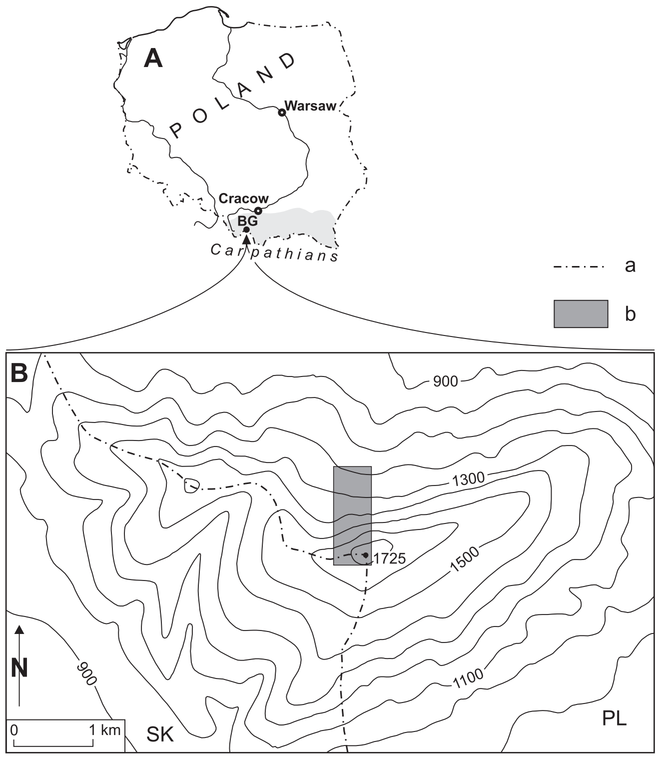


Fig. 1. Study area. A — location of the Babia Góra massif (BG) in southern Poland, B — topography of Mt Babia Góra: a — state border, b — location of the slope sector investigated

and massifs, it does contain certain specific features resembling high-mountain geomorphology. A considerable part of the massif is located within limits of the montane forest belt and considered as a fluvio-denudational domain, but the timberline runs at sufficiently low elevation (1,350–1,400 m a.s.l.) to leave large tracts of terrain in the subalpine (cryonival) belt. Here, the legacy of cold climate conditions of the Pleistocene is evident (Jahn 1958; Ziętara 1989, 2004), and limited frost sorting is probably active today as suggested by upstanding stones, patterns in vegetation distribution, and indistinct stone circles. The evidence of glaciation is controversial, but it is likely that small glaciers did exist on the lee side and re-shaped the northern slope of the main mountain (Klimaszewski 1948; Starkel 1960; Książkiewicz 1963; Niemirowski 1964; Łajczak 1998). However, the most important similarity is the great extent of precipitous slopes (>40°) on the northern side of the massif, which are unlike the typical medium-high mountains, where moderately inclined (10–30°), regolith-covered surfaces form the dominant landscape facet. Therefore, the Babia Góra appears to represent the transitional type of mountain environment, between mid- and high mountains.

This specific geomorphological nature of the Babia Góra massif does have its parallels in other mountain terrains of Central and Western Europe. Certain other parts of the Outer Carpathians, such as the Pilsko massif (Łajczak 1996) and the highest ranges in the Ukrainian Carpathians may be considered in this context. In the Bohemian Massif, the glacial cirques and valleys of the Karkonosze represent this transitional type of environment, which is highly dynamic and even currently moulded by debris flows, slides, rock slope failures, and avalanches (Pilous 1973; Bieroński et al. 1992). The highest parts of the French Massif Central, near Puy de Sancy (1,886 m a.s.l.), provide another example (Krzemień 1991). In all these regions high-magnitude slope geomorphic processes occur more frequently and much faster than in "typical", forested mid-mountain ranges, yet their frequency may still be not high enough to ensure accurate recording. The 2002 debris flow in the Babia Góra massif is a good illustrative case.

STUDY AREA

GEOLOGY AND RELIEF

Babia Góra is the most elevated mountain massif in the flysh-built West Carpathians. It takes the form of a W–E trending monoclinal ridge ca 10 km long, distinctly asymmetric in the cross-section and showing more than 1,000 m of relief on the northern side (Fig. 1). Geologically, it belongs to the Magura Nappe, and more than 80 per cent of the area is built of resistant beds of the Magura Sandstone, dipping to the south. Beneath, less resistant and tightly folded sandstone-to-claystone series occur (Książkiewicz 1963; Alexandrowicz 2004). The base of the Magura Sandstone outcrops at the altitude of about 1,000 m a.s.l. within the northern slope, whereas on the south-facing slope it occurs near the mountain/piedmont boundary (Fig. 2). The Magura Sandstone formation is of Middle to Upper Eocene age and consists mainly of medium- to fine-grained sandstones with clayey-siliceous cement. Intercalations of mudstones, clays and marls occur locally.

The general morphology of north- and south-facing slopes of Mt Babia Góra differs from each other, resulting in dissimilar patterns of mass movements (Fig. 3). The upper section of the cuesta-like northern slope is a huge rock slump of 400 m of relative relief and typical slope gradient between 30 and 45°, locally up to 70°. In the middle section the mean slope decreases to 20–30°, whereas the lower slope is considerably dissected, with a multitude of steep valley heads. The southern slope above 1,400 m a.s.l. is adjusted to the dip of the sandstone beds and its gradient is around 20°. Towards the footslope the gradient increases to 30°, or even 40° in the valley heads.

The frequency of mass movements and the size of resultant landforms are much higher on the north-facing slope. The latter include remnants of landslide scars, indicative of long-term slope retreat (Alexandrowicz 1978). Deep clefts

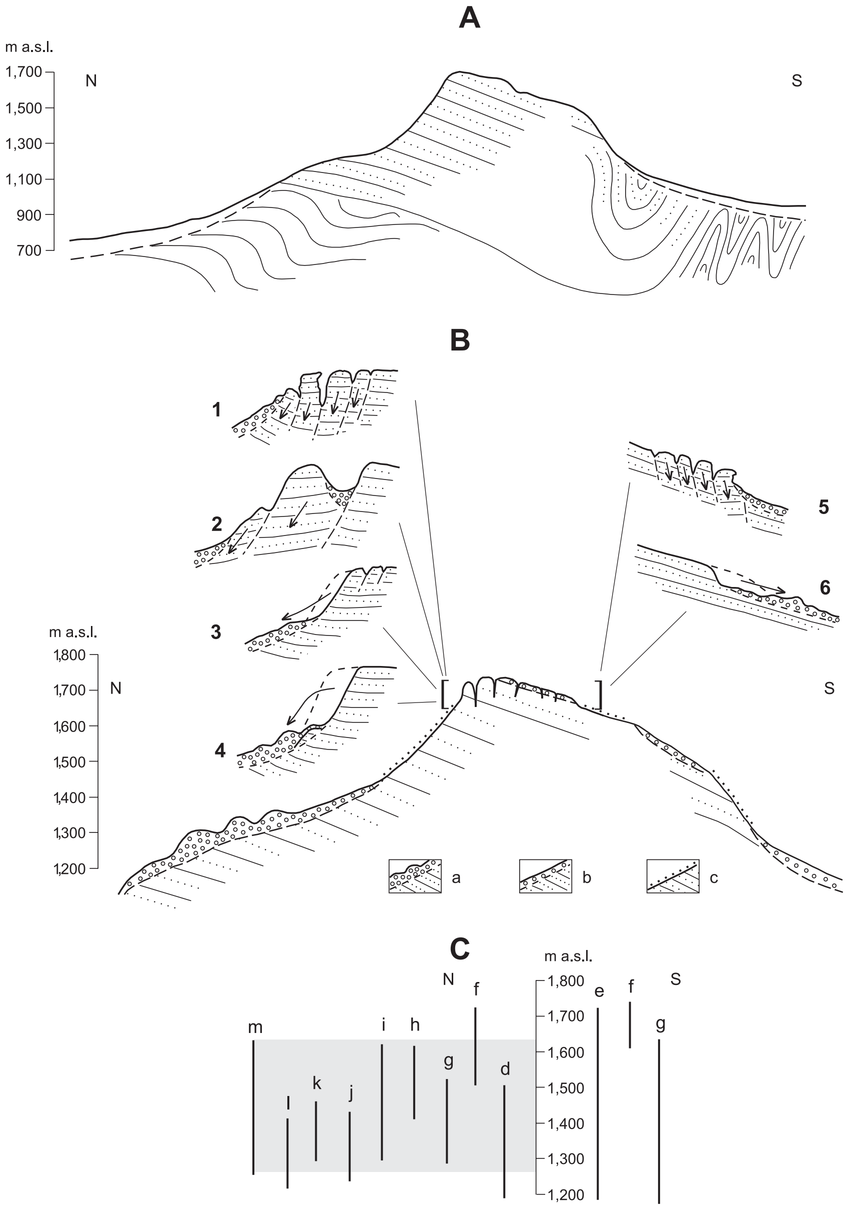


Fig. 2. Schematic N–S cross-section of Mt Babia Góra to show differences in the geological structure and geomorphology of the area (horizontal axis not to scale). A — Magura sandstone beds overlying older flysh deposits, B — morphological differences between N- and S-facing slope (1–6 — examples of mass movement types in the most elevated part of the massif), a — thick colluvial deposits, b — thin colluvial deposits, c — block fields and debris slopes, C — vertical range of occurrence of typical landforms and cover deposits: d — thick colluvial cover, e — thin colluvial cover, f — active block fields, g — inactive block fields, h — nival landforms and deposits, i — glacial undercuts and ravines, j — moraines, partly destroyed by landslides (h–j — interpretation problematic), k — torrential cones, l — fossil depositional landforms left by debris flows, m — debris flow studied in this paper

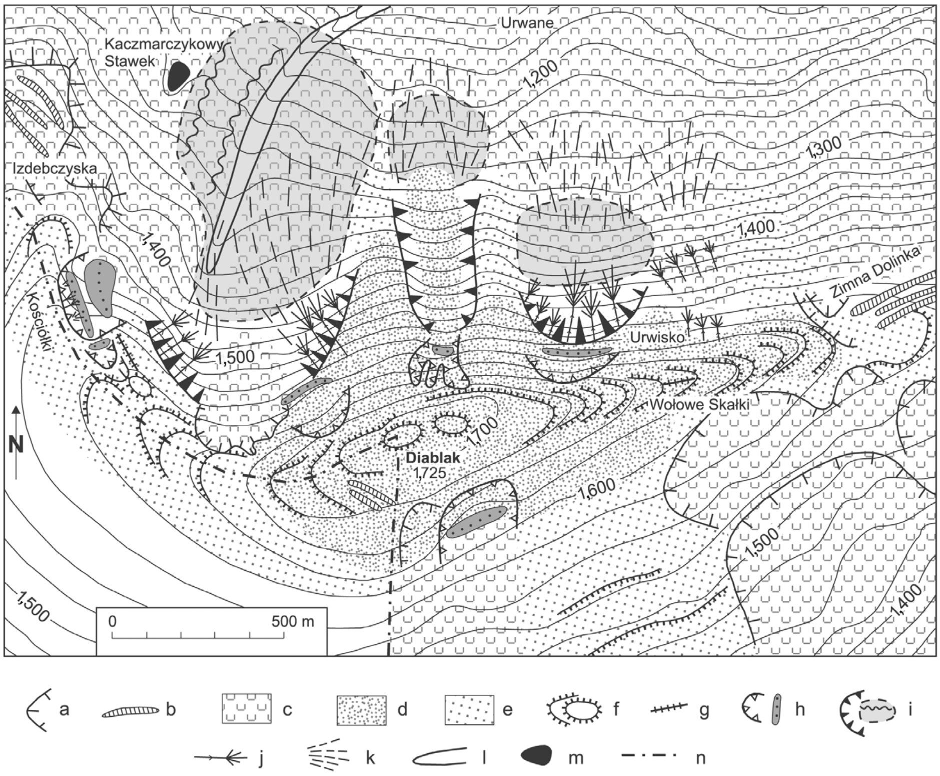


Fig. 3. Geomorphology of the near-summit part of Mt Babia Góra. a — landslide head scars, b — ridge-top trenches, c — colluvial covers, d — active block fields, e — inactive block fields, f — cryoplanation terraces and tump tors, g — rock crests, h — nivation hollows with nival moraines (?), i — problematic glacial hollows, zones of deposition and lateral moraines (?), j — ravines and torrential cones, k — area of occurrence of fossil debris flow deposits, l — erosional furrow, m — pond within a landslide, n — state border

in massive sandstone, ridge-top trenches, deep slope hollows, rock cliffs, and colluvial aprons up to 30 m thick. On the southern slope the extent of landslides is bigger, but the majority of them has been rather shallow, therefore the thickness of slope deposits is much smaller than on the northern slope.

The uppermost, steepest section of the northern slope usually bears a thin (up to 2 m) depositional cover which consists of sandstone blocks set within smaller size debris. Block fields are largely inactive, although those above 1,500 m a.s.l. show the evidence of current build-up due to mechanical weathering of sandstone outcrops above (Jahn 1958). In a few places within the 1,300–1,600 m a.s.l. belt there occur landforms which may indicate local Pleistocene glaciation and/or nival remodelling (Klimaszewski 1948; Starkel 1960; Łajczak 1998). These include arcuate slope hollows with steep (up to 60°) rock faces, shallow depressions backed by low rock scarps and boulder ridges immediately below. This belt of probable glacial re-shaping significantly influences the morphological system of the northern slope and accounts for its tripartite division into distinct process domains. The zone above the rims of problematic glacial corries is modelled mainly by soil and talus creep, with falls and other rock slope failures restricted to low sandstone cliffs (Niemirowski 1964). Within the steepest slope segment, particle fall, voluminous rock falls and linear erosion along the ravines assume the main morphogenetic role. Slope surfaces of lower gradient located below, mainly within the forest belt, have been dominated by deposition and show an array of convex landforms, the actual origin of which is not easy to decipher.

CLIMATE

Mt Babia Góra, due to its elevation over the surrounding terrain, includes as many as five climatic and corresponding vegetation belts. These are: (1) warm temperate (mean annual temperature 6–8°C), with mixed forest communities, up to 625 m a.s.l., (2) cool temperate (4–6°C), with the lower montane forest, up to 1,100 m a.s.l., (3) cool (2–4°C), occupied by the upper montane forest, up to 1,395 m a.s.l., (4) very cool (0–2°C), with dwarf pine communities, up to 1,650 m a.s.l., and (5) cold temperate (0–-2°C), near the summit. In the upper montane forest and dwarf pine belt the length of the period with mean air temperature above 0°C is 6–7.5 months. According to M. Niemirowski (1964), the most elevated belts (4) and (5) belong to the periglacial process domain. However, the timberline is locally shifted downslope by avalanches and in the slope sector investigated here it runs at 1,350 m a.s.l.

In the context of debris flows, rainfall characteristics are very important. Mean rainfall totals calculated for the period 1961–1990 are as follows: (a) 1,202 mm at 697 m a.s.l. at the northern footslope, (b) 1,489 mm at 1,192 m a.s.l. within the north-facing slope, and (c) 1,056 mm at 850 m a.s.l. near the southern limit of the massif (Obrębska-Starklowa 2004). According to the same author (Obrębska-Starklowa 1963), the mean annual total at 1,616 m a.s.l. on the south-facing slope is about 1,200 mm. Summer precipitation accounts for ca 40 per cent of yearly sums, and daily maxima are recorded during this period. At the three sites (a–c) mentioned above, the daily maxima during 1961–1995 were 120, 172, and 234 mm, respectively. The mean number of days with rainfall exceeding 10 mm is, at these sites, 38, 50, and 33. 35–40 per cent of these days is contained by the summer period. B. Obrębska-Starklowa (1963, 2004) emphasizes rainfall inversion on the northern slope of Mt Babia Góra. Hence, mean and maximum precipitation in the feeding zone of the 2002 debris flow are not necessarily higher than those recorded at lower elevations, which complicates the identification of threshold values for debris flows to occur in this particular environment.

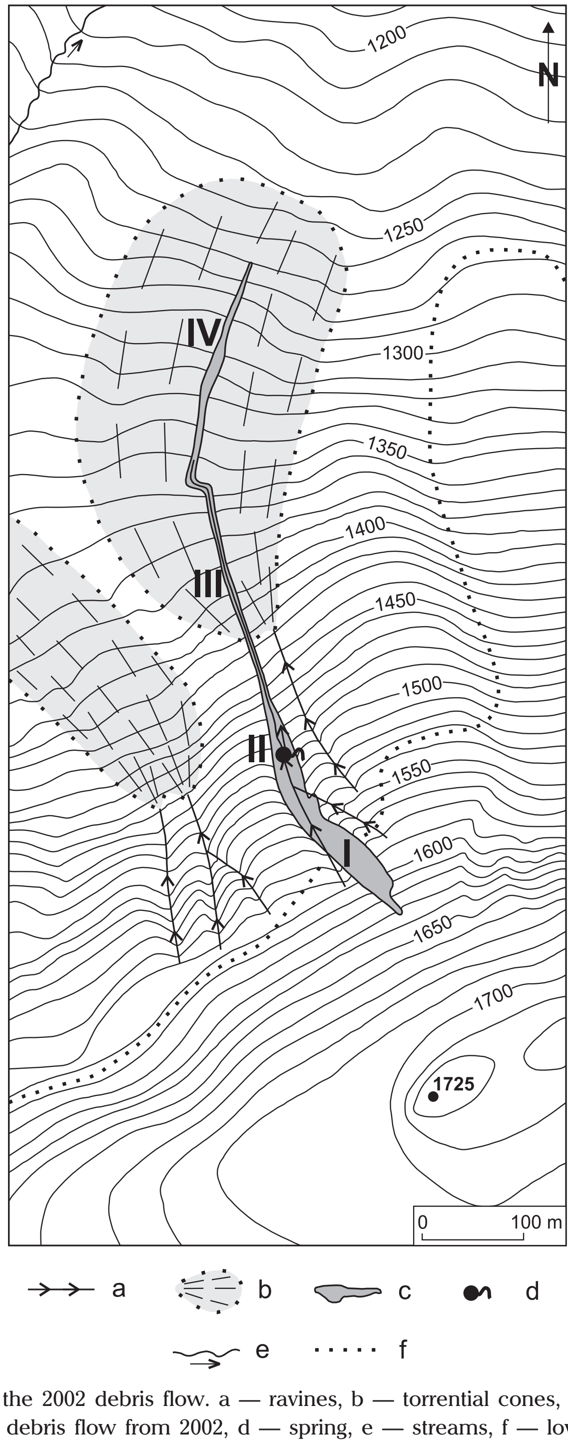


Fig. 4. Location of the 2002 debris flow. a — ravines, b — torrential cones, with ancient debris flow deposits, c — debris flow from 2002, d — spring, e — streams, f — lower extent of active block fields. I–IV — zones within the debris flow track (see text)

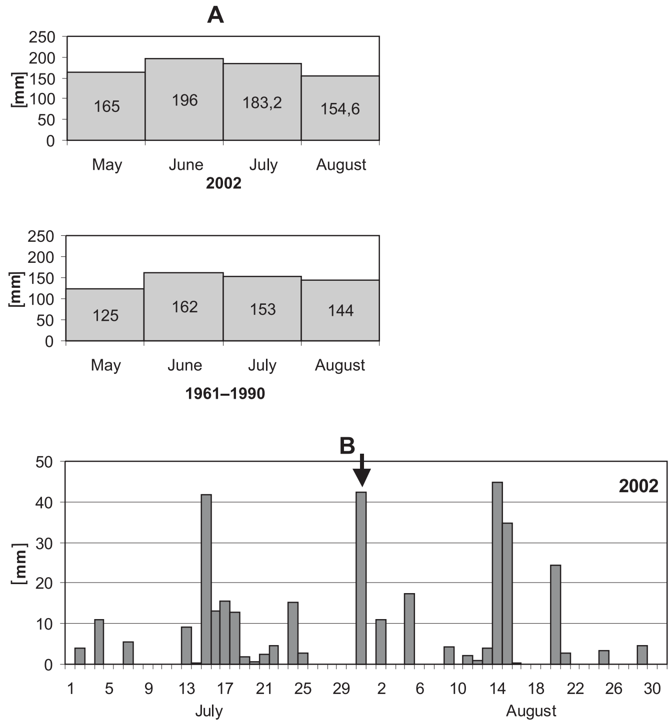
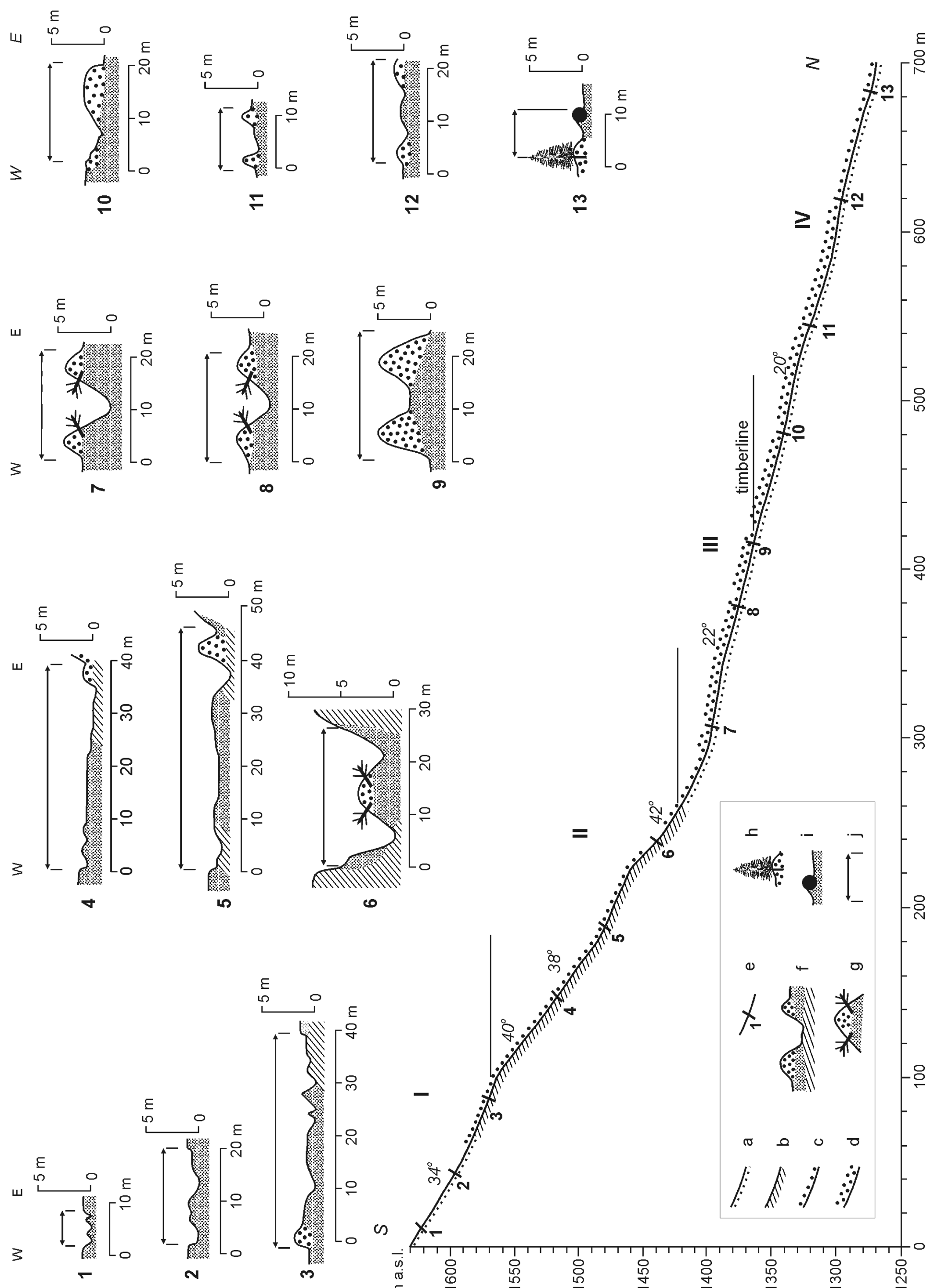


Fig. 5. Rainfall characteristics from the weather station at 697 m a.s.l. A — monthly sums in 2002 against the averages from the period 1961–1990, B — daily rainfall in July–August 2002. An arrow shows the day when the flow likely occurred

THE 2002 DEBRIS FLOW

The debris flow analyzed in this paper occurred at some time in late July/early August 2002, within the steep (34–42°) northern slope of Mt Babia Góra. The initial failure took place at ca 1,635 m a.s.l., roughly 200 m to the north from the summit, and the flow travelled down to ca 1,270 m a.s.l. (Fig. 4). The total length of the affected area, from the head scarp to the zone of ultimate flow dissipation in the forest belt, exceeds 700 m. Although a few flow-type movements have been recorded in historical times in the massif (Łajczak 2007), the 2002 flow was undoubtedly the longest and the only one known to originate well above the timberline.

Unfortunately, little is known about the factors which played a part in the origin of the flow. Especially, the relevance of meteorological record is limited. According to the Babia Góra National Park authorities, the flow must have occurred prior to the beginning of August and therefore it may have been triggered by heavy rainfall on 31 July. At the station located at 697 m a.s.l. the daily total recorded was in excess of 40 mm (Fig. 5). However, air advection from NW have likely caused the build-up of a local convection cell against the NW-facing slope. The combined effect of


W
E
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orographic convection and altitude may have resulted in significantly higher daily rainfall than that recorded at the low-altitude station. In addition, the period of 13–25 July was generally a rainy one, hence the origin of the flow has likely been complex.

Geomorphologically, the flow track may be subdivided into four reaches, each having its own characteristic suite of erosional and depositional landforms (Fig. 4, 6):

Failure zone (I) is a very shallow scar, elongated along the slope, 5 to 35 m wide and ca 120 m long, cut into the slope surface inclined at 34°, within the altitudinal belt 1,570–1,635 m a.s.l. (Photo 1). The failed mass was about 1 m thick and made of debris material, with individual sandstone clasts set in loamy matrix. Sandstone bedrock was only occasionally exposed, otherwise it is the deeper horizon of the debris cover that makes the floor of the hollow. Thin lobes of debris and low ridges occur in the eastern part of the failure zone, indicating that deposition was not restricted to the distal part of the flow. The pre-failure topography consisted of two slope surface undulations which converged at 1,520 m a.s.l. to produce a shallow gully within the steep slope segment below. No bedrock exposures were present prior to the 2002 event and a continuous, vegetated regolith cover occurred instead.

Stripping zone (II) is associated with a pre-existing slope hollow and covers the slope segment from 1,570 to 1,430 m a.s.l. This is the steepest part of the track, with inclination between 30 and 42°. This considerable gradient allowed the failed mass to travel through to lower altitudes, but there was also widespread stripping of slope covers down to bedrock. Subsequently, fluvial incision produced V-shaped ravines up to 3–4 m deep, cut into the sandstone beds (Photo 2). Although erosion was dominant, depositional lobes do occur in a few places. The length of this reach is 210 m, the width varies from 40 to 10 m near the lower end.

Transitional zone (III) below the outlet of the pre-existing hollow formed within the dwarf pine belt at 1,430–1,360 m a.s.l., on a densely overgrown surface of a torrential cone. Slope gradient is about 22–28°. The zone III is made of an almost straight furrow 2.5–3.2 m deep, extending over ca 150 m and followed by parallel levees built of sandstone clasts on both sides (Photo 3). These are 1.5–2 m thick and bury dwarf pine and rowan communities. At the end of the reach, the right-hand side levee widens to an extensive depositional surface, with individual sandstone blocks as much as 0.5 m long, whereas the track itself sharply turns to the left. A 3 m high step made of boulders and jammed tree logs marks the boundary of the zone III.

Fig. 6. Longitudinal profile of the 2002 debris flow and selected cross-sections (1–13). a — debris flow track sections incised into colluvial covers, b — bedrock outcrops, c — levees on one side of the track, d — levees on both sides of the track, e — location and numbering of cross-sections, f — flow-related deposits in cross-section (levees, older regolith, bedrock), g — dwarf pines covered by flow deposits, h — spruce trunks buried by flow deposits, i — spruce logs, j — lateral extent of the track, I–IV — zones within the debris flow track (see text)

Photo 1. Failure zone seen upslope (Photo by P. Migoń)

Photo 2. Deep incision in the zone II, with the Magura sandstone exposed (Photo by P. Migoń)

Photo 3. Debris flow track in the zone III, with the central furrow and parallel levees (Photo by P. Migoń)

Depositional zone (IV) is located within the upper montane forest belt, below the altitude of 1,360 m a.s.l., and is 350 m long. Slope inclination alternates from 6 to 23° and the width of the affected slope varies from 10 to 20 m. The furrow-and-levee morphology becomes less distinct downslope, with the height of marginal levees not exceeding 1.2 m and diminishing with the track length. However, the key role in directing the flow was played by trees and logs. Hence, the track is sinuous in plan, locally it divides into two branches, and there is widespread induced deposition behind the tallest spruce trees and fallen wood. The height of levees in front of the trees is up to 1.6 m, and the largest sandstone blocks are 1.5 m long (Photo 4). No evident depositional landform at the toe exists and clear signs of water flow across the undergrowth indicate that the proportion of water to debris rapidly increased.

Short-term geomorphological consequences of the flow include the following. The upper slope (segments I and II) has lost much of its regolith cover and weathered bedrock is now exposed over large surfaces. Although the thickness of the removed material is not big (ca 1 m on average), it means an almost complete exhaustion of the source for any future failures in this part of the slope. In addition, at ca 1,500 m a.s.l. an efficient spring has been exposed and surface flow is

Photo 4. Induced deposition against spruce trees in the zone IV (Photo by P. Migoń)

now occurring along the flow track down to ca 1,350 m a.s.l., where the stream disappears in the debris cover. Geomorphic changes of highest magnitude are recorded in the zone III, in which local relief increased to 4–5 m due to concurrent erosion and deposition of the levees. In the depositional zone (IV), re-shaping of slope morphology has been accomplished mainly through piling up of the material behind the trees, whereas incision has been limited.

The 2002 flow offers a good opportunity to monitor subsequent changes along the flow track, the lifetimes of depositional and erosional landforms, the rate of renewal of the regolith, and longer-term ecological consequences. At the moment, however, the persistence times of the flow-related landforms can only be speculated.

DISCUSSION

Up to 2002, debris flows of huge dimensions had been unknown in the Babia Góra massif. In particular, no such events had been recorded in the most elevated parts of the area, above the timberline. Landsliding rather than debris flows was considered as the key process to shape the slopes, although different opinions concerning the age, extent, and depth of landslides have been expressed (Alexandrowicz 1978; Łajczak 2004; Ziętara 2004). At the same time, however, the entire timberline zone remained a poorly researched terrain, hardly accessible through the dense primeval spruce stands, thick fern undergrowth, and dwarf pine communities.

The 2002 debris flow provided evidence that very rare, unpredictable events, with the recurrence time in the order of >100 years, do occur in the geomorphic system of the Babia Góra massif and accomplish significant geomorphological work, affecting different geoecological belts. Indeed, the magnitude of geomorphic changes recorded along the flow track has clearly surpassed the effects of all other processes. Instantaneous lowering of the upper slope through sliding by ca 1 m, bedrock incision along the track up to 3–4 m, deposition of levees up to 2 m high along a few hundred meters, and formation of huge debris piles up to 1.5 m high behind the trees have been, for the environment of Mt Babia Góra, quite exceptional geomorphological phenomena. It remains an open question how persistent will be the landforms created by the flow, but in the first five years they have lost little of their visibility.

Closer inspection of the upper montane forest belt in the immediate vicinity of the 2002 debris flow has revealed the existence of landforms which are likely related to previous debris flow events of similar magnitude. They are yet to be investigated in detail (Łajczak, Matyja, in prep.), but a few characteristics are worth emphasizing here. The slope surface is dissected by sinuous V-shaped gully-like features, the depth of which is 2–4 m. Incisions, which do not have any permanent drainage, are accompanied by parallel ridges 1–2 m high, visually similar to levees. The ridges are evidently of old date as shown by the presence of tall, thick spruce trees which may be as old as at least 200 years. Interestingly, distinct furrows and ridges occur in the altitude zone, where the 2002 flow has already faded away and little deposition or erosion took place. It is therefore suggested that at some time in the past (early Little Ice Age?) the northern slope of Mt Babia Góra was subject to much more intense remodelling, and high magnitude debris flows were significantly more frequent than they are under current conditions. The reasons for the increasing stability of slopes in the more recent times remain elusive, though. Whether it is the exhaustion of the source of debris, or fewer extreme weather conditions, is to be recognized.

The sheer size and uniqueness of the 2002 debris flow in the Babia Góra massif, coupled with the recognition of geomorphic legacy of more ancient high magnitude events, validates a new look at geomorphic systems of other mountain terrains, environmentally similar to Babia Góra. In particular, the role of debris flows requires re-assessment. In certain areas, such as the Karkonosze, debris slides turning into flows are relatively frequent and indeed many have been recorded in historical times, and their geomorphic legacy mapped (Pilous 1973; Migoń et al. 2002; Parzóch et al. 2007). However, the geomorphology of the timberline zone in the steepest slope sections may still reveal the evidence of more ancient events. The Hrubý Jeseník massif in the East Sudetes is a particularly interesting case. Only a small fraction of the area is located above the timberline, and yet debris flows recorded since 1920s are common and highly destructive, some having been initiated in the forest belt (Gába 1992). Current dendrogeomorphological research (Hrádek et al. 2006) has already provided evidence for debris and hyperconcentrated flow events which escaped eye-witness record. In the sub-alpine belt of the Tatra Mountains, which represent the high mountain environment in the zone above 1,500–1,600 m a.s.l., debris flows are common (Krzemień 1988; Kotarba 1989, 1992). However, their occasional occurrence in the forest belt, yet with considerable geomorphic consequences (Krzemień et al. 1995), shows further that the stability of steep forested slopes in Central Europe may be overestimated.

In sum, it is concluded that observations carried out in the last 100 years or so do not provide an entirely reliable basis to build a model of a geomorphic system, neither for Mt Babia Góra nor, by analogue, for other mountain ranges similar in altitude and slope steepness. The recurrence period of very rare, but geomorphologically highly potent hillslope events appears to be at least 100 years and needs to be taken into account when magnitude frequency relationships for transitional medium/high mountains are being established.

HAZARD ASSESSMENT CONTEXT

The 2002 debris flow event assumes a key importance in the context of hazard assessment. The construction of hazard maps is again sensitive to what is known about the potentially destructive natural phenomena, whether from geomorphic evidence or historical sources. Consequently, if no such evidence is readily available, then certain hazards may become underestimated or even not realized altogether.

The Babia Góra massif is a very specific case, for which historical record is short and limited to the last 100 years or so (Ziętara 2004). Within this period, rapid geomorphic processes of high magnitude have not occurred very often and involved rather limited portions of the slope surfaces. Hence, the geomorphic environment of the massif might have been considered as one of low energy and disassociated with natural hazards.

The 2002 debris flow has changed our perspective on the long-term stability of the northern slope of Mt Babia Góra, and by implication, of other steep slopes in the Carpathians. The absence of evident signs of current hillslope processes of high magnitude is deceptive. In fact, the combination of very high gradient, occasional extreme precipitation, and near-surface discontinuities along the regolith/bedrock boundary favours rapid movements of unconsolidated slope covers, whereas the lack of topographic constraints allows the moving mass to travel long distances, into the montane forest belt. In a sense, the 2002 event is less surprising than the fact that flows of similar magnitude have not been recorded before, despite the high frequency of heavy rainfall episodes.

Practical implications for hazard assessment programmes include the necessity of special consideration of steep (>25°), deforested slopes as these may yield catastrophically without apparent warning. The likelihood of such events is difficult to estimate, but two circumstances suggest that it may be on the rise. One stems from the current scenarios of climate change which almost invariably predict an increasing frequency of extreme weather phenomena, including heavy rainfall. The other one relates to the long period without debris flows of big size. If the upper slopes of Mt Babia Góra are weathering-limited, then the protracted absence of debris flows may mean exhaustion of regolith supply at some time in the past, followed by its slow renewal.

Another aspect to be considered in the hazard assessment is the prediction of possible travel path of a flow. The 2002 debris flow, despite its sheer size, was harmless because it occurred at high altitude and failed to reach a channel. If it managed to do so, then transformation into a devastating hyperconcentrated flow, capable to travel far downstream, might have taken place. In this context, debris flows in the Hrubý Jeseník Mts need mentioning. A series of debris flows that affected the steep valley side of the Desna valley in 1921 transformed into a fast-moving slurry after reaching the channel. Settlements located downstream were severely damaged and fatalities occurred (Polach and Gába 1998).

CONCLUSIONS

The 2002 debris flow on the northern slope of the Babia Góra warrants attention because of two main reasons. First, as a geomorphic event it was a unique phenomenon in the recent history of the massif. No events of this size have been recorded in the last 100 years or so, nor such a considerable tract of terrain within three different geoecological belts has been affected. In addition, the debris flow under scrutiny has surpassed the majority of similar phenomena in other transitional medium-to-high mountains in terms of size and the landscape change accomplished. Second, it prompts a modified approach to the recognition of mountain geomorphic systems. As a high magnitude but clearly very low frequency event it shows that a few years, or even a few tens of years of observations, may be insufficient to record all important components of the Holocene denudation system. The recognition of this gap does not merely have academic significance but needs to bear on our approaches to hazard and risk mapping. In short, the absence of high magnitude slope processes within the observation period, especially if this is limited to less than 100 years, must not be taken as the evidence that these do not occur and the worst-case scenario needs to be adopted.

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STRESZCZENIE

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SPŁYW GRUZOWY NA BABIEJ GÓRZE Z 2002 ROKU — IMPLIKACJE DLA INTERPRETACJI SYSTEMÓW MORFOGENETYCZNYCH OBSZARÓW GÓRSKICH

W celu poznania zasad funkcjonowania współczesnych systemów morfogenetycznych wykorzystuje się zwykle dwa główne źródła informacji: wyniki długotrwałych pomiarów wybranych procesów rzeźbotwórczych oraz rezultaty kartowania geomorfologicznego. W obu przypadkach następuje nieunikniona koncentracja na procesach i zdarzeniach „typowych", zarejestrowanych instrumentalnie lub zapisanych w formach rzeźby, podczas gdy zdarzenia wyjątkowe o małej powtarzalności mogą umknąć uwadze, a ich udział w funkcjonowaniu systemu może być przez to niedoceniony. Potężny spływ gruzowy, który wydarzył się na północnym stoku Babiej Góry w lecie 2002 r., należy do kategorii procesów o bardzo małej częstotliwości, a znacznym potencjale rzeźbotwórczym. W okresie ostatnich 100 lat nie odnotowano bowiem w najwyższym piętrze wysokościowym Babiej Góry zdarzeń podobnej natury.

Spływ został zainicjowany na wysokości powyżej 1600 m n.p.m., na stromym (>30°) odcinku stoku powyżej górnej granicy lasu, pokrytym cienką warstwą rumoszu. Został prawdopodobnie wywołany silnym opadem deszczu, który miał miejsce 31 lipca. Długość toru spływu wyniosła ponad 700 m, a w jego przebiegu wyróżnić można kilka charakterystycznych odcinków: oderwania, zdzierania pokrywy zwietrzelinowej, tranzytowy z udziałem zarówno erozji, jak i depozycji na wałach bocznych oraz depozycji i rozpraszania energii. Ten ostatni znajduje się w całości w piętrze regla górnego i kończy się na wysokości około 1270 m n.p.m.

Zasadnicze implikacje spływu z 2002 r. są następujące. Po pierwsze okazuje się, że okres 100 lat bezpośrednich obserwacji jest niewystarczający do stwierdzenia występowania wszystkich procesów kształtujących stoki Babiej Góry i właściwej oceny ich skali. Po drugie, analiza form pozostawionych przez spływ w piętrze leśnym pozwoliła wyjaśnić przez analogię sposób powstania wyraźnych wałów i rynien występujących w reglu górnym, dzisiaj całkowicie porośniętych przez kilkusetletnie świerki. Niewykluczone, że przez kilkuset laty spływy gruzowe o znacznym zasięgu były w masywie Babiej Góry powszechniejsze. Po trzecie, mapy zagrożeń i analizy ryzyka dla obszarów górskich powinny uwzględniać także te kategorie ruchów masowych, które nie zostały zaobserwowane bezpośrednio w okresie historycznym.