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RESEARCH ON PRESENT-DAY GEOMORPHIC PROCESSES IN THE POLISH CARPATHIANS
STATE OF THE ART

Studies on the present-day geomorphic processes in the Carpathians have a long and admirable tradition, documented by numerous works also published in foreign languages. Direct measurements of processes, based on field experiments, undertaken by geomorphologists were initiated in this area in the 1950s already, that is at the beginning of development of contemporary dynamic geomorphology.

The purpose of this paper is to provide an overview of the present-day geomorphic studies carried out in the Polish part of the Carpathians during the recent 15 years.

Geomorphic studies not only aim at determination of a rate of processes, which was the goal in an initial stage of research, yet at showing mechanism of these processes and at demonstrating relationships between the forms and processes as well. Therefore, the studies do not exclusively deal with secular processes mainly modifying the relief, but also with the processes of extreme intensity that give rise to new morphological forms. The extremely intensive processes are induced by catastrophic events related to rapid changes in air masses circulation which are a response to global climatic changes. Thus, research trends correspond with a scope of activities of IGU Commission GERTEC (Geomorphic Response to Environmental Changes) which evolved from the Commission of the Field Experiment in Geomorphology. According to a commonly accepted concept on a dynamic quasi-equilibrium in a scale of a several tens of years (Chorley and Kennedy 1971), the phase to which a study period is attributed is taken into account. In the studies on the present-day processes a system approach is adopted, and thus the focus is on cognition of interaction between slope and river channel sub-systems in a drainage basin system (Kotarba et al. 1987; Krzemień 1991; Froehlich 1992, 1995; Froehlich and Walling 1992, 1994, 1997; Kaszowski ed. 1995a, 1995b; Starkel and Gil eds. 1994).

Figure 1 presents localities where the studies of the present-day geomorphic processes were performed in the discussed period. These studies

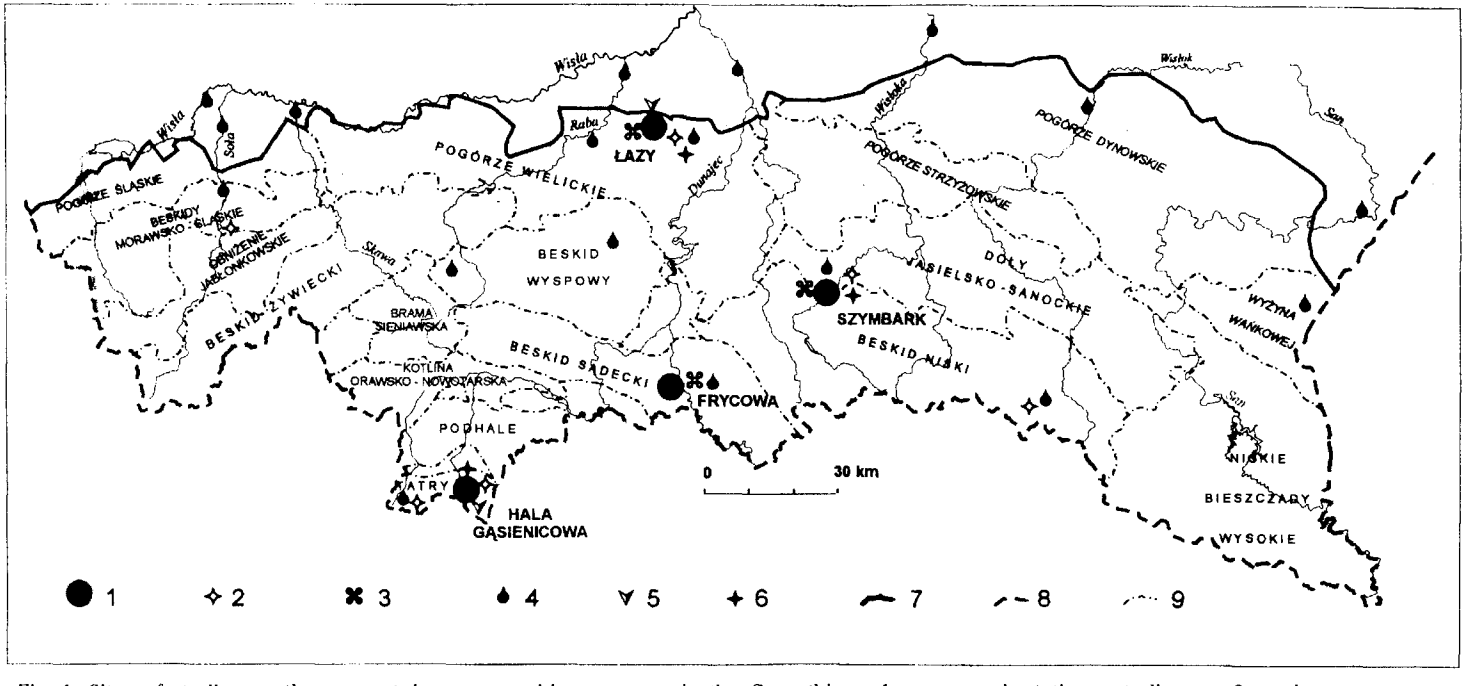

Fig. 1. Sites of studies on the present-day geomorphic processes in the Carpathians: 1 — research stations, studies on: 2 — slope processes, 3 — circulation of energy and matter , 4 — fluvial processes, 5 — aeolian processes, 6 — chemical denudation, 7 — northern border of the Carpathians, 8 — state boundary, 9 — borders of geomorphological regions. Geomorphological division of the Carpathians after Starkel (1972)

Ryc. 1. Lokalizacja badań współczesnych procesów w Karpatach: 1 — stacje badawcze, 2 — badania procesów stokowych, 3 — badania obiegu materii i energii, 4 — badania procesów fluwialnych, 5 — badania procesów eolicznych, 6 — badania denudacji chemicznej, 7 — północna granica Karpat, 8 — granica państwa, 9 — granice regionów. Podział geomorfologiczny Karpat wg Starkla (1972)

cover all types of the relief occurring in the Polish Carpathians, that is a high-mountain relief, Beskidian and foothill one, yet the spatial distribution in the region is not uniform. The investigations are usually performed within a framework of research stations or a "patrol" field work. It should be noticed that a new Research Station of the Institute of Geography of the Jagiellonian University (IG JU) was set up in a marginal zone of Wieliczka Foothills, namely in Łazy (Kaszowski ed. 1995b) and has already been acting for 12 years. On the other hand, Research Station of the Institute of Geography and Spatial Organisation of the Polish Academy of Sciences (IGSO PAS) in Szymbark at the border between the Beskidy and the Foothills has a continuous 30 year-long series of records while the stations belonging to the same Institute but located in Frycowa (the Beskidy Mts) have been functioning for over 20 years. What is more, the role of the station at Hala Gąsienicowa (the Tatras) cannot be overemphasised where the investigations were initiated as early as in the 1950s and are significatly contributing to geomorphological research for over 20 years, i.e. for the period of intensive process studies.

In the studies traditional unsophisticated methods and relatively simple instruments, often self-designed ones, were used most often. Fortunately, there has been a significant progress in this field since the beginning of the 1990s. Automatic devices linked with a computer-assisted system of data acquisition have been implemented in many stations. Such equipment is mainly used for recording hydrometeorological conditions, but is also used to register erosion on slopes or bedload and suspended load transportation.

Application of new methods is widely attempted. A methodological progress is associated with usage of ^{137}Cs isotope as an indicator of intensity of the present-day morphogenetic processes. Differences in ^{137}Cs content in slope deposits and fluvial sediments gave bases to determine the rate and mechanism of denudation process, transportation routes and sources of weathered material supplied to river channels as well as time of transition from erosional zones to accumulation regions in drainage basins of various sizes (Froehlich and Walling 1992, 1994, 1997, Chełmicki and Święchowicz 1992).

Employment of vegetation as an indicator of spatial differentiation of processes is another attempt to introduce new methods in the studies of the present-day morphogenetic processes on a high-mountain slope (Kozłowska and Rączkowska 1994). This method is based on comparison of the maps showing the present-day geomorphic processes with the vegetation maps in scales 1 : 500 or 1 : 1.000 and a statistic documentation of the relationship between these elements.

In the studies on the dynamics of high-mountain slopes analyses of the cores of the bottom lacustrine deposits, archive photographs and lichenometry were successfully used (Kotarba 1992b, 1997).

SLOPE PROCESSES

In the discussed period there is a significant progress in cognition of the slope dynamics both in the Tatras and in the Beskidy Mts. Multi-year studies carried out with a background of the Research Station IGSO PAS at Hala Gąsienicowa (Gąsienicowa Glade) allowed to learn the course and rate of nivation process as well as its mechanism that became the basis for determination of a role of snow patches in the present-day modelling of the High Tatra relief (Rączkowska 1993, 1995, 1997). It led to conclusion that nival niches are developing on mature slopes as a result of nival erosion while nival accumulation niches are forming on debris slopes.

Mechanical denudation of high-mountain slopes due to heavy downpours was subjected to detail investigations. A new term "aluviation" denoting transformation of a debris slope due to precipitation water impact has been introduced (Kotarba et al. 1987) and a new model of a slope transformation by aluviation has been developed (Kotarba 1992a). It has been stated that the present-day debris flows, formed during heavy downpours, are set in the upper parts of the slopes and do not reach their foot as a rule, which is in contrary to the much larger and more frequent flows of the Little Ice Age (Krzemień 1988, 1989; Kotarba 1992a, 1992b). Relationship between the probability of downpours and magnitude of flows (Kotarba 1992a) as well as threshold values of precipitation (80–100 mm a day with intensity of 30 mm/hour) necessary to trigger debris flows (Kotarba 1997) have been determined. Occurrence of debris flows during the last 200 years has been retrieved based on detail geomorphological maps, lichenometric dating (Jonasson et al. 1991) and analyses of lacustrine deposits (Kotarba 1992b). The analysis of lacustrine deposits provided also the bases to determine slope processes intensity in the periglacial zone in the Tatras during the Holocene (Baumgart-Kotarba and Kotarba 1993; Jonasson 1991; Kotarba and Baumgart-Kotarba 1997).

Landslide processes in the Beskidy Mts have continuously been studied in the Research Station of IGSO PAS in Szymbark. These processes belong to the most important morphogenetic processes modelling the slopes in the flysch Carpathians as they result in development of new landforms (Gil 1994b, Thiel ed. 1989). A long series of detail meteorological observations as well as repeated geodetic measurements and mapping of the changes in sizes and shapes of landslides allowed for determination of the relationship between hydrometeorological conditions and rate and mechanism of landslide movement (Gil 1997). Deep rock-debris slumps on the sandstone-shale deposits form under conditions of full saturation which are due to precipitation lasting 20–45 days, amounting to 250–300 mm and with a mean intensity of 0.025 mm/min. On the slopes where sandstones prevail, mass movements occur if precipitation reaches 400–450 mm in 20–40 days and the total of the last 5–6 days is amounting to 250 mm (Gil 1997). The

landslide phenomena were successfully evaluated from the air photographs (Ziętara et al. 1991).

STUDIES ON CIRCULATION OF ENERGY AND MATTER

Studies on circulation of energy and matter are mainly performed in research stations while the way the investigations are carried out is controlled by characteristic features of the natural environment in the mountains (Starkel 1996).

Measurements of soil erosion on slopes and of an output of weathered material, that have been carried out in the Research Station IGSO PAS in Szymbark since 1968, allowed to determine quantitatively particular processes and factors controlling the variability in intensity of the processes in the annual cycle in relation to land use and hydrometeorological conditions (Gil 1990, 1994a). Studies in this domain, performed in the Research Station IGSO PAS in Frycowa using standard and ^{137}Cs methods allowed to find a mechanism of erosion on the slopes in relation to alimentation areas and sources of weathered material to the channels, and in relation to transformation of the transported load downstream in the Beskidian catchments of various sizes (Froehlich 1992, 1995; Froehlich and Walling 1994, 1997). In the studies, a special attention was paid to the mechanism of the weathered material transfer on the slope (Froehlich 1992, 1995). Based on these studies, it became evident that the main sources of the weathered material supplied to the channel are cart roads as they are a direct linkage of the slope and channel system (Froehlich 1992; Froehlich and Walling 1992, 1997). A large role of the roads in circulation of matter in the catchment is evidenced by their large density in the Carpathians (Soja and Prokop 1996). Besides the surface runoff and surface outwash the studies focused of splash erosion as well (Froehlich 1986; Śmietana 1987).

The studies on circulation of energy and matter, started at the Research Station of the IG JU aim at cognition of environmental conditions and at determination of the mechanisms and functioning of elementary catchments and high-order catchments treated as subsystems and systems (Kaszowski ed. 1995b) as well as at cognition of the mechanisms of circulation of anthropogenic contaminants and environmental resistance to the latter (Kaszowski ed. 1995a).

FLUVIAL PROCESSES

Process of transportation of suspended load in large drainage basins of the areas from a dozen to several tens thousand square kilometres has been recognised in details with the Upper Vistula catchment as an example (Łajczak 1989). Spatial differentiation, multi-year and seasonal variability

in intensity of suspended load transportation have been determined. Moreover, a rate of silting of water reservoirs has been estimated. The intensity of suspended load transportation served as a basis for estimation of differences in soil erosion in drainage basins of various sizes (Łajczak 1989; Lach and Ziętara 1990, Froehlich 1992).

Usage of ^{137}Cs method allowed for recognition of magnitude and spatial differentiation of sedimentation on a floodplain and on deltas in water reservoirs (Froehlich 1992, Froehlich and Walling 1994).

Studies on fluvial transportation in small catchments have been continued and included determination of a relationship between the dynamics and load of suspended matter carried out from a catchment and precipitation (Welc 1988) as well as differentiation and seasonal variability in output of dissolved load and suspended load from such catchments (Krzemień 1995a, Krzemień and Sobiecki 1998).

Based on 12-year long stationary studies on stream hydrodynamics, dynamics of supply and transport of dissolved load, suspended load and bedload as well as on dynamics of the channels themselves, the role of fluvial morphogenetic process in modelling of a high-mountain region has been determined as well as the regularities in the fluvial system dynamics in a high-mountain region in an annual cycle. It has been stated that the present-day fluvial processes only slightly model the channels of a mature fluvial system (Krzemień 1991).

In order to figure out the changes in functioning of the systems of certain Carpathian rivers in historical times, archive cartographic materials have been examined minutely together with analyses of hydrologic records and fluvial sediments (Wyżga 1993, Grocholska 1988).

Another direction is associated with the studies on the influence of water reservoirs constructed on the Carpathian tributaries of the Vistula river on slope and fluvial processes in their surrounding. Here, the basis is a geodetic registration of changes in a network of polygons on the slopes and at the bottom of water reservoirs (Ziętara 1992a, 1992b, 1994).

In the studies on fluvial processes, as it was the case in the slope studies, particular interest is focused on changes in relief due to floods induced by precipitation of an extreme intensity. Such events happened in various parts of the Carpathians in the last two years. Although these studies are carried out using different approaches, they are most often limited to recording geomorphic effects of the floods (German 1997). Relief changes as well as flood-induced material losses in the Soła catchment are analysed on the background of a flood history from the 15th century in this drainage basin (Malarz 1997). Consecutively, changes in a cross-section of the Tenczyński Stream (Beskid Wyspowy Mts) as well as the intensity and amount of sediment transported as a bedload provide the basis for simulation and predicting channel changes using advanced computational techniques (Bartnik, Golsz 1997).

It should be emphasised that in the discussed period of investigation, anthropogenic conditioning of fluvial processes attract the attention (Łajczak 1997; Rettinger 1992; Froehlich 1990; Lach and Ziętara 1990; Lach et al. 1990). The effects of channelisation on suspended load transportation and on sedimentation in the Carpathian tributaries of the Vistula have minutely been documented. In the first stage of a channel regulation, which involved the channel straightening, intensity of a river down-cutting was increasing as in consequence was eroded material available for transportation. As the numerous dams and water reservoirs had been built, the transported material was being trapped and its load decreased (Łajczak 1997). Inferring from a water circulation pattern and functioning of regulated Carpathians streams, a small efficiency of regulatory structures as well as a urgent need for complex anti-flood and anti-erosional practices which should refer to the floors and the valley slopes have been noticed (Froehlich 1990). Influence of differences in population density and related to it changes in land use on suspended load transportation (Rettinger 1992, Lach et al. 1990) and on other geomorphic processes (Lach and Ziętara 1990) have been documented.

STUDIES ON OTHER PROCESES

Investigations of aeolian processes are carried out rather rarely. A role of aeolian processes in circulation of matter in a foothill catchment in relation to anemologic conditions has been shown by Izmaiłow (1995, 1998) on the basis of experimental studies carried out at the Research Station of the IG JU in Łazy. She has presented spatial and temporal variability of deflation and deposition of snow, organic, and mineral matter. Besides that, deposition of dust originating from remote sources is exclusively recorded at the Research Station of the IGSO PAS at Hala Gąsienicowa in the Tatras.

In the discussed period of studies on the present-day geomorphologic process, a relatively large emphasis was on investigations of chemical denudation. These investigations aimed at cognition of spatial differentiation of such denudation in a catchment and of its seasonal variability in relation to different climatic conditions (Welc 1989, 1994; Prokop and Soja 1994; Krzemień 1995a, 1995b; Żelazny 1995; Kot 1997; Bochenek 1997). It has been stated that in transformation of the relief of the Carpathian Foothills chemical denudation plays a more important role while in the Beskidy Mts mechanical denudation predominates (Krzemień 1995a).

In the studies on chemical denudation a particular attention has focused on the relation between natural and anthropogenic factors affecting the magnitude and intensity of leaching of rocks and weathering covers. Due to fertilising practices and dust and gases emission, anthropogenic chemical substances are introduced to the environment. However, both the Beskidian and Foothill

environment have sufficient buffering abilities to hold contaminants being introduced to energy and matter cycling (Skiba et al. 1998; Kaszowski 1995a). On the other hand, the high-mountain environment of the Tatras has weak buffering abilities (Kot 1997).

FINAL REMARKS

The presented overview of the studies on the present-day geomorphic processes in the Polish Carpathians is the attempt to show all the ongoing research trends and directions. A significant progress in the research is evident in the discussed period and confirmed by the employment of new methods of study such as analyses of cores of the lacustrine deposits, lichenometry or applications of methods drawn from other branches of science like the ^{137}Cs method. The progress in the investigations is facilitated by automation of data recording which allows for collecting a vast number of data and provides the basis for determination of quantitative indices illustrating the intensity and conditions under which the present-day geomorphic processes operate. Indices of intensity of some processes, for example, of washing out, surface runoff etc. are driven from 20–30 years long series of records which is another advantage.

The system approach applied in the investigation caused the researchers to focus their attention on the relation between the slope and fluvial system in addition to the recognition of the mechanism and rate of particular processes. Learning the present-day dynamics of the relief has also been treated as an element in learning the dynamics of the natural environment as a complex entity composed of geoecosystems.

The progress in the studies is also evidenced by focusing the attention on anthropogenic influence on the geomorphic processes and their intensity which is especially important in the era of a strong and differentiated human impact.

However, the progress was not uniform. Some processes such as, for example, debris flows, transfer of weathered material in the catchment or fluvial transport have been recognised already well and in a complex approach. Yet, the spatial differentiation of particular processes requires further studies.

The future research should involve the study of the course and intensity of the present-day processes under new conditions which resulted from the extreme precipitation that occurred in the last two years as well as the registration of the changes in relief.

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STRESZCZENIE

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BADANIA WSPÓŁCZESNYCH PROCESÓW GEOMORFOLOGICZNYCH W KARPATACH POLSKICH

W artykule przedstawiono przegląd badań nad współczesnymi procesami geomorfologicznymi w Karpatch polskich, prowadzonych w okresie ostatnich 10–15 lat. Analizowano badania procesów stokowych, obiegu materii i energii, procesów fluwialnych, eolicznych oraz denudacji chemicznej. Stwierdzono, że w badaniach nastąpił postęp. Oprócz stosowania nowych metod, wprowadzono automatyzację pomiarów i rejestracji danych, zwłaszcza w badaniach stacjonarnych. W badaniach zastosowano podejście systemowe. Zwrócono uwagę na antropogeniczne uwarunkowania procesów.