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DURATION AND INTENSITY OF GEOMORPHIC PROCESSES IN THE RELIEF EVOLUTION OF THE POLISH CARPATHIANS

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While in normal years there predominate the secular processes, episodic ones of high intensity occur only during extreme years. In a longer time scale, the phases of high frequency of extreme events are of great importance. These phases disturb the equilibrium of slope and the river channel systems. During the Quaternary, special changes took place in transitional periods. The polycylic relief of the Carpathians reflects a sequence of phases of more or less intensive processes.

INTRODUCTION

Relief evolution is realized in time. The more nature is the landscape, the longer is the period of evolution. But the real duration of events, responsible for the transformation, is usually much shorter we expect (Thornes and Brunsden 1977). It may be proved by direct measurements of processes, starting with monitoring the rainfall duration. The characteristics of the summer rainfalls (May-October) in 1969—1937 at the Szymbark field station reported by Wit—Jóźwik (1978) show that the duration of rainfalls only amounts to 6.9 % of the time, i. e. 254 hours per summer (it varies from year to year from 180 to 360 hours). Only 46 % of these were represented by rains of total precipitation of more than 20 mm (the morphologically effective rainfalls). The real duration of the overland flow is restricted to more or less 100 hours during the whole year. A distinct part of the flow is related to the snow-me-season. The individual heavy rain may form 50—95 % of the total annual overland flow (Słupik 1977).

In long time units, we distinguish a great variety in the duration and frequency, as well as in the effectiveness of geomorphic processes. This variety, interpreted as the reflection of climatic changes, is visible in the maturity and the chronological sequence of forms, as well as in the course of deposition. While analysing the sequence of fluvial or slope deposits we may conclude,

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that the deposition represents only a small fragment of time, and — on the contrary — much longer time intervals are reflected in a hiatus or in erosional surfaces (Starkel 1977c).

All the problems mentioned above will be discussed and illustrated by the examples from the relief evolution and present-day processes in the Polish Flysch Carpathians.

ANNUAL CYCLE OF THE PRESENT-DAY PROCESSES

The geomorphic processes act in time, following the seasons of the year, especially the annual sequence of water circulation. The water carries matter in suspension and in solution; it also is the cause of the slope cover liquefaction. In the annual cycle, 2 main groups of processes, different in duration, may be distinguished (Starkel 1979, see Fig 1): the secular and the episodic groups of processes.

The secular processes are characterized by their low intensity and long duration. In the case when a selected process (slope wash) will reach a rate not encountered in the scale of a year (or years), then such an even will be called episodic or extreme. Among secular processes we may distinguish continuous processes such as chemical denudation (solution) going on in soil, in fact during the whole year, and seasonal (or periodic) processes existing during a relatively long time in summer or winter, such as slope wash, cryogenic processes or transport of the suspended load in rivers.

The processes of the other group may be called episodic; they are of very low frequency, act only during several days or even hours in a year, and occur only during some years. Among them there are above all the extreme events of high intensity and a long recurrence interval (mostly once per years). In the mountains of the temperate zone these are connected with 3 types of extreme rainfalls: downpours (with thunderstorms), continuous rainfalls, and rainy seasons with a high total rainfall (Starkel 1976).

Downpours of a daily rainfall up to 100 mm and intensity 1—3 $mm.min^{-1}$ cause in the Flysch Carpathians a rapid overland flow, washing of soil amounting to several centimeters, gullying, as well as earthflows (Gerlach 1966, Gil 1976). Continuous rains of a duration of 2—5 days, total rainfall 200—500 mm, and an intensity up to 10 $mm.h^{-1}$ are accompanied by shallow landslides on slopes and floods in valley bottoms. Such floods continuing in the Beskydy Mts. for several days are able to carry off even 90 % of the total annual suspended load and bed load (Froehlich 1975). Therefore, downpours disturb the stability of the slope system, and continuous rains the stability of the fluvial system. Rainy seasons with a high total rainfall form a separate group of extreme events. They happen when a rainy summer is followed by a rainy autumn, which causes a permanent saturation of soils and rocks, and a general reactivation of landslides in the Flysch Carpathians (the autumn of 1974 in the neighbourhood of Szymbark — Gil and Starkel 1979).

Among other episodic events there should be mentioned the highspeed winds and deflation; this process mostly lasts during 4—17 % of the winter season and may be included in the periodic secular processes (Gerlach 1976).

Therefore, the years with extreme events, with a recurrence interval of 10 or more years, have a different structure of effectiveness of the process in an

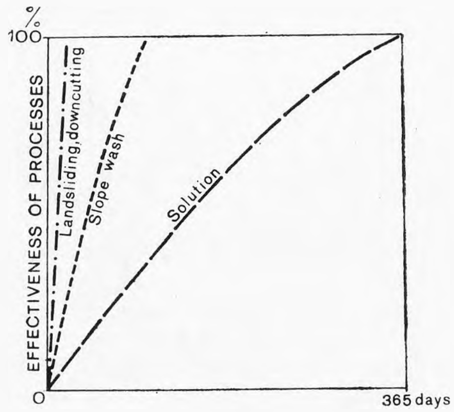

Fig. 1. Time structure of geomorphic processes (cumulative curves of process productivity in the annual scale).

annual scale. While during a „normal“ year the secular processes predominate, in an extreme year, on the contrary, it is the episodic processes that are the leading ones (Fig. 2).

THE ROLE OF EXTREME EVENTS DURING LONGER TIME UNITS

Analysing the frequency of great floods as well as the course of the Holocene fluvial deposition, we come to the conclusion that extreme events may be of different frequency, and that the latter may play an essential part in the transformation of the slope and river channel systems (Froehlich 1975, Starkel et al. 1981, Starkel 1983).

During the periods with a low frequency of extreme events the total effect of „normal“ years with secular processes prevails in the modelling of slopes and valley bottoms (Fig. 3—I). Single extreme years are not able to disturb the equilibrium of the system. And even if it were locally disturbed, the whole fluvial system would be able to return again to an equilibrium during the phase called the „adjustment“ or „recovery time“ (Selby 1974). Such a system of metastable equilibrium (after Schumm 1977) may be exemplified by most Carpathian slopes, and only rarely by the river channels, which now undergo substantial transformation.

During the periods with a high frequency of extreme events lasting for 100—400 years, the threshoold value may be surpassed much easier as regards the slope of river channel parameters (Fig. 3—II). During the Holocene, several phases of that character occurred, among them a very distinct one ca. 8400—8000 yrs BP (Starkel 1983). During such periods new equilibrium patterns are created, such as great landslides or changes from meandering to braided channels. The occurrence of alternating phases with higher and lower frequency of extreme events in the Holocene causes that after several centuries of decreased fluvial activity a braided channel returns to a more stable meandering one (B — A, Fig. 3—II). As a result, we find in the river valley the alluvial fills and abondoned channels of different age, side by side (Starkel et al. 1981).

CLIMATIC CYCLES AND THE CHANGES OF MORPHOGENETIC ZONES DURING THE QUATERNARY

The global climatic rhythmicity of a duration of 100, 40 and 20 thousands of years cause essential changes in geomorphic processes, both secular and extreme. There may be distinguished a different course of processes during cold (periglacial) and warm (interglacial) stages. In these two types of stages the annual cycle and the intensity of processes is different in the slope system than in the fluvial system.

During the cold stage, the summer season on slopes is characterized by a high intensity of cryoplanation as well as of slope wash. Due to the permafrost the Flysch slope can reach its threshold value more easily and more frequently. There follows an active downwearing of slopes. The snow-melt floods create braided channels, the rivers being overloaded with coarse debris. The interfingering of slope sediments with alluvial ones in the valley bottoms is the result of a simultaneous activity of both systems (Dziewański and Starkel 1962, Klimaszewski 1971).

During the interglacial stage, the threshold values of the overland flow or landsliding are reached very rarely due to the lack of permafrost and very deep water percolation on slopes. The leading role is played by leaching and soil formation under the cover of forests (Starkel 1977). The measurements performed at field stations shows that the episodic modelling of slopes during downpours is not synchronous with summer floods in larger river basins after continuous rains.

THE ROLE OF TRANSITIONAL PHASES

The change of morphoclimatic systems needs some time. In the case of the last turn from the periglacial to the temperate forest environment, this happened between 13 000 and 9500 yrs BP in the Carpathians (Starkel 1977b). It was a change in the duration of the individual processes as well as of their inten-

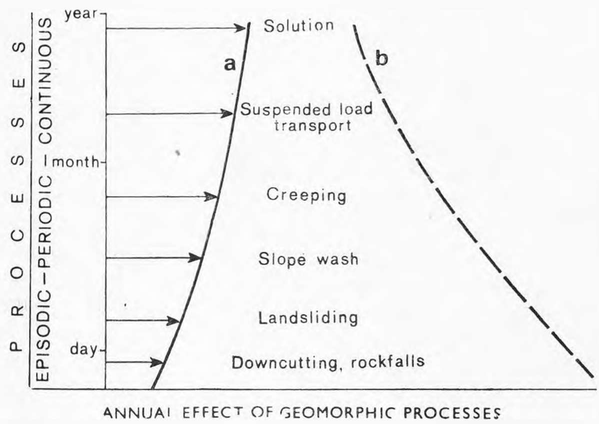

Fig. 2. Pattern of secular (continuous) and episodic processes during different years (a — mean year, b — extreme years).

sity. The processes related to the permafrost were replaced by those connected with the deep percolation of water. The earlier prevailing continuous or periodic processes were restricted only to episods and — on the contrary — the earlier episodic ones attained a dominating position. The character and frequency of extreme events changed, too. In the Late Glacial, due to the reactivation of downcutting and decreased bed load, the stability of many slo-

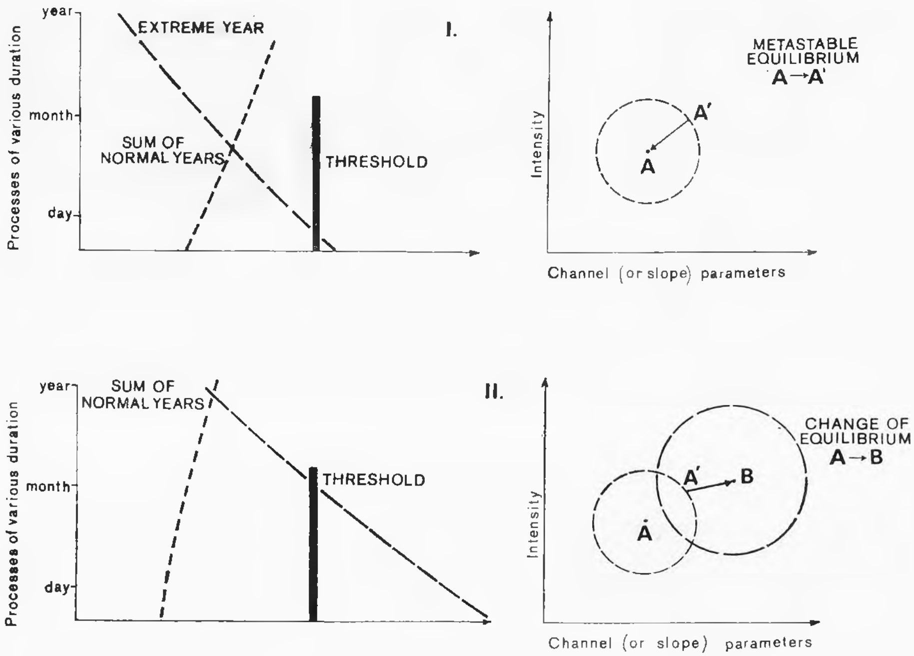

Fig. 3. Total effectiveness of geomorphic processes in the century scale (I — with low frequency of extreme events, II — with high frequency of extreme events).

pes was disturbed, and the extreme events played a leading role in the adaptation to the new climatic conditions. In the Flysch Carpathians there formed many new landslides, and the channel-forming discharges of rivers were several times higher, which is indicated by the size of palaeomeanders (Szumański 1983, Starkel et al. 1981). But another short phase dated at 8400—8000 yrs BP also was of high importance. High flood frequency caused a deepening and widening of river channels, not supplied with sediments in the totally forested mountains. This incision of an interglacial types was related to the change in the circulation of air masses, delated in comparison with the warming of climate (Ralska-Jasiewiczowa and Starkel 1975). The facts mentioned above indicate that such transitional periods are characterized by the highest intensity of erosion and the removal of material (Fig. 4). Probably this is the reason of the distinct separation of forms and deposits related to the cold and the warm stages.

THE POLYCYCLIC CHARACTER OF THE RELIEF AND VARIOUS RATES OF ITS EVOLUTION

The Carpathian landscape is a result of the superposition of climatic and tectonic variations during the Neogene and Quaternary. These changes were accompanied by continuous fluctuations in the intensity of processes. There-

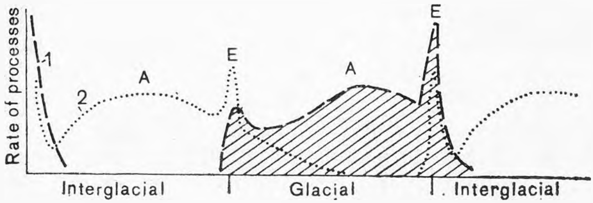

Fig. 4. Changes in the rate of processes, characteristic for the warm ages (1) and cold ones (2), reflected in the phases of aggradation (A) or downcutting (E) during the transitions.

fore, we cannot transfer the results of measurements of the present rate of processes (slope, fluvial or tectonic) to time intervals lasting hundreds of thousands or millions of years. The scale of events in those long periods can be reconstructed only by the analysis of the altitude of planations and river terraces as well as correlative deposits in the subsiding depressions (Birkenmajer 1978, Dżułyński et al. 1968).

The relief, which exists in every period of time, is in fact an inherited relief, a result of the overlapping of different climatic and tectonic conditions. Such a relief responds, with a distinct delay, to various factors. The degree of the adaptation of the relief to the existing factors depends on various conditions, including stable (continuous) and periodic ones. Among the stable ones there is the resistance of rocks, which in extreme situations leads to a full preservation of the palaeorelief (on quarzites and limestones) or to a full transformation (on claystones). The short-term cause may be exemplified by the glacial valley sides in the Tatra Mts. quite unadapted to the Holocene conditions, or by the preservation of periglacial blockfields due to a very slow soil formation and a delayed invasion of forest, or by the delay in the channel incision following the uplifting. As the effect of those delays there exist in the present-day landscape the inherited and the new features side by side (Starkel 1978).

The essential condition of understanding the differentiated rate of relief adaptation is the recognition of the parallel or diachronous evolution of slopes and valleys in the glacial-interglacial cycle. Both systems, the slope and the fluvial one, are diachronous in the climatic conditions of the Holocene. The slope system today is slightly changing due to linear erosion, piping and mass movements (in natural conditions). It has the features of an inherited system, which, under periglacial conditions, reached higher level of maturity, when the threshold value of slope stability was easier to be reached. On the contrary, the river channel system is adapted to the contemporaneous hydrological conditions. It is a young system with a frequent surpassing of the threshold. Therefore during the Holocene there existed two systems in the Carpathians: the inherited and the younger one. It should be taken under consideration that extreme events, differring in type and size, disturb the systems of various scale (slopes and small or large river basins).

In the sediments deposited at the bases of slopes and at the bottoms of valleys and depressions there are recorded many individual extreme events. There should be mentioned the Plio-Quaternary conglomerates in the western part of the Orava-Nowy Targ Basin (Birkenmajer 1978) and at the northern margin of the Sandomierz Basin Dżułyński et al. 1968), or the fossilized landslides incorporated in the solifluction deposits of the Vistulian age (Starkel 1977b).

Comparing all these facts with the present-day processes we conclude that the relief evolution in time is a sum of individual events, especially of those agglomerated in relatively short time intervals, when the threshold value of the slope or river channel system can be reached easier. The surpassing of such a quantitative threshold causes a qualitative change of the Carpathian landscape, and adds new elements to the existing polygenic relief. These new features can be superimposed on the older ones, or cut in them, in the case of river valleys in tectonically active areas.

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Leszek Starkel

TRVANIE A INTENZITA GEOMORFOLOGICKÝCH PROCESOV VO VÝVOJI RELIÉFU POĽSKÝCH KARPÁT

Obdobie trvania morfogenetických procesov, modelujúcich súčasný reliéf Karpát, je rôzny. V normálnych rokoch majú prevahu sekulárne procesy a v extrémnych rokoch epizodické procesy väčšej intenzity, malej častosti výskytu, ale významným spôsobom pretvárajúce reliéf (obr. 1, 2). V dlhšom časovom období, napr. v holocéne významnú úlohu zohrávajú fázy o väčšej častosti extrémnych javov, porušujúce rovnováhu stráňových a korytových systémov (obr. 3). V kvartéri pozorujeme zmeny súboru procesov medzi chladnými a teplými obdobiami. Osobitné zmeny nastupovali v prechodných štádiách pretvárania súboru procesov (obr. 4). Polycyklický charakter reliéfu Karpát je odrazom nakladania morfogenéz obsahujúcich striedanie fáz intenzívnejších a miernejších zmien. V holocénnom období spolupôsobí stráňový systém, čiastočne zdedený z periglaciálneho obdobia a prispôsobený súčasným hydrologickým podmienkam korytového systému.

Obr. 1. Časová štruktúra geomorfologických procesov (kumulatívne krivky účinnosti procesov v ročnom hodnotení).

Obr. 2. Schéma sekulárnych (kontinuitných) a epizodických procesov podľa diferencovaných rokov (a — stredné roky, b — extrémne roky).

Obr. 3. Celková účinnosť geomorfologických procesov v storočnom hodnotení (I — s nízkou frekvenciou extrémnych úkazov, II — s vysokou frekvenciou extrémnych úkazov).

Obr. 4. Zmeny v rýchlosti procesov, ktoré sú charakteristické pre teplé (1) a studené štádiá (2) a odzrkadľujú sa vo fázach agradácie (A) alebo erózie (E) v prechodných obdobiach.

Лешек Старкел

ПРОДОЛЖИТЕЛЬНОСТЬ И ИНТЕНСИВНОСТЬ ГЕОМОРФОЛОГИЧЕСКИХ ПРОЦЕССОВ В РАЗВИТИИ РЕЛЬЕФА ПОЛЬСКИХ КАРПАТ

Период продолжительности морфогенетических процессов, моделирующих современный рельеф Карпат, является разнообразным. В нормальные годы преобладают секулярные процессы и в экстремальные годы эпизодические процессы повышенной интенсивности с небольшой частотой проявления, но более значительно преобразовывающие рельеф (рис. 1 и 2). В более продолжительном периоде времени, например в голоцене, важную роль играют фазы с повышенной частотой экстремальных явлений, нарушающие равновесие склоновых и донных систем (рис. 3). В четвертичном периоде наблюдаются изменения системы процессов между прохладными и теплыми периодами. Особые изменения начинались в переходных стадиях преобразования системы процессов (рис. 4). Полициклический характер рельефа Карпат является отражением накладывания морфогенезисов, содержащих в себе чередование фаз более интенсивных и умеренных изменений. В голоценовом периоде содействует склоновая система, частично унаследованная после перигляциального периода и приспособленная современным гидрологическим условиям донной системы.

Рис. 1. Повременная структура геоморфологических процессов (куммуляционные кривые действенности процессов с годичной оценкой).

Рис. 2. Схема секулярных (континуальных) и эпизодических процессов, дифференцированных по годам (а — средние годы, б — экстремальные годы).

Рис. 3. Общая действенность геоморфологических процессов при оценивании за сто лет (I — с пониженной фреквенцией экстремальных явлений, II — с повышенной фреквенцией экстремальных явлений).

Рис. 4. Изменения скорости процессов, характерных для теплых (1) и холодных (2) стадий и отражающихся в фазах аградации (А) или эрозии (Е) в переходные периоды.

Перевод: Л. Правдова