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SOME REGULARITIES OF MOUNTAIN RELIEF EVOLUTION

Abstract. The author tries to summarise main regularities of relief evolution in mountain areas. Their main characteristics are the higher energy and faster circulation of water and mineral matter as well as the vertical zonality expressed in different complexes of processes. The polygenetic and polychronic character of forms is connected with instability due to tectonic factor reactivating mountains, with climatic fluctuations causing permanent vertical shift of morphoclimatic zones and with great differentiation in substratum resistance. Various types of human intervention leading to degradation of natural resources are connected also with that vertical zonality.

Key words: regularities of mountain relief evolution, vertical zonality, polygenesis, tectonic factor, climatic fluctuations, resistance of substratum, human intervention

Trying to talk on patterns of mountain relief evolution we should remember that: A. mountains are products of plate tectonics, B. from the very beginning and emergence from the sea mountains are exposed to external processes regulated by climatic changes and C. their preservation depends on the resistance of substratum. Therefore, the whole story of a mountain relief evolution is realized in the triangle of factors: tectonics, climate and resistance of substratum, all acting in time.

1. Larger differences in elevation and higher slope gradient result in higher energy of processes and faster circulation of water and mineral matter (increasing downslope), as well in formation of vertical vegetation zones and also morphoclimatic ones (Troll 1973).

Therefore, a crucial, outstanding feature of the mountains is their erosional landscape, which frequently shades the tectonic foundations. Negative water balance and sediment load higher than the rate of weathering are in a sharp contrast with a depositional regime of submontane depressions (Fig. 1). Internal diversity in rate and type of processes is connected with slope aspect, especially at the margin of arid zone and margin of permafrost.

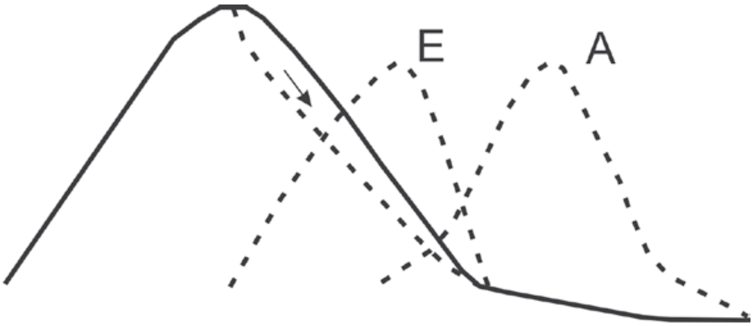


Fig. 1. Schematic cross-section of mountain ridge (with dissected slope) and subsiding foreland. Intensity of erosion (E) and aggradation (A).

2. Mountain landscapes are effects of combined actions of various forces and processes. Therefore, polygenesis is their principal feature. Tectonic movements are responsible for the rate of vertical uplift and horizontal shift. Erosional-denudational processes first dismember the initial relief, then, incision by rivers, lowering and planation of uplifted areas take place. Majority of slope and valley forms are the products of several processes which act superficially or linearly, and are spatially differentiated (see IX canon of relief evolution after D. Brunsden 1990). A series of processes act together from the very beginning of relief formation. This may refer both to anticlinal ridges emerging from the sea, plains of piedmont fans as well as to rills and gullies created during downpours. Frequently, in the course of relief maturation, other processes start to play the leading role and even determine the direction of transformation of particular forms. Landslide valleys or valley heads may serve as examples (Fig. 2).

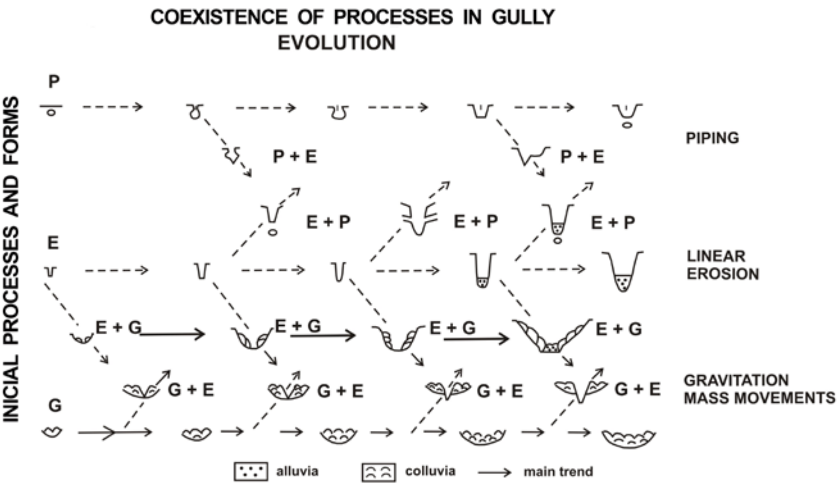


Fig. 2. Example of polygenetic forms — coexistence of processes in gully evolution (after L. Starkel 2011b).

3. A continuous adaptation of relief to changing climatic and tectonic conditions are fundamental attributes of the mountains with steep slopes and high relief energy and result in progressive maturation of relief or its rejuvenation. Thus, a polychronic relief is formed. This is especially well evidenced by the Quaternary rhythm of climatic fluctuations during which the more stable phases with formation of regolith interlace with phases of intensified process activity manifested by either secular or extreme events. Repetition of climatic phases and duration of particular phases are not without importance. It appears that transitional phases, when one, more stable morphogenetic system stops to function and a new system comes into being, are most crucial to relief evolution. At that time, the thresholds of various processes are reached, and removal of weathering products and sediments, that have been left by the previous system, takes place (Fig. 3). Threshold crossing goes on in a period of permafrost formation and its recession as well as during progression and retreat of forest communities. In the high mountains it occurs during vertical shift of morphogenetic belts. But, a completely opposite effect may be linked with forest expansion – a gradual stopping of denudation processes may proceed. In case of mature forms, like levelled slope bases, it is now difficult to recognize the role of particular processes. The forms could be outcomes of cryoplanation or landsliding. In the mountains such changes were realized jointly with shifting of vertical morphoclimatic belts reaching to 1000 meters in the Quaternary.

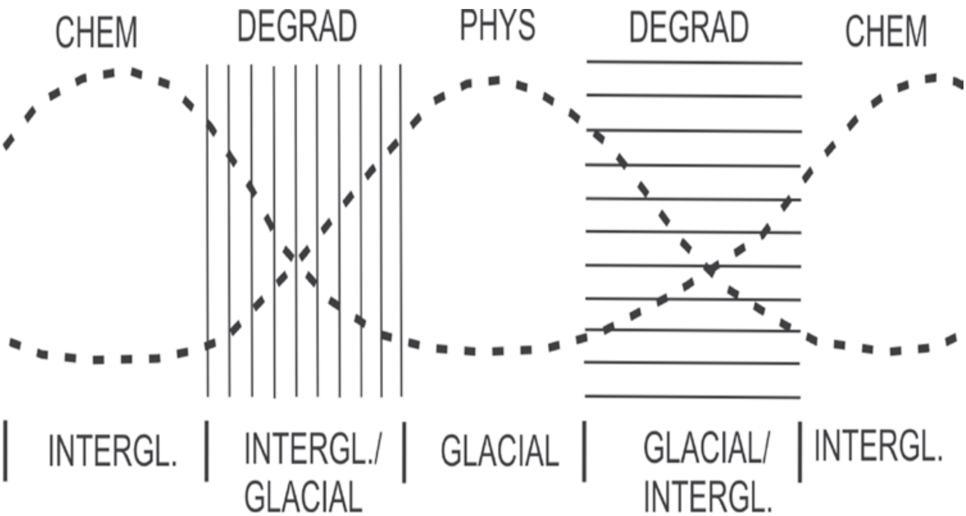


Fig. 3. Increased denudation during transitional phases in the Quaternary in Central Europe

However, the rejuvenation of relief took place most frequently during phases, when fluvial activity dominated over supply of debris from slopes to river channels and was supported by lowering of erosional base of the slopes due to a tectonic uplift. Such patterns are registered by strath levels in the sequence of Quaternary terraces.

4. The altitudinal boundaries of vertical morphoclimatic zones are usually not sharp and form ecotones. This is an effect of the spatio-temporal change of climatic parameters as well as of elements inherited from past landforms and soils. Therefore, it is difficult, for example, to mark borderlines of periglacial processes, of upper tree line or even the border between middle and high mountains (Rączkowska 2007; Kotarba, Migoń 2010). In the case of periglacial processes we observe gradual changes and some authors distinguish three subzones: infraperiglacial, typical periglacial and supraperiglacial (Chardon 1984).

The ecotones (transitional belts) of morphoclimatic vertical zones may reach a width of hundreds meters and their limits may be shifted several dozen meters in response to a singular extreme event (e.g. rapid snowmelt, great landslide etc.) We should also revise our view on vertical belts fluctuations of an order 500–1000 m during particular glacial — interglacial cycles in the Quaternary. In reality, on the mountain slopes various processes are in a continuous competition, so duration of different geoecosystems may cover various time spans. This incessant sequence of changes and adaptation to new conditions is expressed most inclusively in the polygenesis of mountain landscape and in its complex age, also in the case if only elements of the youngest Quaternary cycle of evolutional chain may be recognised.

5. Scale and rate of adaptation to a new climatic regime depend also on the resistance of substratum. Therefore, on the less competent, easily weathering bedrocks, secular processes, such as solifluction, slope wash or deflation, seem less effective, but as being long-lasting they appear to be more substantial in slope evolution than singular extreme events. And reverse, the resistant bedrocks control and preserve the main features of primary forms inherited from ancient geological epochs (Starkel 1965, 1987a).

In the case of the mixed substrate of contrasting resistances (which is characteristic of the folded flysch or molasse rocks), the glacial-interglacial cyclicity, leading to skeletonising of rocky members or even single beds that have not been intensively weathered in glacial or interglacial stages, play also a substantial role in formation of relief (especially in the temperate zone). The products of chemical weathering and the soils are carried away mainly during early phase of a subsequent cold stage. These processes may be spatially differentiated, depending on the exposure of slopes against rainfalls or winds.

New shapes of forms, which have not preserved primary features or have been dismembered, are the final effect of juxtaposition of adaptation processes. Therefore, in particular mountain landscapes, forms of different ages may exist in parallel (Fig. 4). The older ones are usually greater, represent long periods of planation and are preserved on rocks of higher resistance. The younger ones

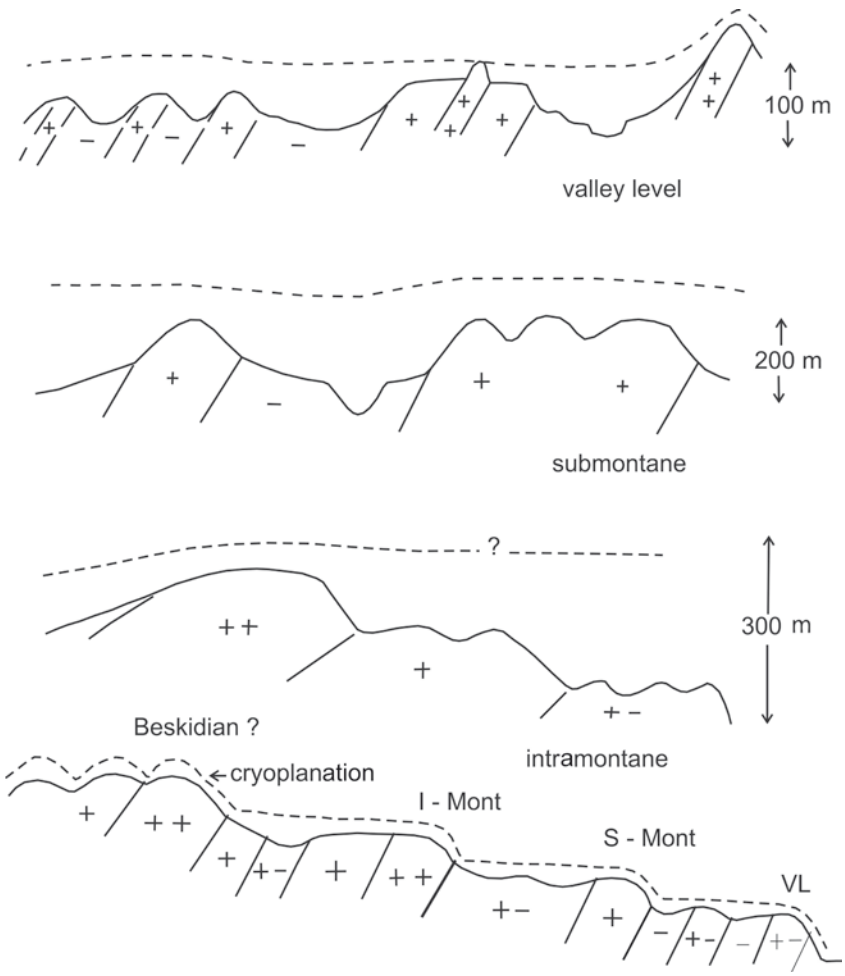
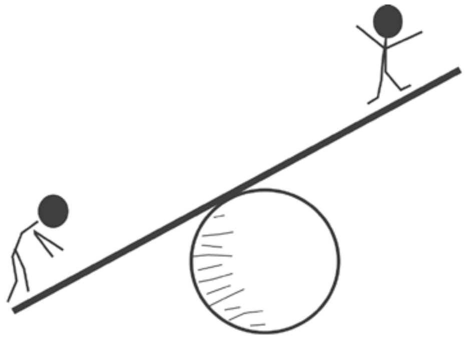


Fig. 4. Rate of adaptation of denudation levels in the Flysch Carpathians depending on resistance of rocks (S t a r k e l 1965, 2011a).

are more frequent and represented either by erosional forms or by sediments covers, only partly preserved till now.

6. In the mountain landscape a specific mixture of landforms exist. They are either in equilibrium or in disequilibrium or have not reached equilibrium stage yet (cf. R e n w i c k 1992). The second stage is the most characteristic of the mountains, due to high frequency of extreme events after which both the slopes and the river channels have not returned yet to their previous equilibrium. But in the tectonically active mountain ranges the third stage may dominate, even pointing out the actual trend of relief evolution. In the longitudinal profile of valley floors or long slopes we may observe whole sequence of various maturity stages or progressing rejuvenation (Fig. 5).



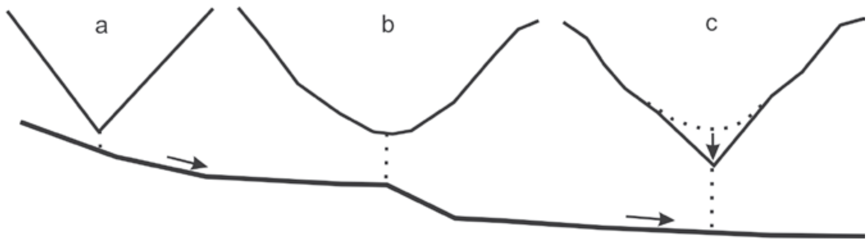


Fig. 5. Various stages of maturity of river valley sections which: a) have not reached equilibrium yet, b) in equilibrium stage, c) rejuvenated (based on the concept of W. H. R e n w i c k 1992)

7. The paradox of mountain valleys is a changing function of individual slope segments that gradually increment together with deepening and maturing of the valleys. The slope segments located higher, mainly of older foundation, are continuously denuded, while lower erosional parts of younger age show a tendency to aggradation and even fossilization of terrace steps (Fig. 6). This zone gradually shifts downslope. Parallel with that, the levelling of the whole profile of mountain slope occurs. The effects of that levelling are expressed best in the areas of ceasing uplift. Therefore, a slope of a large deep mountain valley is a polychronic form, which reveals multistage deepening induced by tectonic uplift and includes elements of different age belonging to a specific slope system controlled by gravity and circulation of water.

8. Old forms, created under particular conditions, may be merged into new tectonic and morphoclimatic systems (Fig. 7). This observation refers especially to the high mountains with intensive uplift (over 1–2 mm/year), where the fluvial relief was transferred to the cryonival vertical zone or even to the glacial one during several millions of years or in a shorter period (S t a r k e l 2011a) and now is transformed by cryoplanation or glacial erosion. The transformation may refer also to the mature relief modified by tectonic processes. The type of

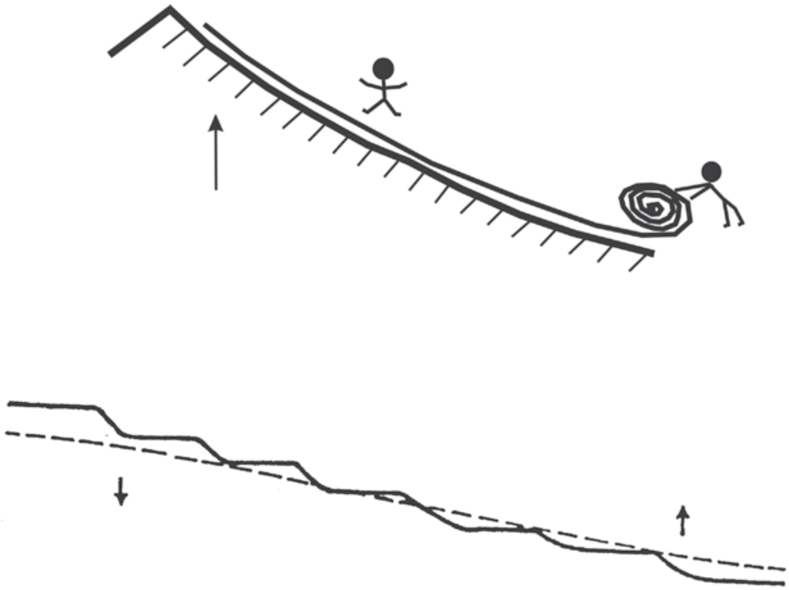


Fig. 6. Deepening and maturing of a mountain slope with tendency to degradation of upper part and aggradation of lower one (based on L. S t a r k e l *in print*)

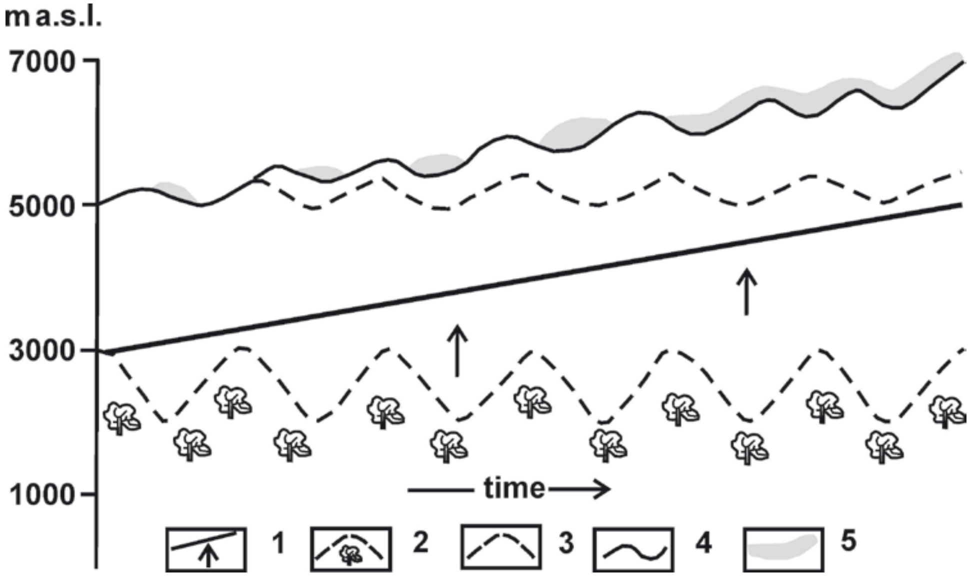


Fig. 7. Scheme of Quaternary changes of morphoclimatic vertical zones in the Himalayas during cyclic climatic fluctuations and simultaneous tectonic uplift. 1. Uplift up to 2 km documented by palaeontological findings, 2. Cyclic fluctuations of upper tree line of an order of 1000 m, 3. Fluctuations of lower limit of permafrost, 4. Rising elevation of high mountain relief, 5. Growing extension of glaciers (after L. S t a r k e l *in print*)

transformation depends on the character of inherited relief. It may be a dissected mountain group (like the Alps) or planated elevated platform like most parts of the Tibetan Plateau (see Zheng, Jiao 1991). As an example we may give the relief of intramontane level of Pannonian age in the Western Carpathians, which had been warped in the form of a great "dome structure" during the Pliocene neotectonic uplift (Minar et al. 2011).

9. In the mountain landscapes, especially in young stage of evolution, the main course of radical transformations is attributed to extreme events (Hewitt 1972; Starkel 1976, 1996; Fort 2011; Fig. 8). During such events threshold values are exceeded and new forms develop. These forms are consolidated especially by clustering of events in short time intervals, when recovery to the primary equilibrium is impossible. These clusters may repeat in a time span of days, weeks as well as in periods of decades and centuries. In some climatic provinces, like tropical–monsoonal or Mediterranean ones, frequent local downpours or continuous rains repeating every year are fundamental factors of directed relief transformation. In others, these may initiate a new direction in evolution of mountain slopes (Froehlich, Starkel 1995; Baker at al. 1988; Soja, Starkel 2007).

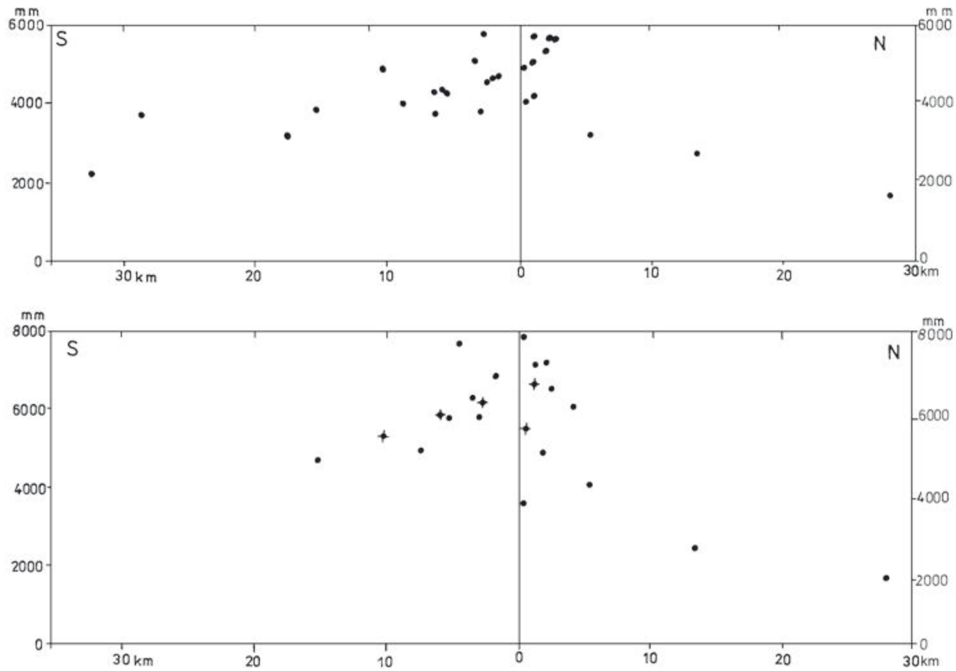


Fig. 8. Mean annual rainfall (above) and rainfall in 1998 (below) along S-N transect of Piedmont and margin of Himalaya (between the Tista and Torsa rivers). Highest values at the front of mountains. Vertical line 0 indicates the margin of mountains (after L. Starkel in: L. Starkel et al. 2008)

10. While the mountains are natural producers of surplus of water and sediment loads that are transferred downstream, the low local foreland is the first natural depositional area of that surplus. In the piedmont zone, with varied subsidence rates, the undergoing aggradation is registered in lithology of alluvial beds during all phases of uplift, downcutting and clearing out in the mountains. The climatic changes, especially in the Quaternary, are also reflected in the cut-and-fill sequences. In the areas of differentiated tectonic movements aggradation may alternate with tendencies to antecedence.

11. Human activity in the mountains, due to destruction of natural vegetation cover, leads to accelerated run-off and increased sediment load, then finally to degradation of soils and formation of badlands well recorded in the humid tropics and Mediterranean regions. Frequently, it is the result of several repeating waves of migration and deforestation connected with them. In the final stage, it may lead to exposure of bedrock or to formation of secondary "armoured layer" on the surface with a protective plant cover (Starkel, Singh (eds.) 2004).

Besides deforestation, cultivation and overgrazing, human activities, which comprise construction of various barriers and dams, seem to be equally important for functioning and evolution of mountain landscapes. Such activities result in fragmentation and isolation of natural slope and valley floor systems (especially river channels), regulation of watercourses, controlling of sediment load and junction of transportation routes. In outcome, the separated fragments of slopes and valley floors start to function as independent entities (though sometimes joined by artificial roads, canals, bridges etc.). Only during extreme events (downpours, floods etc.) the interrupted routes of circulation of water and matter in the whole slope and river channel profiles may become reconnected and reused to carry the surplus of water and matter outside the mountains (across destroyed barriers) (Starkel 1987b, 2012; Fig. 9). The nature restores a normal function of mountains. The sections of slopes or river channels with forced depositional activity (the deposition zones for load carried from headwaters) become the sections of erosion.

12. Mountain landscapes, especially for the older rejuvenated systems, have other specific features: they are great diverse, unique and exhibit a mosaic spatial pattern. Such features are very rare in other monotonous parts of continents. The diversity results from complex geological structure and evolution of mountain chains as well as from previous and current climatic conditions registered in forms in various stage of evolution of natural geoecosystems. Besides that, mountain geoecosystems are subjected to diversified man-induced degradation and spatial fragmentation of natural systems (Ives, Messerli 1989).

The overexploitation of natural resources of mountain areas oblige towards restoration of equilibrium in natural systems, which should proceed in conformity with vertical zonation in the mountains and with a tendency to climatic change.

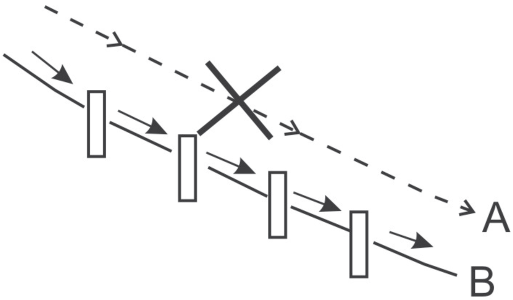


Fig. 9. Natural transfer of water and sediment load in the longitudinal profile of mountain slopes and river channels. (A) blocked by human activity, (B) Natural circulation may be restored only during extreme events

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