VERSITA

STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA

VOL. XLVI, 2012: 71–99 PL ISSN 0081-6434

DOI 10.2478/v10302-012-0005-z

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GEOMORPHOLOGIC EFFECTS OF ANTHROPOPRESSION IN THE MOUNTAINS OF VARIOUS CLIMATIC ZONES (SELECTED EXAMPLES)

Abstract. The change of land use (deforestation, overgrazing and cultivation) is reflected in acceleration of water circulation and denudation. The effects of human activities are different depending on vertical zonality and variation of ecosystems existing in different climatic zones as well as duration of anthropopressure. The author exemplifies the effects in several mountain areas of a temperate zone (Central and Western Europe), in Mediterranean region, in the arid zone (Mongolia) and humid tropics (India).

Finally, several types of new secondary geoecosystems are distinguished: bare rocky slopes with completely degraded soils; slopes with residual soils covered with secondary shrubs and forests; partly degraded tropical regoliths with armouring layer of gravels on the surface; cultivated terraced slopes protecting most of the soil cover; blanket bogs covering slopes after deforestation in maritime humid climate.

Key words: soil degradation, deforestation, overgrazing, cultivation, vertical mountain zonality

ACCELERATION OF RUNOFF AND DENUDATION CONNECTED WITH LANDUSE CHANGES

Water circulation and water balance, different in vertical zones of various climatic zones, are modified by human activities that cause acceleration of overland flow and disequilibrium, leading to increased transportation of mineral matter and soil degradation within slope and channel systems. Extreme rainfalls, playing particularly important role, may be of three types: (i) short-lasting downpours of high intensity, (ii) continuous rainfalls lasting 1–3 to 5 days and amounting to high totals, and (iii) long rainy seasons allowing deep infiltration. Their function could have changed after deforestation (Starkel 1976, Fig. 1). At first stage, human impact led to degradation of natural plant communities due to: (a) forest clearing in the mountains, (b) overgrazing in

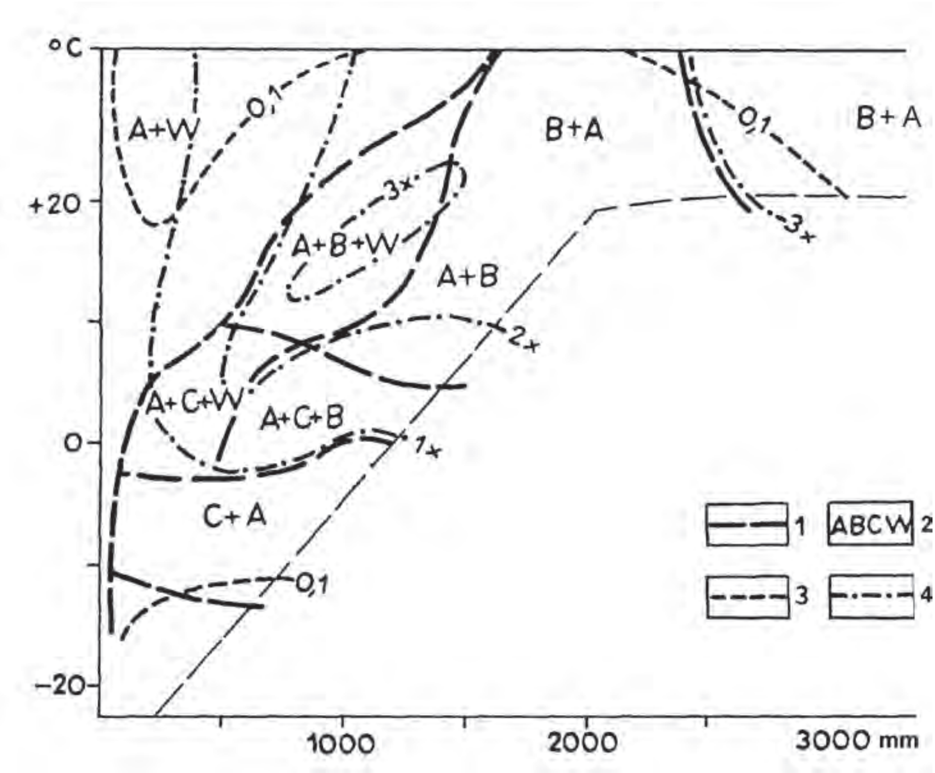

Fig. 1. Dominant extreme events in various morphoclimatic regions after deforestation shown on the climatic diagram (mean temperature — annual precipitation) (after L. Starkel (1976), changed) 1 — limits of areas fashioned by different extreme events, 2 — leading extreme events (A — downpours, B — continuous rains, C — rapid snowmelts, W — strong winds), 3 — isoline of denudation rate 0.1 mm year in quasi-natural conditions (after Carson and M. Kirkby (1972), see in (Starkel 1976)), 4 — isolines of the probable rate of denudation in deforested areas during catastrophic events (1×, 2×, 3× — relative scale of intensity).

steppe, forest-steppe, semi-desert or mountain meadow communities, and (c) farming practices or (d) setting road networks that function as outflow routes.

Deforestation progressed as tree clearing or burning, which was usually linked with the destruction of undergrowth, and sometimes accompanied by pasturage. Deforestation in mountain areas accelerated overland flow and slope wash, and favoured development of rills and gullies along tree-felling trails on slopes.

In areas of high precipitation (monsoon or Mediterranean zones) due to lack of deeply rooted trees, numerous mudflows and debris flows occurred. Such cases were known from the lower parts of the Himalayas (Starkel 1972b, Brunsden et al. 1981) or New Zealand foothills (Selby 1974, Crozier 1997). Deforestation in areas with precipitation deficit, even if such a deficit was only temporary, caused transition into steppe or even resulted in complete degradation of soils and desertification, known not only from the forest vertical belt of the semi-arid zone (Jansson 1982) but also from the whole Mediterranean region (known as badlands — Thornes 1990; Morretti, Rodolfi 2000). Such a complete degradation of soils occurred also on the southern slope of the Meghalaya Plateau, despite extreme seasonal rainfalls (Starkel 1972a; Starkel, Singh, eds. 2004).

Opposite effects of deforestation were observed in maritime climate regions, where forest-free soil could not store water surplus (provided frequent horizontal precipitation). Heath or blanket bogs, which developed on the slopes of Scotland and England, stored water and prevented re-establishment of forests (Crabtree 1971, Birks 1996).

Overgrazing occurred mainly in steppe- and forest-steppe belts of the semi-arid zone. Because of that, herbaceous plant cover became discontinuous, certain species were eliminated, and soil became more prone to washing out and deflation. These features are particularly well expressed in the ecotones at the boundary areas of steppe and semi-deserts, steppe and forest-steppe or steppe and savannah. Experiments carried out at the research station in Rajasthan evidence that in the areas with annual (seasonal) precipitation of 200–300 mm just a few-year long period after grazing had been stopped was sufficient for the renewal of continuous vegetation cover (Starkel 1972a).

The above findings also apply to a belt of mountain meadows above the upper tree line, where overgrazing causes plant cover to thin out, making soil prone to wash and creep, frost action, deflation, gully erosion or even generation of debris flows (Midriak 1972, Rączkowska 2007).

Rates of slope wash recorded by research stations located in the Flysch Carpathians show differences in the scale of the process between cultivated land and that under natural plant cover (Gerlach 1976; Gil 1976, 1999). Slope wash rates on arable fields with cereals can be 3 orders higher than in forests, and 2 orders higher than on meadows. On the other hand, in the case of fields under cultivation of potato or other root plants, slope wash can exceed that on winter cereals even by 100 times. During highly intensive precipitation or rapid snow melt, the entire arable layer can be washed out or cut by deep rills, which can then develop into gullies and glens (Starkel 1960, Święchowicz 2004). In winter, dried and frozen soil is exposed to deflation especially on elevated ridges (Gerlach 1976, Welc 1977). In the high-mountain vertical zones, e.g. in the Caucasus, rapidly increased deposition of dust driven by wind from ploughed steppe areas in the mountain foreland is observed (Davitaja 1969).

Processes of slope denudation occur diversely, depending on plant rotation system and on farmland and cart-road patterns. Agricultural terraces play particularly important role in limiting soil erosion in the mountains. According to T. Gerlach (1966) they reduce slope wash rate by ca. 30% (see Fig. 2). The slope-faces of the agricultural terraces, shaped by slope wash and ploughing practices, are the areas where earth slides and earth flows occur during downpours.

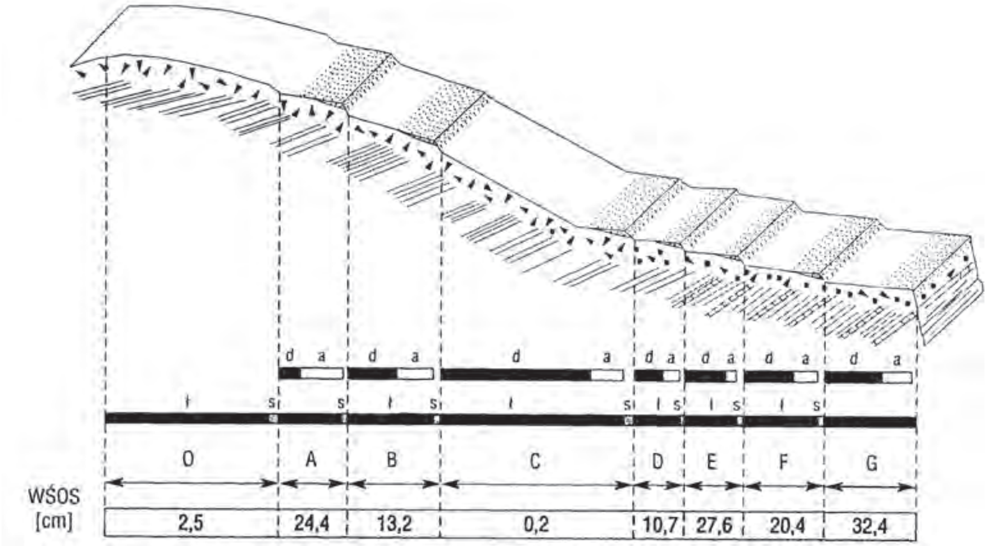

Fig. 2. Denudation of convex — concave slope with field terraces studied by T. G e r l a c h (1966). A–G terrace steps, d — denuded segment, a — segment of deposition, t — terrace surface, s — terrace scarp, WŚOS — size of mean lowering of slope in cm during the period of cultivation. Denudation rate of terrace C in reality is much higher

Human activity that affected relief also includes mining which, in the mountain areas, leads to steepening of slopes (quarries), formation of holes and depressions or underground tunnels, and enhances development of landslides (B a s u 2006).

TEMPORAL AND SPATIAL DIFFERENTIATION OF ANTHROPOPRESSURE REFLECTED IN EVOLUTION OF RELIEF

A larg-scale human impact on mountain landscape started with the development of economic activity (S t a r k e l 1977). At first, it was mainly cultivation of land (that required forest clearing) and domestic animal husbandry (pasturage in forest-steppe and steppe zones, then also in the alpine meadows above the upper tree line or in savannah and semi-deserts). During the last two millennia human activity also included mining, metallurgy or smelting and building practices, most of which required forest clearance (com. R o b e r t s 1989, S t a r k e l ed. 1987).

Anthropopressure varied by region, depending on environmental assets and the level of economic development, the latter often interrupted by periods of recession forced by climatic changes, natural disasters and social or industrial changes. The human impacts are discussed with examples of mountain regions from various parts of the world.

MOUNTAINS OF THE NEAR EAST

The steppe foothills of the Middle Eastern mountains, especially those of the "Fertile Crescent" embracing the Mesopotamian lowlands, were the cradle of cereal cultivation at the beginning of the Holocene ca. 10 thousand years BP (Wright, Thorpe 2003; Roberts 1989). Animal grazing on forested slopes and a decline in precipitation from ca. 5000–4000 BP contributed to deforestation of the mountains and aridization of the foothills. That forced the onset of irrigation practices essential for supporting even rudimentary cultivation. The latter was possible only periodically, during wetter climate episodes (Avner 1998, Issar 1995).

In the areas of the present-day Israel and Jordan, at the frontiers of the Roman Empire, peoples and state organisms developed into a state of the Nabataeans (10 BP – 70 AD) where various practices were used. Improved from a century to century they lasted until the Byzantium period (Issar 1990). Despite aridization of the discussed area and abandonment by farmers, reclamation by irrigation is attempted in the area of Israel until nowadays.

MOUNTAINS OF THE MEDITERRANEAN REGION

Mountains of the Mediterranean region experienced human impact in the Mezoholocene, following the period when forests encroached on foothills that had been earlier occupied by steppe plant communities (Bottema 1974). Climatic oscillations in the foreland of the Greek mountain ranges, registered from the Neolithic (Paepe et al. 1987), evidence a series of wet and drier phases that were synchronous with deforestation and farming practices on mountain slopes in the Roman period, when the upper tree line reached ca. 2500 m a.s.l. Human activity transformed the landscape up to 1800–2000 m a.s.l., and caused soil degradation, exposure of skeletal regolith and the underlying, usually waterless, karstified limestone rocks (Hempel 1966). A 100–150 m wide belt of humid forest, occupying a relic zone of skeletal soils inherited from the late Pleistocene remained above that elevation

Human activity resulted in catastrophic soil erosion, reflected in torrential fans mantling the floors of intra-mountain basins and valleys, e.g. the famous Olympia (Vita-Finzi 1969, Büdel 1977). During the period of increased precipitation at the time of the fall of the Roman Empire, the abandoned slopes were invaded by shrub plants, counteracting against cattle and goat pasturing or re-growing after fires triggered by frequent drought.

The period of medieval warming enabled human activity on the still forested mountain areas closer to the upper tree line (Photo 1).

Photo. 1. Deep gullies dissecting old alluvia of the Pirin Mountains piedmont in SW Bulgaria

THE ALPS, CARPATHIANS, AND LOWER MOUNTAINS OF THE MIDDLE EUROPE

People settled the Alps, Carpathians, and lower mountains of Central Europe, initially entering the foothills, intra-mountain basins and ridges separating valleys, in the early Neolithic (8–6 ka BP). This is recorded in kurgans and raised overgrazed land, deforested during the Funnel-Beaker Culture (5600–4900 BP –– Machnik 1993), as well as in delluvial and alluvial covers containing pollen of cultivated plants, as indicated in pollen diagrams (Ralska-Jasiewiczowa, Latałowa 1996). Thick alluvial and delluvial covers at the bottoms of fore-mountains depressions, evidencing large scale soil erosion (Kalicki 1991, Starkel et al. 2002, 2012; Dotterweich 2008, Gębica 2011), date to the Roman period. The lack of black oaks in 4th century AD deposits in the upper Vistula Valley and the onset of growth of a new generation of trees point to a recession in agriculture at the northern fringe of the Carpathians. Then, fluvial processes were reactivated in 5^{th}–6^{th} century AD (Krąpiec 1992, 1998). It is likely that at the same time forest returned to its primary habitat also in the Carpathians. Palynological studies of F. Kral (1972) in the alpine massif of Dachstein provide evidence that the Roman period was the first time when animals were grazed above the upper tree line, causing its lowering to the elevation of 2000 m a.s.l. (Fig. 3).

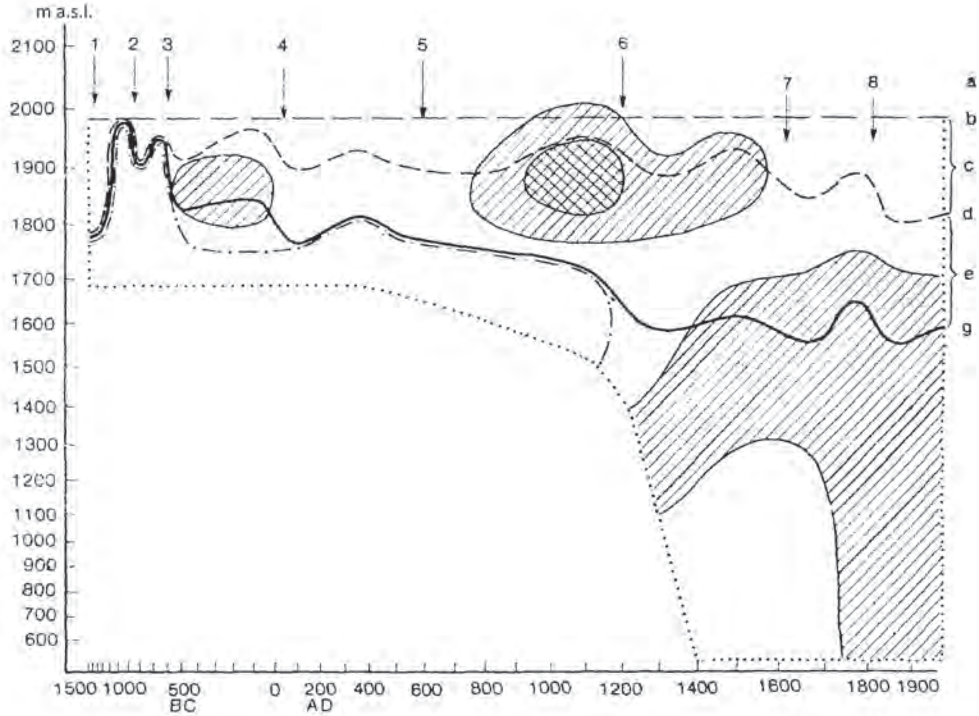

Fig. 3. Changes of vegetation vertical zones and human impact in Dachstein massif in the Alps during last 3000 years (K r a l 1972). Percentage of plant indicators characteristic for pastures (diagonal hachure > 5%, squared > 10%), a — arrows — phases of glacial advances, b — high position of forest limit, c — role of climatic factor in lowering of forest limit, d — potential limit of forest, e — anthropogenic role in lowering of forest line, g — actual upper forest line

A subsequent expansion of man started in the early Middle Ages, and initially, in 7th–9th century, it concentrated in the western and southern parts (B o r k et al. 1998, D o t t e r w e i c h 2008). It took also place in the Morava Valley during the times of the Great Moravian State (H a v l i č e k 1991) and, slightly later, in 10–11th centuries, in southern Poland. That is registered in pollen diagrams, accretion of floodplains and thick delluvia at the Carpathian margin (S t a r k e l ed. 1981, N i e d z i a ł k o w s k a et al. 1985, S t a r k e l et al. 2002, 2012). In the analogous period in the Alps, grazing practices caused lowering of the upper tree line by another 100–150 m (K r a l 1972). The medieval warming was accompanied by settling of mountain valleys by farmers (S t a r k e l 1994) and development of mining — prospecting followed by exploitation of ores suitable mostly for smelting copper, iron, zinc, lead, but also gold and silver. That is registered in various parts of the Carpathians and the Sudetes (L a t o c h a 2007) and resulted in a local lowering of the tree line. By the end of the Middle Ages, within the area of the Carpathian arc, pastoral populations migrated from east to west and their activity also resulted in a lowering of the upper tree line.

In Germany and in the Czech Republic intensified soil and gully erosion was registered in the 11th century, which was associated not only with settlement expansion but also with numerous downpours followed by farming recessions (B o r k et al. 1998). The next period of accelerated erosion occurred during the Little Ice Age (B r a z d i l et al. 2005, D o t t e r w e i c h 2008). A few centuries of frequent epidemics, wars and soil degradation resulted in the retreat of farming and the expansion of forest communities. The prosperity of agriculture can be traced from agricultural terraces and gullying related to cart-road network present in the forests of the German Highlands (M o r t e n s e n 1958). From the 16th to 19th century, cooling of climate and more frequent downpours of the Little Ice Age (G r o v e 1988, M i d r a k 1983, K o t a r b a 2006) favoured erosional processes, slides, gully erosion etc.

In the lower parts of the Carpathians, population growth and famines between the 17^{th} and the19^{th} centuries caused forest area to shrink and to be taken under cultivation. In the upper San Valley, where percentage of foothill relief and of wide valley bottoms is significant, the forest acreage decreased from 77.8% in 1589 to 47.1% in 1869, while in the mountain catchment of Wołosaty Stream only from 88.7% to 67.7% (K u k u l a k 2003). Simultaneously, at the beginning of the 19th century, potato cultivation which accelerates overland flow and soil erosion was introduced (S ł u p i k 1981). The data from the village of Ochotnica located at the elevation of 500–1200 m a.s.l. in the Gorce Mts. can serve as an example (C z a j k a 1987). While the population doubled in the years 1787–1876, the area of arable fields increased almost by 60%; potato fields, still absent at the end of the 18th century, expanded to 15–17% of the area. Similarly, between 1852 and 1931, in the villages of Bieszczady at the elevations of 600–1000 m a.s.l., the area occupied by arable fields increased by 50% at the expense of meadows and pastures which initially covered twice the area of the arable fields but shrank by 20–35% (W o l s k i 2006, Fig. 4). In the 19th century, this was accompanied by wasteful exploitation of private forests (C z a j k a 1987, K u k u l a k 2003). In the mid-19th century Sudetes, cultivation of root plants on skeletal soils forced agricultural terracing in order to prevent erosion (L a t o c h a 2007).

All those changes resulted in increased overland flow, intensified bedload transport and development of braided pattern in small streams and larger mountain rivers (T r a f a s 1975, K l i m e k 1974, Photo 2).

Particularly rapid changes in land use of mountain areas have occurred and are still ongoing in the Carpathians and the Sudetes. After WW2 these areas saw mass displacement of people and the onset of collective communist farming. The latter changed again to a free market economy system after 1989, although in many cases only to a small-scale economy. In general, increased forestation and a decline of farming practices are observed (K o z a k 2005).

A number of models illustrating the changes can be distinguished:

A. mass relocation of people to areas where earlier recession of agricultural practices have been abandoned (the Sudetes); followed by attempts to introduce new settlers;

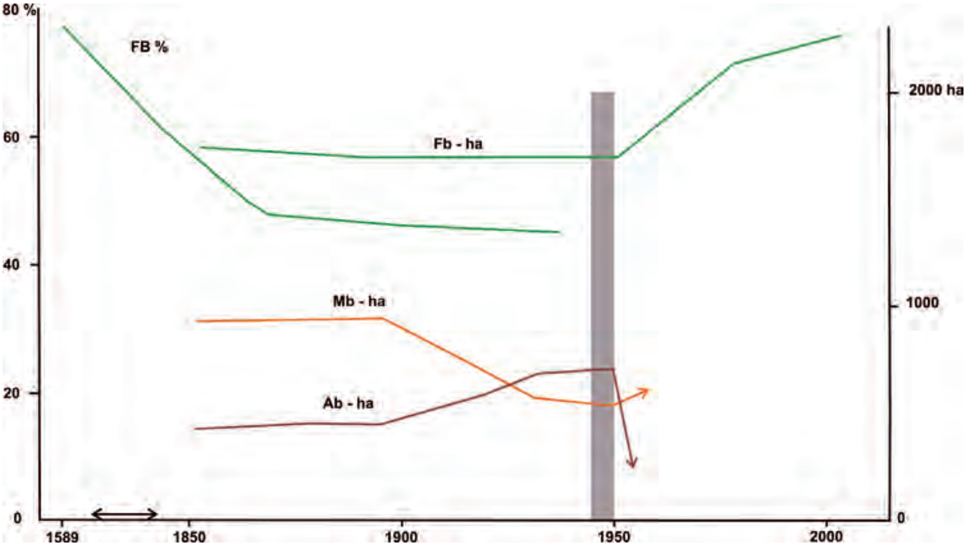

Fig. 4. Landuse changes in Bieszczady Mts. in last centuries: FB % — forest decline in 19th century (after J. K u k u l a k 2003). Various land use in Berehy village (after W o l s k i 2007) in ha: Fb — forests, Mb — meadows, Ab — arable land. The years (1945–1950) of displacement of Ukrainian population underlined

Photo. 2. Aggradations after heavy rains in July 1997 in Beskid Wyspowy Mountains

B. mass displacement of people (from overpopulated areas), attempts to introduce organised collective farms (eastern part of the Polish Carpathians);
C. introduction of collective, command economy that functioned until the political breakdown of 1989 (Slovak, Romanian Carpathians, mountains of Bulgaria etc.);
D. gradual decline of agricultural practices in the mountains due to socio-economic transformation (progressing in western part of the Polish Carpathians).

Socio-economic changes make the environment adjust slowly to the changes in land use. Mountain streams carry less sediment load, bedrock becomes exposed in river channels, former bars become stabilized by encroaching vegetation (Lach, Wyżga 2002; Bucała 2012). Precipitation triggers numerous landslides which may be also associated with additional load on slopes from newly built recreational cottages and with the construction of new access roads that undercut steep slopes (Rączkowski, Mrozek 2002; Starkel et al. 2007, Photo 3).

Photo. 3. Shallow slumps and earthflow at steeper scarp in Wielopolka catchment, the Carpathian foothills, after heavy storm on 25 June 2009

In the mountains of western Europe, changes towards a sound management of the environment took place much earlier, were not so drastic, and their progress is still being monitored in frames of European Union and national programmes (Mac Donald et al. 2000, Fallucci et al. 2007). Everywhere, a slow withdrawal of agricultural practices from the mountains and a decline in population, are accompanied by increased forestation that is believed to reduce the effects of extreme weather events. Here, two distinct models of change can be distinguished:

Alpine model — developed mainly in Switzerland and Austria; it is a model of transition from traditional farming to animal husbandry linked with development of tourism and recreation. It is linked with an expansion of road network and infrastructure which might be exposed to avalanche, landslide and flood hazards.

Mediterranean model — much less advanced than the former one; it is a model of transition from traditional pasturage and horticulture economy to forestry and which requires a complete rebuilding of plant communities, especially by introducing species resistant to droughts and fires. During downpours mass movements are triggered and the sediment load transported by rivers changes their channels.

MOUNTAINS OF GREAT BRITAIN AND SCANDINAVIA

In the Scottish mountains, the Holocene upper tree line reaches the elevation of 400–750 m a.s.l., and is accompanied by a narrow cryonival zone above (B i r k s 1996). Deciduous forests, especially those on the western slopes exposed to continuous rains and strong winds, approach the upper moisture threshold which otherwise could not have been reached. Human impact has been expressed by indiscriminate felling of forests for the sake of cultivation, pasturage and developing mining and metallurgy. Deforested slopes, depending on bedrock and their aspect, became colonized by blanket bogs and moorland which store water surplus, and therefore make the renewal of forest communities impossible (C r a b t r e e 1971). Several-metres thick blanket bogs are sometimes dissected by systems of gullies and piping.

In the early Middle Ages, in the mountains of northern England, arable fields reached the elevation of 350 m a.s.l. Still at the beginning of the 14^{th} century, in Northcumberland, cultivation was practised 150 m higher than at present (L a m b 1967, P a r r y 1975). In the 15th century, the cultivation boundary descended abruptly due to higher frequency of natural disasters. During the Little Ice Age this boundary fluctuated in an even wider range.

A similar situation was in the mountains of Scandinavia, where recurrent extreme events: avalanches, landslides, rockfalls, and floods, were registered in the villages (G r o v e 1972). The record of these events in Scandinavia, the Alps (P f i s t e r 1988) and also in the Tatras (K o t a r b a 2006) helps understand the complex mechanisms of fluctuations (migrations) of the vertical climatic-vegetation zones.

KHANGAI — THE MOUNTAINS OF THE DRY CONTINENTAL CLIMATE

In the mountains of central Asia, the thermally-controlled upper tree line and precipitation-controlled lower tree line converge. Low winter temperatures, allowing the persistence of permafrost that far south, support a poor forest zone (Starkel 1980). On the southern slopes of the Khangai, the southernmost forest zone with *Larix siberica* extends from 2200 to 2700 m a.s.l. Seemingly, this zone is climatically controlled, but in fact it is influenced by permafrost which, although limited to the N-exposed slopes, provides water from 1–2 m thick active layer melting in the summer (Photo 4).

Photo. 4. N-exposed slopes in the Sant Valley with patches of the same age larches, developed after destruction of animal husbandry in the 1920s

In these extreme conditions, human impact is also present. (Kowalkowski et al. 1977; Kowalkowski, Starkel, eds. 1980). On the north-facing slopes, at the elevations of 2400–2700 m a.s.l. patches of larch forests, covering 20–30% of the area, comprise 30–40 year old trees which are accompanied by single, over 100 year old specimens. The extent of brown soils and dark chestnut soils, typical of the forest-steppes, as well as of solifluction forms and herbaceous plants indicate that the entire northern slope, currently with permafrost, must have been overgrown with trees in the past (Fig. 5).

In contrast, the south-facing slopes bear traces of intensive soil erosion, i.a. linear erosion with shallow gullies formed two years earlier during a downpour (Starkel, Lomborinchen 1976). In the delluvia of the upper face of a 10 m high, south-facing terrace remains of a furnace were found; the presence of charcoal indicates it could have been used for iron smelting (Fig. 6). The ^{14}C date of 1670 ± 35 BP points to the significance of forest felling in the 4th century. Trees were likely cleared already a few centuries earlier but also later, as confirmed by charcoals found in the delluvia at the foot of tors on the southern ridge embracing the Sant Valley (dates: 2120 ± 85 BP and 960 ± 65 BP).

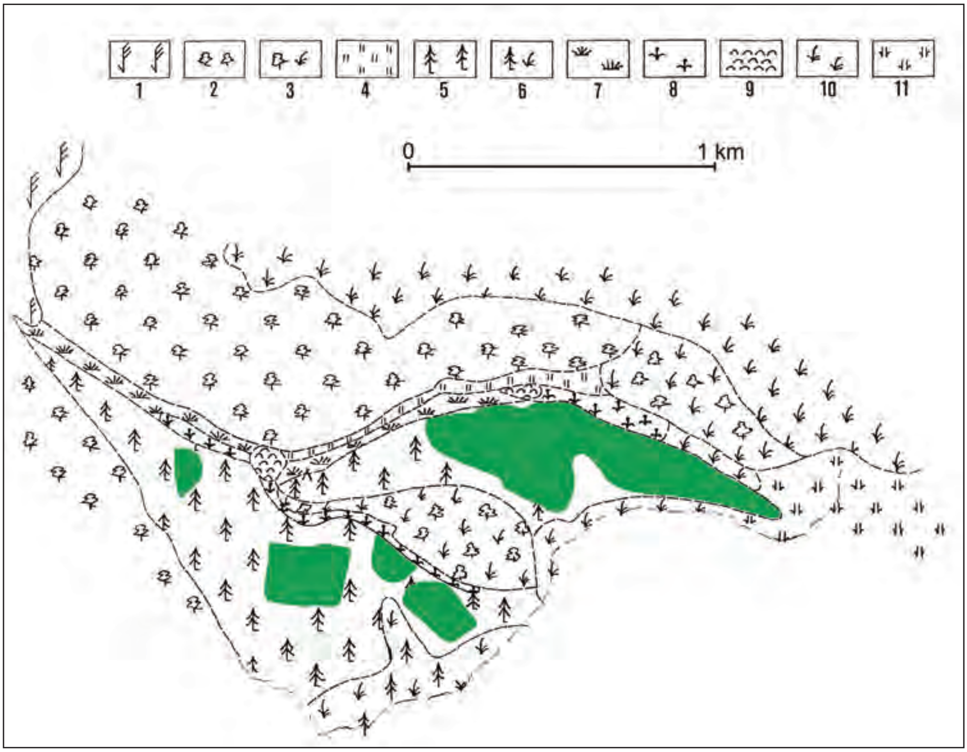

Fig. 5. Fragment of larch forests on the background of more extensive area of forest soils on the N- facing slope in the Sant Valley (elaborated by A. Kowalkowski and A. Pacyna, see (Kowalkowski, Starkel eds. 1980)). 1 — steppe habitats on pediments, 2 — dry steppe on rocky S- facing slopes (light chestnut soil), 3 — as above — dark chestnut soils, 4 — steppe on deluvial chernozems, 5 — forest habitat on dark- chestnut and chernozem soils, on N- facing slopes with permafrost, 6 — as above on shallow soils, 7 — moist meadows on deluvial chernozems with permafrost, 8 — as above — flooded, 9 — marshy habitats, 10 — subalpine grassland, 11 — subalpine grassland on shallow soil; dense larch forest shown by full dark colour

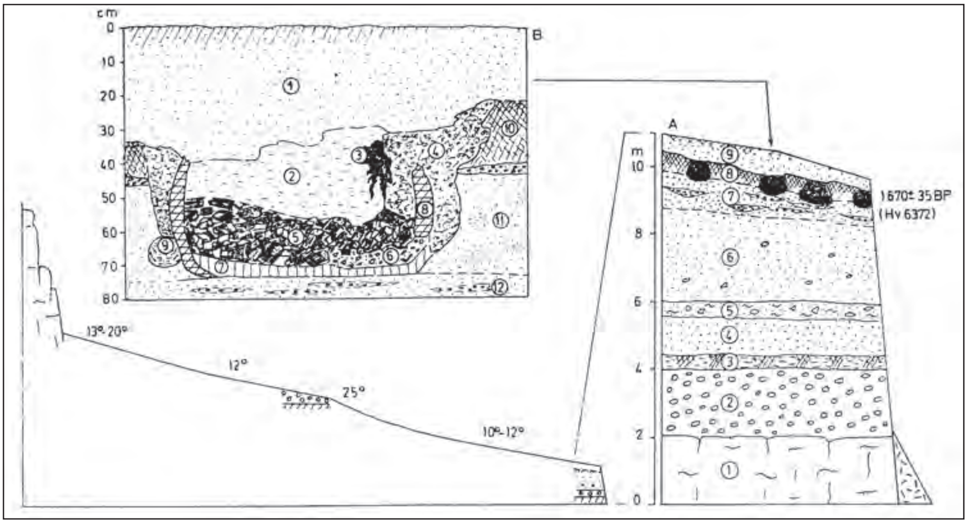

Fig. 6. Profile of alluvial and deluvial deposits with remnants of iron blast-furnaces in the valley of the Tsangan-Turutuin-gol (Kowalkowski et al. 1977). 1 — granite-cut bench, 2 — fluvial gravels, 3 — clays and sands with humus lumps, 4 — deluvia of granular granite rock-waste (granite grit), 5 — loams with sharp-edged debris and gravels derived from the 35-m terrace, 6 — deluvia, with granite grit, 7 — deluvia with lenticular insertions of coarse granite grit, 8 — chestnut soil with blast furnaces, 9 — granular deluvia with chestnut soils in the initial stage of development

Remnants of tree stumps were also found in the permafrost active layer, in the post-forest habitat.

Human activity was imprinted also in the last century. Due to livestock grazing, especially sheep and goats, only the older and over 2–3 m high specimens could have survived while small self-grown species were eaten. A Buddhist monastery existed in the neighbourhood, by the River Tsagan-Turutuingol. In the early 1920s, during the so-called cultural revolution, the monastery was damaged, monks were murdered, and animal flocks were killed. Around single older trees, new forest grew and in 1974 it was ca. 40 years old. After WW2 animal flocks were restored. Therefore, there were no old trees within the patches of young forest, neither in the 1970s nor during our later visits in the 1990s (Fig. 5).

DARJEELING HIMALAYA

In the forest zones of the eastern Himalayas, reaching up to 3500–3900 m a.s.l., human activity other than pasturing does not occur above the elevation of 2000–2500 m a.s.l. In the Darjeeling Himalaya (in a marginal zone of the Sikkim Himalayas) the forests were mostly cleared within a few decades after the East India Company had purchased the eastern parts of the mountains from the Sikkim maharajah in the 1830s and established tea plantations in the early 1850s. In other areas, after forest clearing tree stands started to be recovered by planting the fast-growing *Cryptomeria japonica*. This is when slope degradation began. The degradation is related to continuous rainfalls of the order of 500–1000 mm in 2–3 days and of frequency of 2–3 rainfall events per century, as well as to local downpours (S t a r k e l, B a s u eds. 2000) Degradation of soils is mainly caused by debris-mud flows, which is associated with high water capacity of silty-sandy weathering covers. After one of such events in the tea plantations, in October 1968, the weathering cover was removed from 20–30% of deforested slopes (S t a r k e l 1972b, Photo 5). At the same time, mass movements affected only up to 2% of the forest area. Such events were followed by accumulation of colluvia, sometimes up to 5–10 m thick, at the bottoms of the present-day valleys (Photo 6). In the Tista catchment that refers to middle courses of the tributary valleys as the Tista River itself, in the uplifted area at the outlet from the mountains, still has a tendency to incision (Fig. 7; F r o e h l i c h, S t a r k e l 1993).

Observations made on the slopes in the area of Bannockburn plantation after the extreme precipitation in 1968 (S t a r k e l 1972b) and a record of the effects of downpours in the 1980s show that new troughs of debris-mud flows form on the deforested slopes. With time, the troughs usually evolve into small shallow valleys. Taking into account two former events (1899 and 1950) we can estimate that the density of slope dissection increased even 3 times (Fig. 8, F r o e h l i c h, S t a r k e l 1990).

Photo. 5. Earth flows after rain about 800 mm in October 1968
at Rington Tea Garden near Darjeeling

Photo. 6. Channel of Posam Creek covered by debris flows in October 1968

Photo. 7. Extensive alluvial fan of Gish river at Himalayan foreland, upstream of bridge narrowing the channel

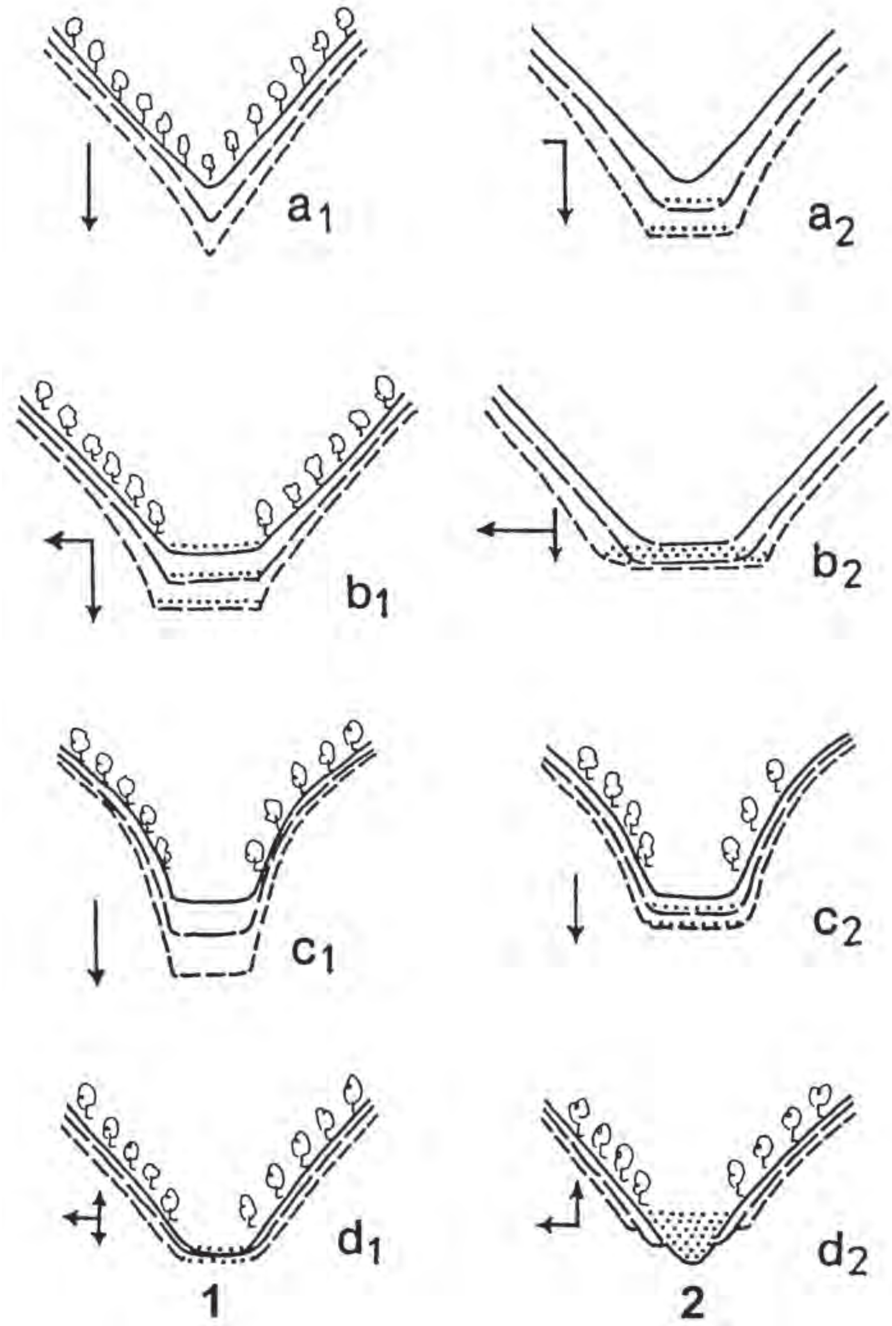

Fig. 7. Tendencies of transformations of valley cross-sections in Darjeeling Himalaya before (on the left) and after (on the right) deforestation (F r o e h l i c h, S t a r k e l 1993). a — upper reach, b — middle reach, c — outlet of Tista river from the mountains, d — outlets of smaller rivers from the mountains (aggradation)

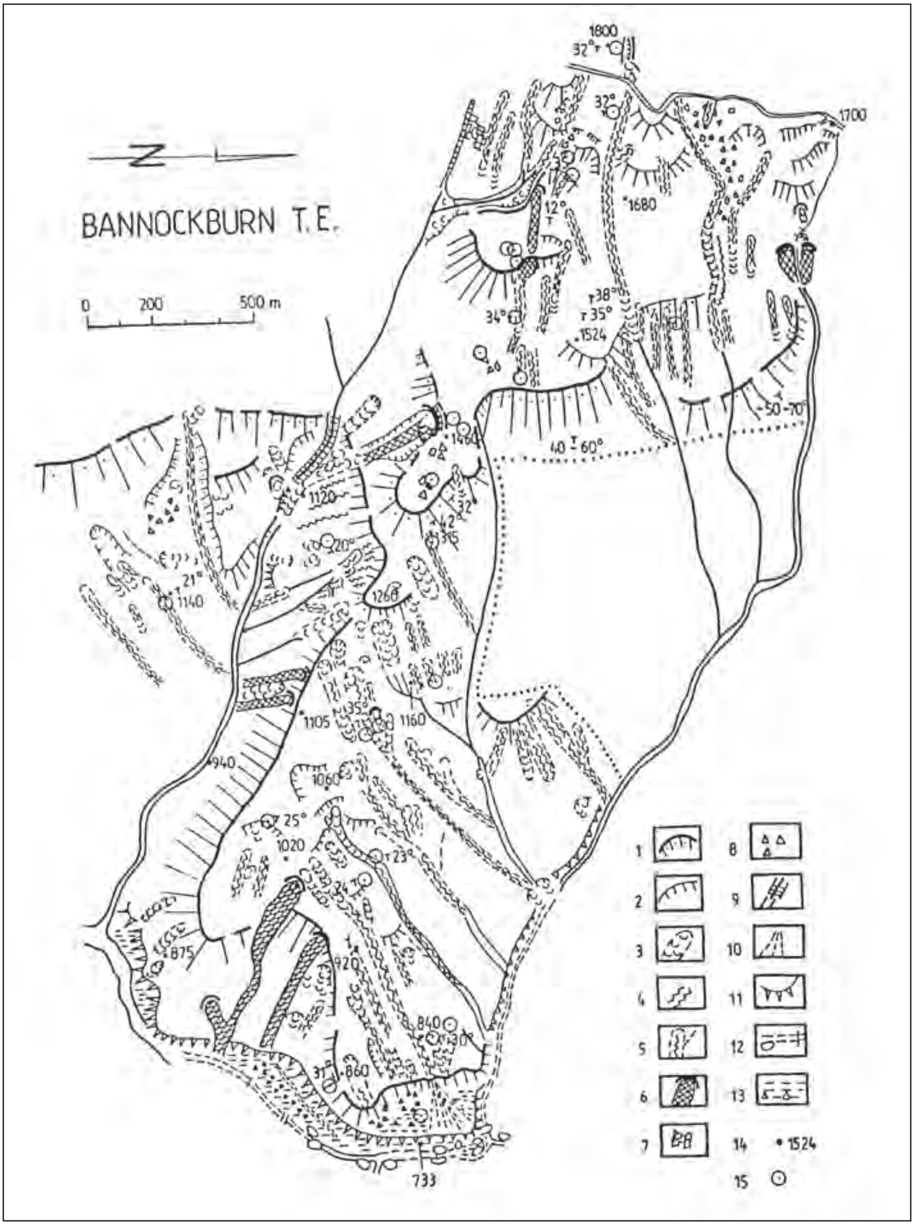

Fig. 8. Geomorphic map of part of the Bannockburn Tea Estate (by E. Gil and Starkel, in (Froehlich et al. 1990). 1 — structurally controlled scarps, 2 — other breaks of slope, including old niches, 3 — post-landslide depressions formed in 1968, 4 — slope fragments with degraded soil, 5 — debris flow channels formed in 1968, 6 — new landslides and flows formed in 1987 (some of them in 1983), 7 — rocky slopes, 8 — rocks (or big blocks), 9 — channels cut in bedrock (also with waterfalls), 10 — proluvial or colluvial fans, 11 — undercuts, 12 — channels cut in coarse debris with big block and waterfalls, 13 — terrace fragments, 14 — elevation (in meters a. s. l.), 15 — sites where soil properties were measured

In some smaller catchments at the margin of the Himalayas (Lish, Gish), forest clearing combined with exploitation of thin coal seams resulted in the development of landslides. Their surface area increased 2.5 times from 1930 to 1990, i.e. from 4% to 10% of the catchment area (B a s u, G h a t o w a r 1988; B a s u 2006). This contributed to fast accretion of alluvial cones at the mountain foreland with a rate of 2–3 m per decade (S t a r k e l et al. 2008, Photo 7).

In the easternmost part of the Himalayas, in Arunachal Pradesh state, inhabited by local tribes, natural forest communities prevail until now, and are partially subjected to shifting cultivation. After a couple years cultivation shifts onto neighbouring slopes (Photo 8).

Photo. 8. Shifting cultivation on Himalayan slopes in the state Arunachal Pradesh

SOUTHERN SLOPES OF THE MEGHALAYA UPLAND

A gentle southern slope of Meghalaya Upland, rising almost to 2000 m a.s.l. is nearly completely deforested, but below it descends as 1000-m high scarp dissected by canyons covered with jungle (S t a r k e l 1972a). The face of this scarp receives the world's highest precipitation of 8000–15000 mm annually (to 3000–5000 mm monthly). Above the zone of tropical forests, with the highest precipitation at the elevation of 600–1500 (1600) m a.s.l., the subtropical green forest occurred. Above, poorer communities with pine (*Pinus kasya*) occupied summit parts of the Upland. Deforestation, which started perhaps already in the Neolithic, took place on the gentle summit parts of the plateau, to the elevation of ca. 1100 m a.s.l. Shifting cultivation and fallowing did not prevent intensive erosion on the slopes with root plant fields, which increased in area after the introduction of potatoes in the second half of the 19th century (Ramakrishnan, Ram 1988). According to P. Prokop (2007) the indiscriminate deforestation of the Upland above the elevation of 1200 m a.s.l. was mainly due to iron smelting which required considerable amounts of wood. Deforestation of the entire area, which nowadays is a poor steppe, could have happened within 200–300 years. Nevertheless, beginnings of metallurgy on the Upland can be as ancient as 2000 years.

Near the road from Cherrapunji to Leiduh, in the old river channel, the author found abandoned channel clays resting on a gravel layer and covered with loamy-sandy delluvia with a total thickness of 1.9 m. At the lower face of these clays the author found fragments of charcoal and branches. The charcoals, dated at 1600 ± 40 BP by the Gliwice Radiocarbon Laboratory suggest that forest could have been cleared in the 4th century AD. Slag found at a nearby location also points to iron smelting. The recently published palynological results (Prokop, Bhattacharya 2011) show that already 2500 years ago there were open forest glades, and that 800 years BP the percentage of pine pollen in peat deposits increased significantly (pine invaded certain deforested areas) along with the percentage of mineral particles, which in turn point to soil erosion on the deforested slopes.

In the upper part of the Meghalaya Plateau remains of human activity are also distinct despite relatively lower annual rainfall ranging from 3000 to 4000 mm. Deforestation of granite rocks, weathered to a depth of 10–20 m, caused exhumation of several-metre-large corestones, and formation of iron crusts on the surface (Fig. 9; Photo 9). In the upper river courses, several-metre-thick sandy delluvia and proluvia were deposited (Photo 10). That intensive denudation took place in last centuries. P. Prokop (2010) has documented the above with ^{14}C datings of charcoal obtained from a depth of 3.80 m (375 ± 30 BP) and 1.60 m (130 ± 30 BP).

Due to deforestation, patches of the Upland in Cherrapunji region, excluding steep slopes of the canyons, changed into waterless rocky surfaces of sandstone beds, or on the preserved remnants of tropical regolith 10–20 cm thick gravel armouring consisting of rock clasts and ferruginous concretions developed (Photo 11). Such stony slopes are overgrown with poor steppe vegetation with deeply rooted grasses which survived after deforestation. Here, biomass productivity is lower by a half when compared with that of the few sacred groves with preserved multi-species forests (Ramakrishnan, Ram 1988; Ramakrishnan 1992). Measurements of denudation by ^{137}Cs method showed that after the formation of a protective armouring the present-day slope wash is low. Its rate is only 0.21 kg/m^2/year which equals an average lowering of the surface by 0.1 mm/year

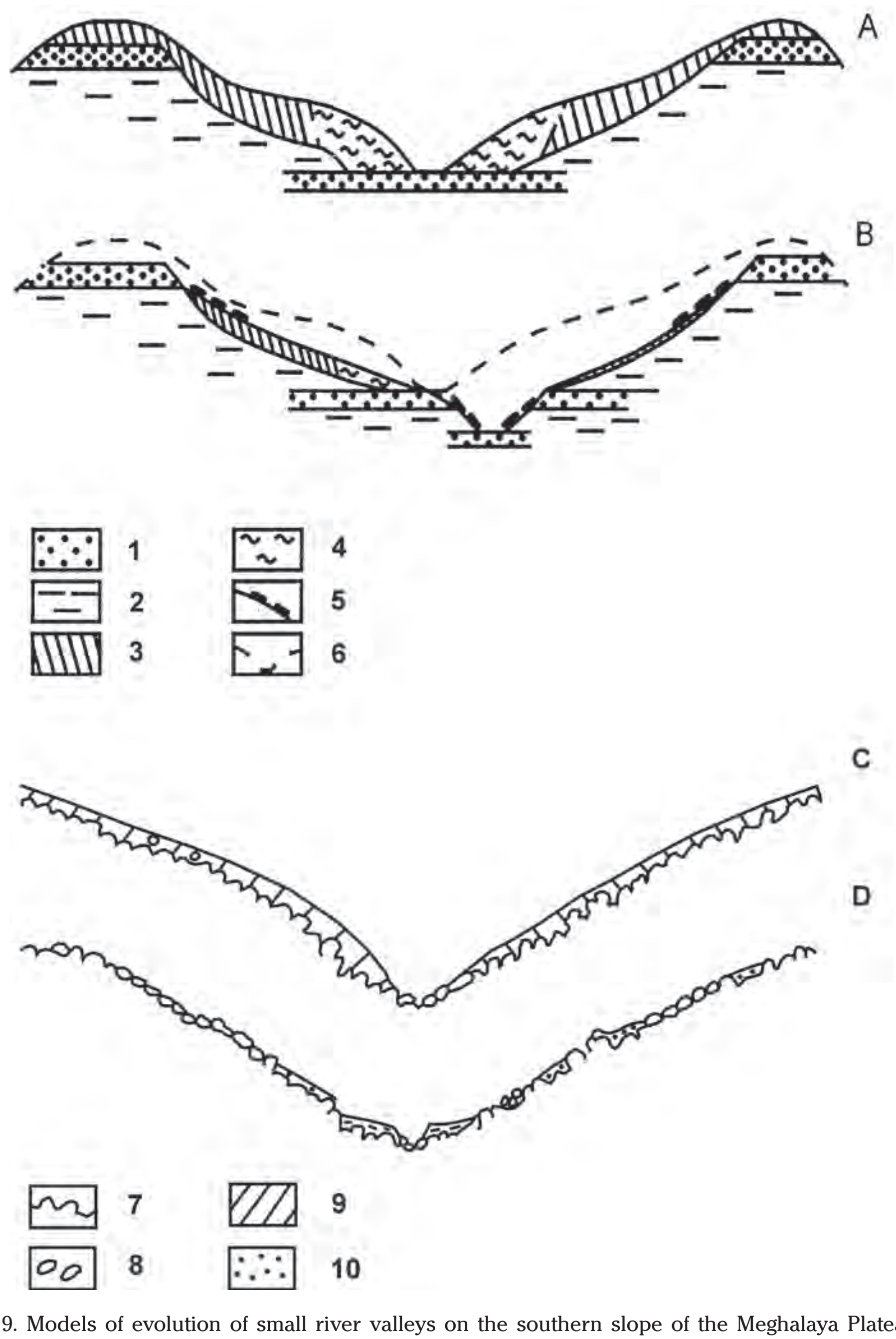

Fig. 9. Models of evolution of small river valleys on the southern slope of the Meghalaya Plateau on the sandstone beds at Cherrapunji before deforestation (A) and after deforestation (B) as well on the Mylliem granite before deforestation (C) and after it (D). 1 — resistant beds, 2 — less resistant sandsones and shales, 3 — regolith of lateritic type, 4 — colluvial deposits, 5 — sliding sandstone blocks, 6 — former valley cross profile, 7 — unweathered granite, 8 — corestones, 9 — laterithic cover, 10 — sandy-silty deluvia

Photo. 9. The degraded deforested slope on the Meghalaya Plataeau with exposed granitic corestones. On the fragments with preserved laterite cover the typical bun cultivation

Photo. 10. The deluvial sandy deposits 3–4 m thick accumulated in upper valley courses in last centuries after deforestation of granitic slopes (see photo 9). Profile elaborated by P. P r o k o p (2010)

Photo. 11. The armoured layer of residual gravels protecting against erosion with poor grass vegetation near Cherrapunji

Photo. 12. Horizontal bedding and iron crusts cause that channels of creeks near Cherrapunji are subjected mainly to a lateral erosion than a downcutting

(F r o e h l i c h 2004). The natural ecosystem of the subtropical forest did not survive, but a new steppe-semidesert formed and adjusted both to high intensity of summer downpours and to the extended, often several months long periods of drought. The sides of the small valleys dissecting the slope of the Meghalaya Upland near Cherrapunji, which is built of horizontal beds of sandstones and mudstones, were initially covered with a thick mantle of weathered material and colluvium. However, the covers were only preserved as patches and now the outcrops of more resistant beds are exposed (Fig. 9, Photo 12).

On the plateau, especially on the Cherrapunji spur, large flat areas or slopes are undermined by dig-holes, shallow shafts and galleries set for the exploitation of thin coal seams. The steeper slopes, and especially head niches of small valleys, are pierced (demolished) by hundreds of open-pits made when prospecting for iron ores or coal. Some of such caverns evolved into rills and gullies.

EFFECTS OF HUMAN IMPACT — FORMATION OF NEW EQUILIBRIUMS OF GEOSYSTEMS

When comparing types of human impacts in various climatic zones we observe certain regularities. Generally, degradation of the vegetation cover was accompanied by intensification of erosional processes. At the scale of the entire mountain ranges we notice a narrowing of the forest zone. Pastoral economy results in both: a lowering of the upper tree line and a rise of the lower tree limit.

After leaving by human beings, natural forest and grass communities usually start to renew. That is only possible if the natural habitats, and especially soil covers, have not yet been destroyed. Badlands, communities of Mediterranean macchia and steppe-desert habitats in humid tropics developed under such extreme conditions.

The process of the abandonment of mountain areas by man can occur suddenly in relation to political changes or to extreme natural hazardous events, which are followed by economic changes. However, this process can also be slow and disproportionately distributed in space due to ongoing transformation of social and economic structures.

Three basic human impacts, namely deforestation, pasturage and farming, can eventually result in differentiated adjustments of plant communities, soils or relief forms to new conditions by developing a metastable equilibrium of circulation of water and solid matter. Among these final effects we can distinguish:

1. Rocky slopes or slopes covered with block fields that have been left after deforestation and degradation of soil covers, as well as the results of cultivation or overgrazing, found most often in the mountains of the Mediterranean climate. The slopes covered with corestones exposed from under laterite covers on granites after deforestation in Cherrapunji region are also of similar origin.

2. The slopes mantled with skeletal soils, after deforestation occupied by secondary shrub communities of the macchia type e.g. with *Quercus ilex* (Hempel 1966, Bottema 1974).

3. The slopes with remnant laterite soils formed under monsoonal tropical forests over which a surficial stony layer developed, protecting against continuous degradation and covered by scanty grass (Ramakrishnan, Ram 1988; Starkel, Singh eds. 2004).

4. The terraced slopes protecting against intensive runoff and slope wash, limiting these processes to particular steps, developed especially in areas of rice cultivation as well as in the areas of water deficit that require irrigation.

5. The slopes covered with blanket bogs and heather, which developed in temperate humid climate with a surplus of water after total deforestation, with no potential for natural recovery of a forest cover.

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