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OPEN

STUDIA GEOMORPHOLOGICA CARPATHO-BALCANICA
Vol. XLVIII, 2014: 53–60 PL ISSN 0081-6434

DOI 10.1515/sgcb-2015-0004

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THE QUATERNARY TRANSFORMATION OF OLDER INHERITED MOUNTAIN LANDSCAPES

Abstract: The Quaternary transformation of the inherited mountain relief was controlled by three factors: cyclic climatic changes, resistance of the substratum and neotectonic uplift. Cyclic climatic fluctuations in the majority of European mountains were reflected in the alternation of interglacial and cold stages, the former characterized by a dominance of forest and chemical weathering, the latter by permafrost, solifluction, wind activity and, at higher elevations, by glacier advances. The transitional phases played an important role as periods of re-establishment of water circulation and transfer of regolith and sediment, formed during the previous cold or interglacial stage. The rates of degradation of inherited planation surfaces and slopes depend on bedrock resistance. In the case of less resistant flysch deposits, degradation during a single (last) cold stage reached 10 metres. Therefore, the higher planation levels may have been either better preserved on more resistant bedrock or even emphasized by cryoplanation processes. The lowest piedmont developed on less resistant beds was lowered to 50 m. In the young mountains, the Quaternary uplift may have played an additional role. In the case of uplift reaching or exceeding several hundred metres, the former fluvial forms were shifted to the cryonival or even nival (glacial) vertical zone where they became entirely transformed.

Key words: mountains, inherited landscapes, Quaternary transformation, climatic changes, neotectonics, resistance of substratum

Among the existing mountain ranges we distinguish two basic types. The first type is represented by older planated blocks which were later lifted along fault lines and dissected upstream from their margins. The second type comprises young orogens gradually expanding outward towards the margins of continental plates. In such mountain ranges, the successive orogenic episodes were separated by the formation of piedmont levels that developed mainly along a fluvial system of valleys dissecting them.

The transformation of the inherited relief during the mid- and Younger Quaternary (last 0.5–1.0 mil. years) was controlled by three main factors: cyclic climatic fluctuations expressed in glacial and interglacial stages, by differentiated resistance of the substratum and by neotectonic uplift. The role of these factors will be exemplified by the results of studies conducted in the Polish flysch Carpathians, the range closest to the zone of the Scandinavian ice-sheet advance.

Climatic fluctuations are expressed in the vertical shifting of morphoclimatic zones of an order of 800–1000 m that repeats during every cold stage. In the lower belt of the Carpathians and other European mountains, this was reflected by the alternation of interglacial stages with the occurrence of forests and treeless cold stages. Deep infiltration and chemical weathering during interglacials led to the formation of soil covers. During cold stages with the expansion of permafrost, processes such as overland flow, congelifluction and wind activity prevailed. In the old mountain systems, thick regolith covers produced as a result of subtropical weathering were degraded, exhuming structure-controlled relief that is well known from granitic massifs of the Sudetes (Migoń 2011) or Dartmoor (Linton 1955) and others. At higher elevations advances of valley glaciers or formation of ice sheets, as in the Scandinavian Mountains, took place. Even during short episodes such as the Younger Dryas small ice caps developed over the Scottish Highlands (Clapperton, Sudgen 1977).

During transitional phases water circulation was re-established, followed by establishment of vegetation and transfer of regolith and sediment from slopes and along valleys. These transitional phases lasted about 50% of the last cold stage. These phases were typified by transfer of regolith and deposits formed during the previous phase. It may be exemplified by thick early-Weichselian alluvial fans well documented at the margin of the Moravian-Silesian Beskid in the flysch Carpathians (Hradecky et al. 2011). Similarly, high transfer of regolith is connected with thick solifluction layers of long Interpleniglacial phase registered at many localities in the flysch Carpathians (58–25 ka BP — Klimaszewski 1971; Starkel 1968; Starkel et al. 2007). That Interpleniglacial phase is also reflected in 20–30 m thick alluvium forming extensive fans at the foreland of the flysch Carpathians (Starkel 1995; Gębica 2004). Finally, the Late Glacial melting of permafrost was expressed in deep infiltration and removal of periglacial deposits (Starkel 1960, 1995; Pellegrini et al. 2006; Margielewski 2006, Fig. 1).

The rate of degradation of the inherited Tertiary planation surfaces and slopes depended on climatic variations and bedrock resistance. For example, three levels developed in the folded flysch Carpathians: IM level — intramontane level (of Pannonian age) at 300–400 m above river channels; SM level — submontane level (of upper Pliocene age) at 200 m; and VL level — valley level (of lower Quaternary age) about 80–100 m above river channels — (see: Starkel 1965, 1987b; Minar et al. 2004, 2011; Zuchiewicz 2011, Fig. 2).

The highest level (IM) is preserved on flat ridgetops underlain by resistant sandstones, but mostly forms horizontal axis of ridges (Starkel 1965). Many of these flat surfaces show traces of distinct transformation by cryoplanation processes during the Quaternary.

The middle level (SM) is underlain by rocks of high to medium resistance and is separated from the lowest level by steep 50–100 m high and mainly structure-controlled scarps. The landscape of this level comprises undulated ridges with very rare flat fragments, preserved in the interfluve areas, and isolated tors

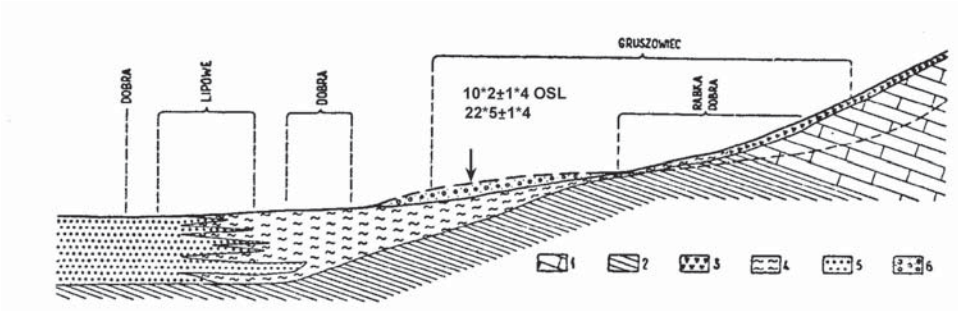

Fig. 1. Periglacial covers over slopes and in valley floors of the Beskid Wyspowy (after S t a r k e l 1960). 1 — thick-bedded Magura sandstones, 2 — Submagura sandstone and shales, 3 — debris covers, 4 — solifluction covers, 5 — alluvia, 6 — overlying lateglacial fans at the outlets of gullies dissecting slopes (dated by OSL). Localities representing various parts of synthetic profile underlined

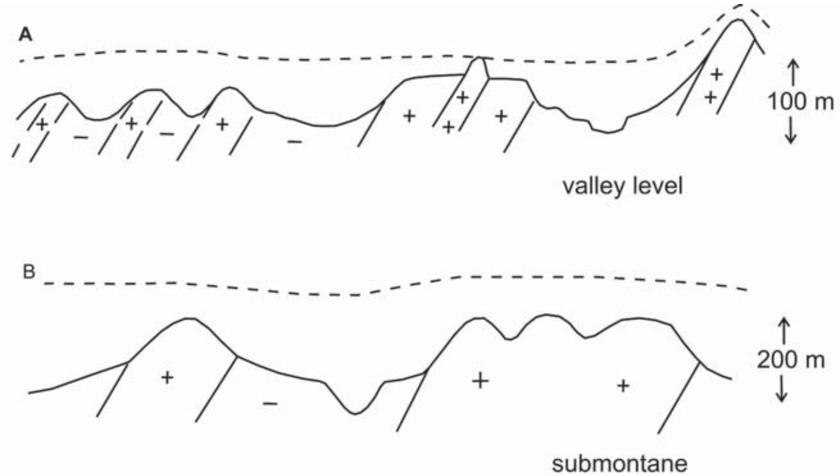

Fig. 2. Relation of two main levels and their preservation to lithology (rock resistance) in the flysch Carpathians; 1 — present-day relief (continuous line) and primary flat level (dashed line), + and — signs indicate various resistance of bedrock; levels: A — valley level (VL), B — submontane (SM)

up to 10–20 m high, indicating the depth of alternating weathering and cryoplanation processes.

The most complex relief is represented by the lowest piedmont level called “valley level” VL that developed along larger river valleys. It can be identified at elevations from 20–50 m (above river water level) in intramontane depressions to 100–120 m in the upstream sections of major river valleys (Mazur 1963; Starkel 1965; Zuchiewicz 2011). It developed mainly on less resistant shales and sandstones. In the case of vertically bedded rocks, the role of resistance is well-expressed (Fig. 2). Only on the most resistant bedrock has that level been preserved — in the form of a strath terrace with a thick layer of coarse fluvial gravels (Starkel 1965). On moderately resistant sandstones wide, flat ridges with single several-metre high tors or undulated flat ridges, separated by niches of valley heads, have been preserved (Fig. 3). This indicates that the great transformation continued during the Quaternary. This type of relief is frequently bordered by an edge separating it from a zone of the less resistant shales and sandstones located 30–50 m lower. This is a zone of parallel hummocks indicating the lowering of the 100-m high VL by at least 50 m. The continuous denudation of those nonresistant rocks in the flysch Carpathians led to progressive exhumation of resistant beds and formation of structure-controlled ridges. In the small intramontane depressions in headwater areas, this level is in the form of pediments, dissected up to 20–40 m and later transformed into cryopediments that gradually change downslope into colluvial glacis (Starkel 1965, 1987a; Czudek, Demek 1973).

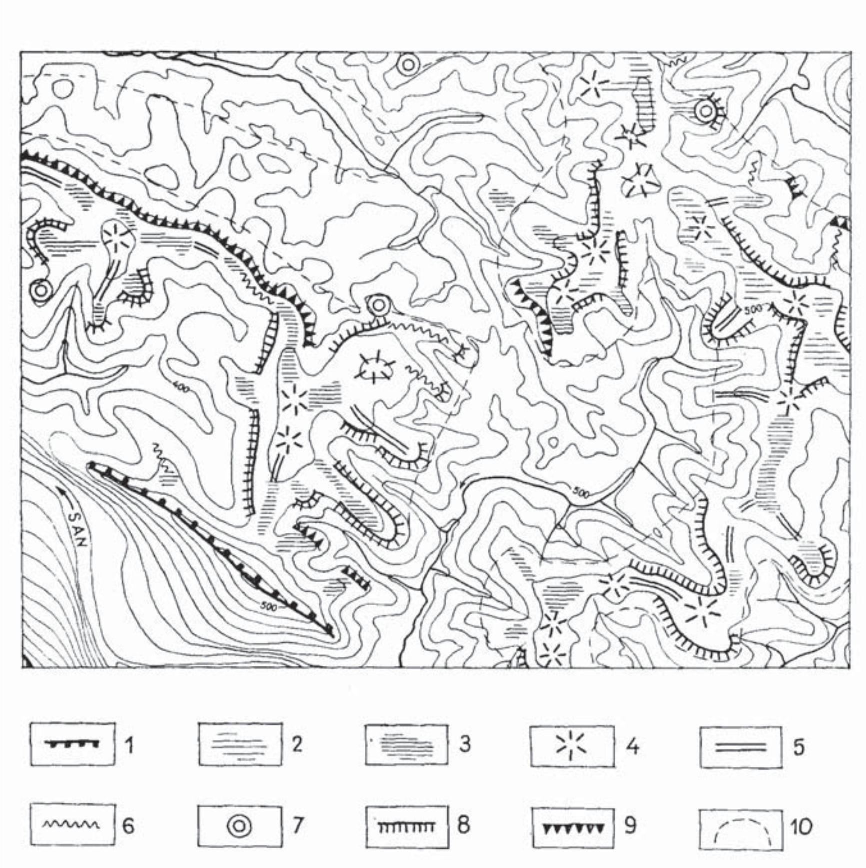

Fig. 3. Elements of relief connected with 100 m valley level in the catchment of upper San river (Starkel 1965). 1 — monoclinal ridges above 100 m level, 2 — flattening on humps rising above 100 m level, 3 — flattening at 100 m level (VL), 4 — residual hills in 100 m level, 5 — humps at 100 m level, 6 — wide humps lowered, 7 — residual hills lowered, 8 — edges separating relief of 100 m level (VL) from slopes of deeper valleys, 9 — structure controlled scarps, 10 — extend of forms connected with 100 m level

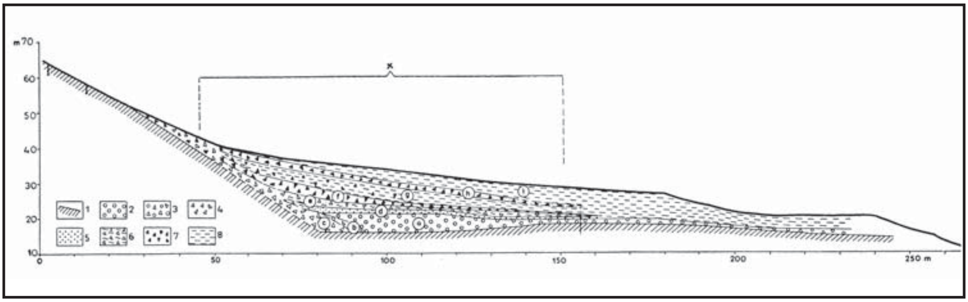

Fig. 4. Profile of slope covers on the fossil terrace in axis of the dam in Solina (Dziewański, Starkel 1967); 1 — rock surface, 2–6 — covers dating from Middle-Polish glaciation, 2 — alluvia of stream-bed facies (a series), 3 — alluvia mixed with debris (b series), 4 — talus covers (c series), 5 — alluvia of flood facies (d series), 6 — solifluction and proluvial covers dating from the decline of glaciation, weathered (e series), 7–8 Vistulian-glaciation covers: 7 — covers predominantly solifluctional with debris (f, h series), 8 — covers predominantly proluvial (g, i series)

A detailed study of slope sediments (up to 20-m thick) deposited at slope bases during the last cold stage showed the effect of a single cold period on slope degradation (Fig. 4) to be of an order of 10 m (Sobolewska et al. 1964; Dziewański, Starkel 1967; Starkel 1969). Then, the total lowering of the VL level reaching 50 m during several glacial–interglacial cycles seems not to be overestimated.

In the young orogens the Quaternary tectonic uplift plays an additional role. The uplift fluctuated from 100–200 m only in the flysch Carpathians (Zuchiewicz 1984, 2010; Starkel 1985) to over 2000 m in the Himalayas or the Pamir Mountains (Gansser 1964; Kostienko 1962; Valdyia 1998; and others). As the downcutting usually progresses upstream, older forms may be better preserved in the upper courses of river valleys. But at the same time we should remember that the old relief of interfluve zones has not reached the stage of planation. The flattening in the interfluve zones is rather the product of younger Quaternary planation by other processes. It is not only the effect of vertical shift of morphoclimatic zones of the order 800–1000 m (discussed above) between cold stages and interglacial warm phases, but also, in the boreal zone of northern Eurasia, of transformation of older planation by ice sheets (as in Scandinavia).

In the central Asian mountains the uplift, exceeding 2 km, transformed the whole mountain landscape by shifting an originally fluvial landscape (occupying both the headwater zones dissected by the Himalayan valleys and planated basins of the Tibetan Plateau) to the permanently cryonival or even glacial vertical zone (Zheng, Jiao 1991). Then deep valleys became wider and deeper by glacial excavation. The glacial overdeepening and thresholds may be indicated on the pre-Quaternary steps that prevented younger incision in the hanging upper courses of the rivers (Baumgart-Kotarba et. al. 2008).

In transitional elevations, especially in arid central Asia, the higher mountain ranges, elevated now to 3000–4000 m a.s.l., were continuously in cryonival

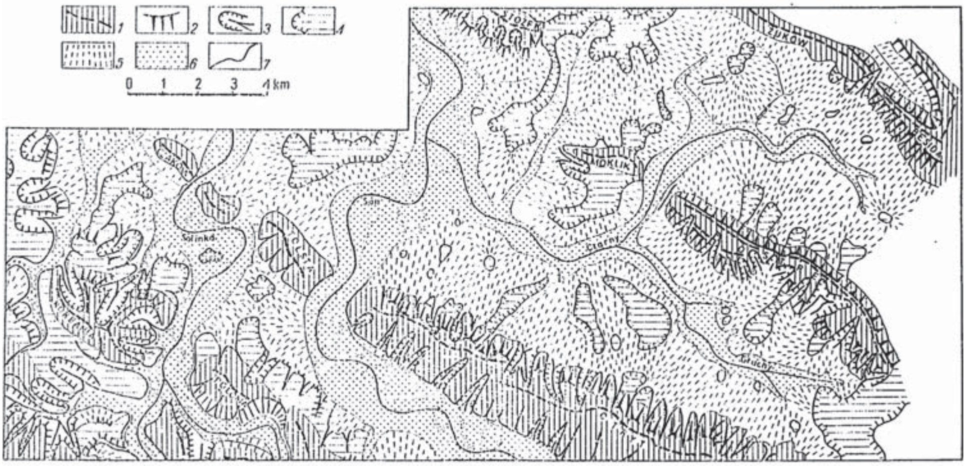

Fig. 5. Paleogeomorphological map from period of formation of early Quaternary 100 m valley level for part of upper San River valley (after S t a r k e l 1965). 1 — structure controlled ridges, 2 — denudation escarpments, 3 — valleys dissecting slopes of ridges, 4 — remnants of foothill level, 5 — inclined feet of slopes — pediments, 6 — valley floors (partly with alluvia), 7 — present-day river channels

belts during both cold and warm stages of the Quaternary (S t a r k e l 1980; K o w a l k o w s k i, S t a r k e l 1984; P ę k a l a, R e p e l e w s k a - P ę k a l o w a 1993). This resulted in the development of whole systems of cryoplanation terraces over wide ridges of the Khangai, the Khentai and other mountain ranges and a total transformation of the former landscape of uplifted horsts.

These three factors: cyclic climatic fluctuations, diversified lithology of substratum and active tectonic movements caused that in the mountains the elements of older, pre-Middle to Younger Quaternary relief have been well preserved only over very resistant rocks and outside the zone affected by glaciations and permafrost. Therefore, the older roots of present-day mountain relief may be reconstructed and depicted only on palaeogeomorphological maps (Fig. 5).

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