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NEOTECTONICS AND PLANATION SURFACES IN THE HIGH BIESZCZADY MOUNTAINS (OUTER CARPATHIANS, POLAND)

Józef KUKULAK

Institute of Geography, Cracow Pedagogical University, Podchorążych 2, 30-084 Kraków, Poland; jkukulak@ap.krakow.pl

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Abstract: The interfluves and slopes of the High Bieszczady Mts., SE Poland, bear flat surfaces that are both structurally-controlled and represent fragments of planation surfaces. More extensive are planated surfaces that can be associated with the intramontane, foothills, and riverside levels of planation. The oldest planated surfaces are most numerous in the most elevated parts of the Bieszczady Mountains. Older surfaces display traces of relief rejuvenation, including steps and minor ridges developed upon thick-bedded sandstones. These planated levels display relief energy of 50–100 m, increasing within older landforms of that type. Locally occurring rolling topography of structurally-controlled flat surfaces appears to result from tectonic undulations and the presence of fault zones. Strong structural control dominating the topography of the Bieszczady Mts. obliterates any possible young tectonic influcences upon development of flat surfaces on the slopes.

Key words: planation surfaces, neotectonics, Bieszczady Mountains, Poland.

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INTRODUCTION

Inconsistencies in altitudinal position of ancient landforms, like planation surfaces, is one of manifestations of young uplift (Klimaszewski, 1948, 1987, 1988; Cys, 1966; Henkiel, 1977; Gofshtein, 1979; Baumgart-Kotarba, 1983; Zuchiewicz, 1984a; Kukulak, 1991; and references therein). The longevity of planation surfaces makes these landforms perfectly suitable for preservation of the effects of long-term uplift. Nevertheless, neotectonic nature of some of the observed inconsistencies is poorly documented, particularly when not taking into account other possible factors, like: bedrock resistance to denudation, structure, distance to local erosional bases or long-term effects of stable climatic conditions (*i.a.*, Starkel, 1965, 1972, 1985; Tokarski, 1975; Zuchiewicz, 1987). The amplitude and spatial extent of deformations are also important.

The High Bieszczady Mts. represent an area wherein evaluation of the extent and rate of young vertical crustal movements, based on planated surfaces, is very complex. This complexity results in part from variable interpretations of the origin of planated surfaces, as well as from recent changes of the base of erosion due to reorganization of the drainage network. The results of hitherto-conducted geomorphological studies indicate that flat segments of slopes and ridges result from planation processes (Pękala, 1971, 1997; Starkel, 1972; Henkiel 1977, 1980), whereas geological data point to purely lithological and structural control (Tokarski, 1970, 1975). Moreover, the age and number of planated levels is still a matter of debate (Teisseyre, 1928; Pękala, 1971, 1997; Henkiel, 1977). Nevertheless, it is commonly accepted that the High Bieszczady Mts. have been subject to tectonic uplift.

The aim of this paper is to document co-occurrence of both planated surfaces and those lithologically and/or structurally-controlled upon the slopes of the High Bieszczady Mts. Moreover, an attempt has been made to evaluate manifestations of young tectonic movements in the morphology of planated surfaces, basing on local changes in their absolute altitudes. To achieve this task, a complex map showing spatial distribution of the preserved planated surfaces, graphic visualisation of hypsometric data, as well as long- and cross-profiles through the main and side ridges bearing planated surfaces have been made. All the preserved planated areas have been mapped (Haczewski *et al.*, 1998, 2001), and the results of field studies have been supplemented by critical evaluation of the existing geomorphological and geological literature. As compared to the hitherto-published data, this work takes into account the headwater part of the San River drainage basin, characterizing as well the relief of individual planated surfaces from both geological (like in the papers by Tokarski, 1970, 1975),

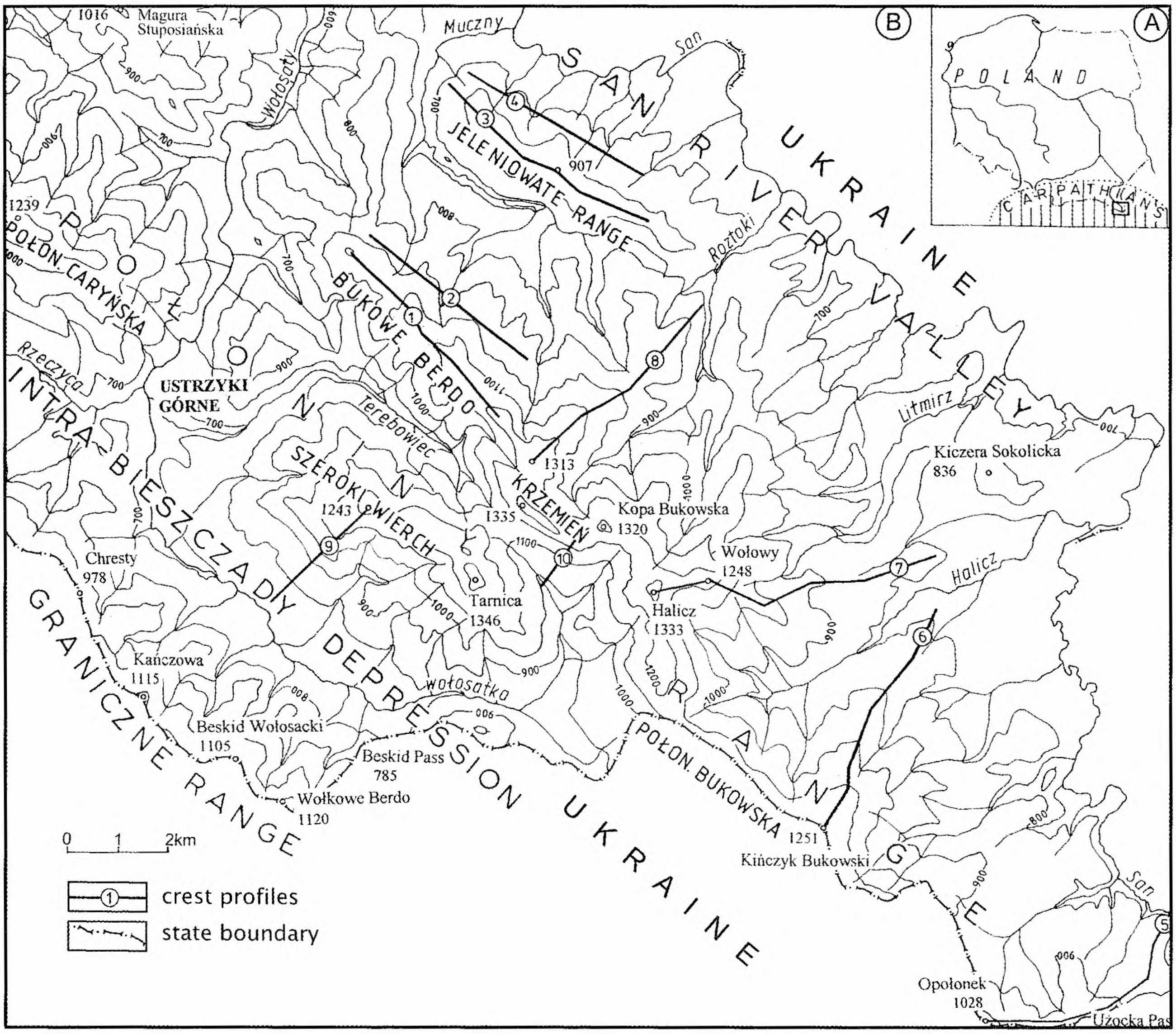

Fig. 1. Location of the study area in the Carpathians (**A**) and its orography (**B**)

and geomorphic (like in Pękala, 1971, 1997) points of view. The bulk of planated surfaces dealt with in this study clearly show structural control; these landforms have developed upon bedrock of variable resistance to erosion and showing different attitude of beds. The shaping of these landforms has frequently proceeded through exhumation of more resistant rocks underlying old planated surfaces.

MORPHOTECTONIC SETTING OF THE WOŁOSATY CATCHMENT AREA

The Upper San River drainage basin (*ca.* 250 km^2 up to Stuposiany area) comprises the most elevated part of the High Bieszczady Mts., situated in the SE corner of the Outer East Carpathians in Poland (Fig. 1A). The morphology of this region is structurally-controlled and characterized by a rectangular pattern of ridges (Starkel, 1965; Tokarski, 1975; Henkiel, 1977, 1980). Two parallel ranges (Pasmo Graniczne Range, including Wielka Rawka Mt. 1,304 m a.s.l., and Połoniny Range, including Tarnica Mt. 1,346 m a.s.l.), separated by the deeply-cut intra-Bieszczady Depression with subsequent valleys of the Wołosatka, Rzeczyca and Prowcza Rivers, dominate in the study area. On the NE, a vast valley of the San River occurs (Fig. 1B). The rectangular pattern of mountain ridges is accompanied by an analogous pattern of valleys which is composed of alternating subsequent (longer) and transversal (shorter) segments. The rectangular valley pattern includes both the main rivers (San, Wołosatka-Wołosaty) and their tributaries (*i.a.*, Muczny, Roztoki, Halicz, Litmirz). The vast Połoniny Range is transversally dissected by the gorge-like Wołosaty River valley. Local interfluves in the intra-Bieszczady Depression comprise up to 150 m high transversal ridges (Wyżniańska Pass, Nad Berehami, Beskid). Elevation differences between the highest ridges (Połonina Caryńska - Szeroki Wierch - Tarnica, Bukowe Berdo - Krzemień - Halicz - Połonina Bukowska - Kińczyk Bukowski, Wielka Rawka - Kińczyk Wołosacki) and main valley bottoms range between 400 and 500 m, attaining locally even 600 m. The

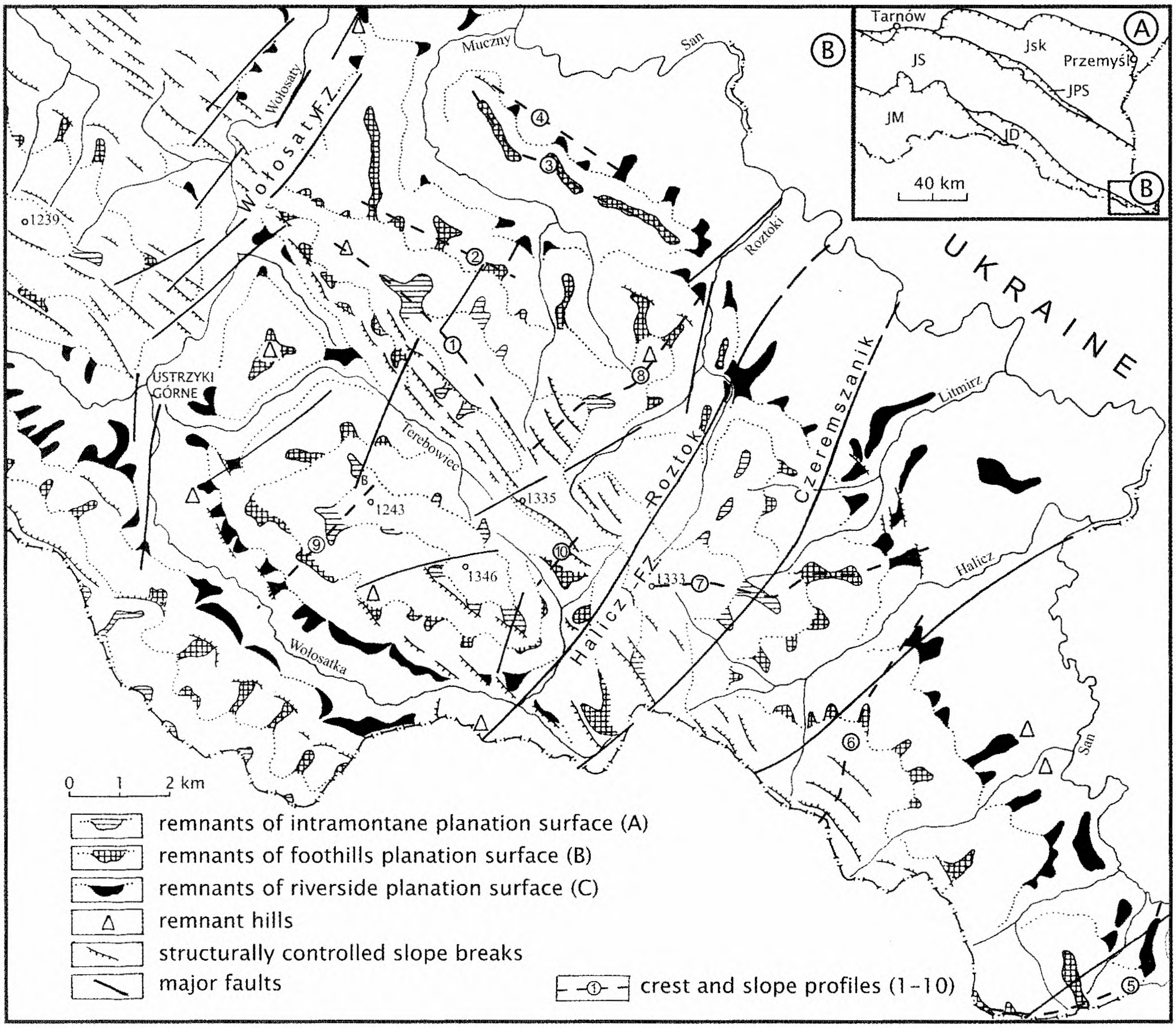

Fig. 2. Location of the study area versus tectonic units of the Polish Carpathians (**A**) and distribution of flattened surfaces upon ridges and slopes in the Upper San River drainage basin (**B**). The fault pattern adapted from Haczewski *et al.* (1998, 2001). JM – Magura Unit, JD – Dukla Unit, JS – Silesian Unit, JPs – sub-Silesian Unit, Jsk – Skole Unit; F.Z. – Fault zone

ridges are characterised by relatively long slopes showing singular or composite breaks.

As far as geological setting is concerned, the study area is situated at the boundary of the Dukla and Silesian Units (Fig. 2A). The narrow belt of the Silesian Unit (1–2.5 km) in front of the Dukla thrust is strongly imbricated and called the Fore-Dukla zone. The entire Silesian Unit, building most of the Bieszczady Mts. area, belongs to the so-called Central Carpathian Depression. Its folds are composed, in near-surface parts, of sandstone-shaly and siltstone Krosno beds of Oligocene age (*i.a.*, Opolski, 1933; Żytko, 1968; Ślączka, 1971; Ślączka & Żytko, 1978; Haczewski *et al.* 1998, 2001). Thick-bedded sandstone complexes of these beds (Otryt division) build the Połoniny, Magura Stuposiańska, and Jeleniowate ridges. Shale and siltstone complexes of the Krosno beds (sub-Otryt and supra-Otryt divisions), in turn, are dissected by the San and Terebowiec-Caryński River valleys. The shale-dominated Fore-Dukla zone, composed of the Hieroglyphic, Menilite, and Transitional beds of Eocene–Early Oligocene age, underlies the subsequent intra-Bieszczady Depression. Ridges of the Pasmo Graniczne Range (Wielka and Mała Rawka, Dział, Semenowa, Kańczowa, Wołkowe Berdo Mts.) are underlain by alternating sandstone- (Cisna and Wielka Rawka beds) and shale-dominated (Łupków, Majdan, Hieroglyphic beds) Late Cretaceous through Eocene strata of the Dukla Unit (Świdziński, 1953; Koszarski *et al.*, 1961; Ślączka, 1971, 1985; Haczewski *et al.*, 2001). The Dukla Unit frontal thrust upon the Silesian Nappe (Fore-Dukla zone) is marked in the topography by a distinct structural step.

Both the Dukla and Silesian Units are transversally cut by a number of fault zones, the largest of which coincide with the Wołosaty River valley, as well as Roztoki and Halicz areas (Fig. 2B). These are mostly normal-dextral faults, the displacements along which being responsible for gradual bending of the strike of principal folds of both units

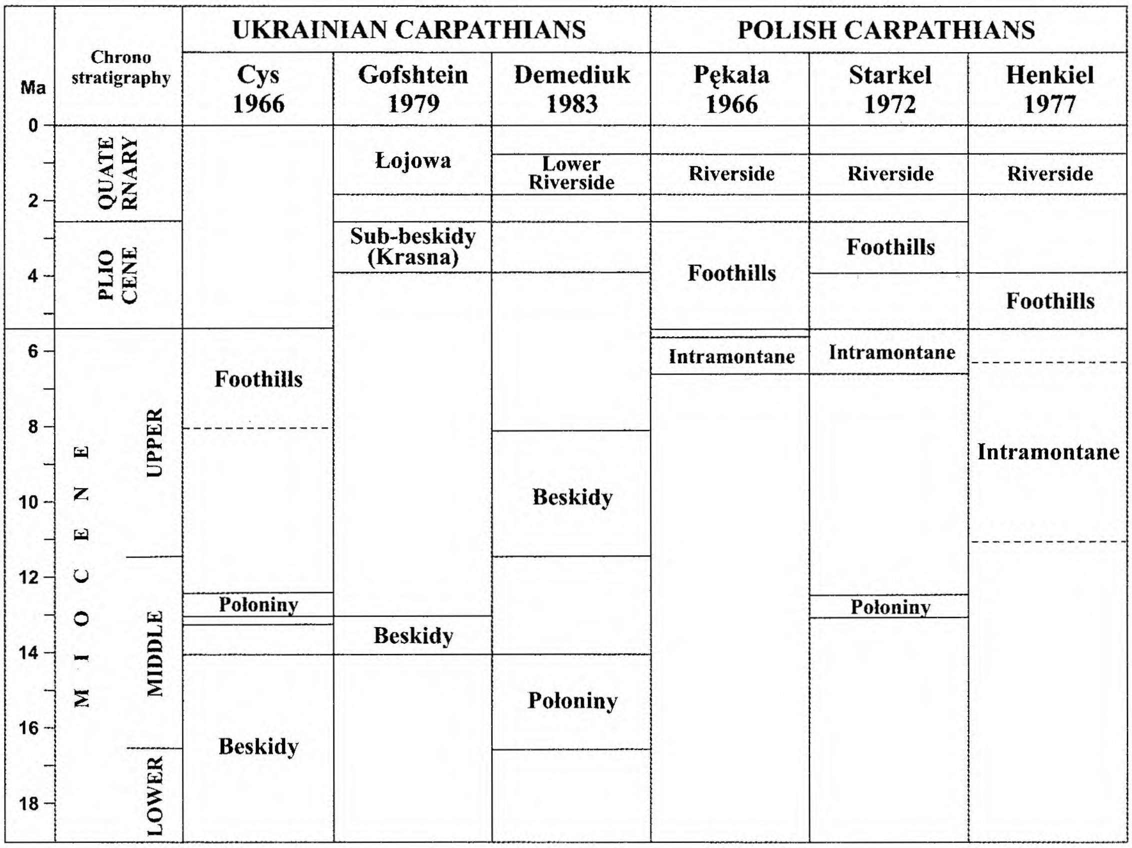

Fig. 3. Selected views on the number and age of the Carpathian planation surfaces (based on Zuchiewicz, 1984b, 1995; and Klimaszewski, 1987)

(Żytko, 1968, 1985; Ślączka, 1971; Tokarski, 1975; Zuchiewicz & Henkiel, 1993; Haczewski *et al.*, 1998, 2001). The Wołosaty fault zone is 2–4 km wide and composed of numerous en echelon faults. Their dextral character is indicated, *i.a.*, by the pattern of displaced hogbacks and V-shaped narrow valleys on either side of the Wołosaty River valley. The Roztoki-Halicz fault zone, 4–5 km wide, includes three parallel faults (Roztoki - Upper Wołosatka River valley, Czeremszanik, Halicz), accompanied by subsidiary faults and strongly rotated and squeezed rock complexes inbetween. The greatest dextral displacement is to be noted on faults that strike along the Roztoka River valley, through a pass between Halicz and Kopa Bukowska Mts., up to the Upper Wołosatka River course (Tokarski, 1975; Ślączka & Żytko, 1978; Haczewski *et al.*, 1998, 2001). Attitudes of beds that build the Połoniny Range are different on either side of this fault line. The fault zone is also accompanied by a well-visible fault separating the Tarnica and Szeroki Wierch Mts. (Siodło Pass). The Fore-Dukla zone is cut by a dense network of short faults which, however, are not marked in the topography.

NEOTECTONIC STUDIES IN THE HIGH BIESZCZADY MOUNTAINS: AN OVERVIEW

The Bieszczady Mts. belong to one of long-term uplifted regions of the Outer Carpathians (Zuchiewicz, 1984a, b). Diachronous character of individual uplift pulses in Pliocene and Quaternary times resulted in their relatively late occurrence in the eastern portion of the Outer Carpathians of Poland, although causing the greatest deformations of the pre-existing morphology (Klimaszewski, 1948; Książkiewicz, 1972; Zuchiewicz, 1983, 1984b, 1991). Even though the uplift has been of continuous and not pulsative character (Tokarski, 1975), the amount of uplift was considerable, as shown by the size of erosional downcutting (400–600 m). It is generally accepted that the Bieszczady Mts. were uplifted most strongly before Pleistocene continental glaciations (Henkiel, 1977; Zuchiewicz, 1987, 2000), but the uplift tendency has continued as well in the Eemian Interglacial and the Holocene (Pękala, 1971; Zuchiewicz, 1983). The rates of these movements have varied in space and time, leading to the formation of longitudinal elevations and depressions (morphostructural microregions). The uplifted morphostructures include the following groups of ridges: Tarnica - Halicz - Szeroki Wierch Mts., Połonina Caryńska and Wetlińska Mts., and Pasmo Graniczne Range with Wielka Rawką Mt. The adjacent, parallel depressions (intra-Bieszczady Depression, San River valley) have witnessed either minor uplift or even subsidence (Henkiel, 1977, 1980, 1997; Zuchiewicz, 1987, 1995). The Wołosaty River valley belongs to one of the secondary depressions that are aligned perpendicularly to the uplifted structures. This depression is characterised by predominance of alluvial river reaches, the lack of more prominent breaks of slope, and poorly marked, lithologically-controlled gap and basin-like segments (Hen-

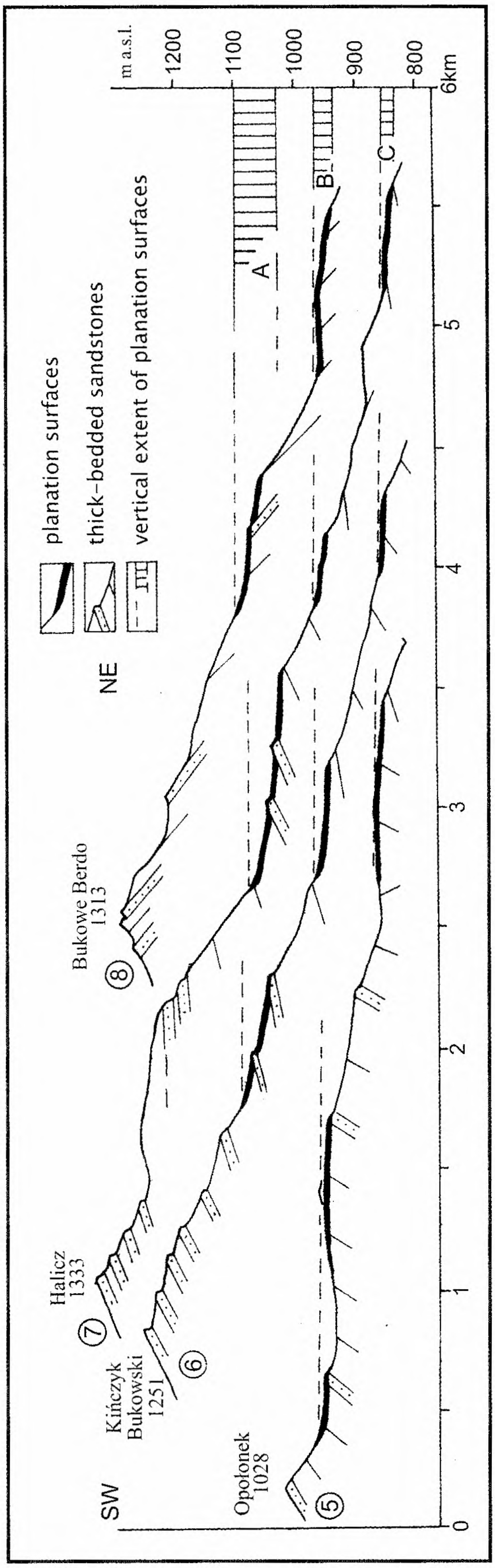

Fig. 4. Planated surfaces of the intramontane (A), foothills (B), and riverside (C) levels shown on profiles of side ridges of the Połoniny Range (NW slope). For profile numbers – see Fig. 1

kiel, 1997). Quaternary activity of elevated and subsided structures in the study area has probably resulted in local drainage pattern changes (Pękala, 1971, 1997; Henkiel, 1977; Zuchiewicz, 1987).

The activity of young uplift has usually been reconstructed basing on a study of remnants of planation surfaces. In the Outer West Carpathians, the intramontane, foothills, and riverside levels have been distinguished (Pękala, 1966, 1971, 1997; Starkel, 1972; Henkiel, 1977, 1980, 1997), whereas in the Ukrainian Carpathians the number and nomenclature of planated surfaces are different (Teisseyre, 1928; Cys, 1966; Gofshtein, 1979; Demediuk, 1983; cf. Fig. 3). All these levels reveal inconsistencies in altitudinal position, usually interpreted as resulting from fault rejuvenation. A good example is provided by a nearly 100-m-high drop in elevation of the riverside level on either side of the Halicz fault in the Upper Wołosatka River valley (Henkiel, 1977, 1997), or *ca.* 80-m-high drop in elevation of the intramontane level on the Wołosaty fault, in NW part of the Bukowe Berdo and Szeroki Wierch Mts. (Pękala, 1971, 1997).

PLANATED SURFACES UPON INTERFLUVES AND SLOPES

The studied portion of the Bieszczady Mts. reveal numerous flat areas occurring upon slopes, although of usually small dimensions. Landforms of this type do also show different altitude, making their assignment to commonly distinguished "planation surfaces" difficult. Assuming planation origin of these surfaces, one can distinguish three planated levels which are overtopped by flat ridge-top areas and/or monadnocks. I am inclined to call planated surfaces only those fragments of ridges and slopes whose surfaces are relatively vast, are clearly less inclined as compared to the neighbouring areas, and belong to a series of similarly developed surfaces of comparable altitudes, irrespective of the underlying bedrock. These surfaces usually truncate beds of variable resitance to erosion (discordant surfaces); and rarely are structurally-controlled (accordant surfaces), following gentle dip of the underlying strata (e.g., in the northern part of Szeroki Wierch Mt., and upon Jeleniowate and Wołowy ridges; cf. Fig. 4).

The spatial pattern of slope and ridge planated areas, probably representing ancient intramontane, foothills, and riverside planation surfaces, is shown on Figure 2. All the flat surfaces portrayed on the map have been considered planation surfaces, despite strong rejuvenation of most of them. Such a pattern follows the classification and spatial distribution of planated surfaces accepted by Pękala (1966, 1971, 1997) and Henkiel (1977, 1980, 1997). Locally, this picture has been supplemented or modified by the results of recent geomorphic studies, and in the SE part (headwater segment of the San River drainage basin up to the Roztoki stream) it is based on recently completed mapping.

Remnants of the *intramontane level* (950–1,150 m a.s.l.) in the Połoniny Range are probably represented by broad, flat ridge-top fragments of the Szeroki Wierch, Tarnica, Bukowe Berdo, Halicz and Wołowy Mts., rising 350–500 m above the San and Wołosatka-Wołosaty River beds.

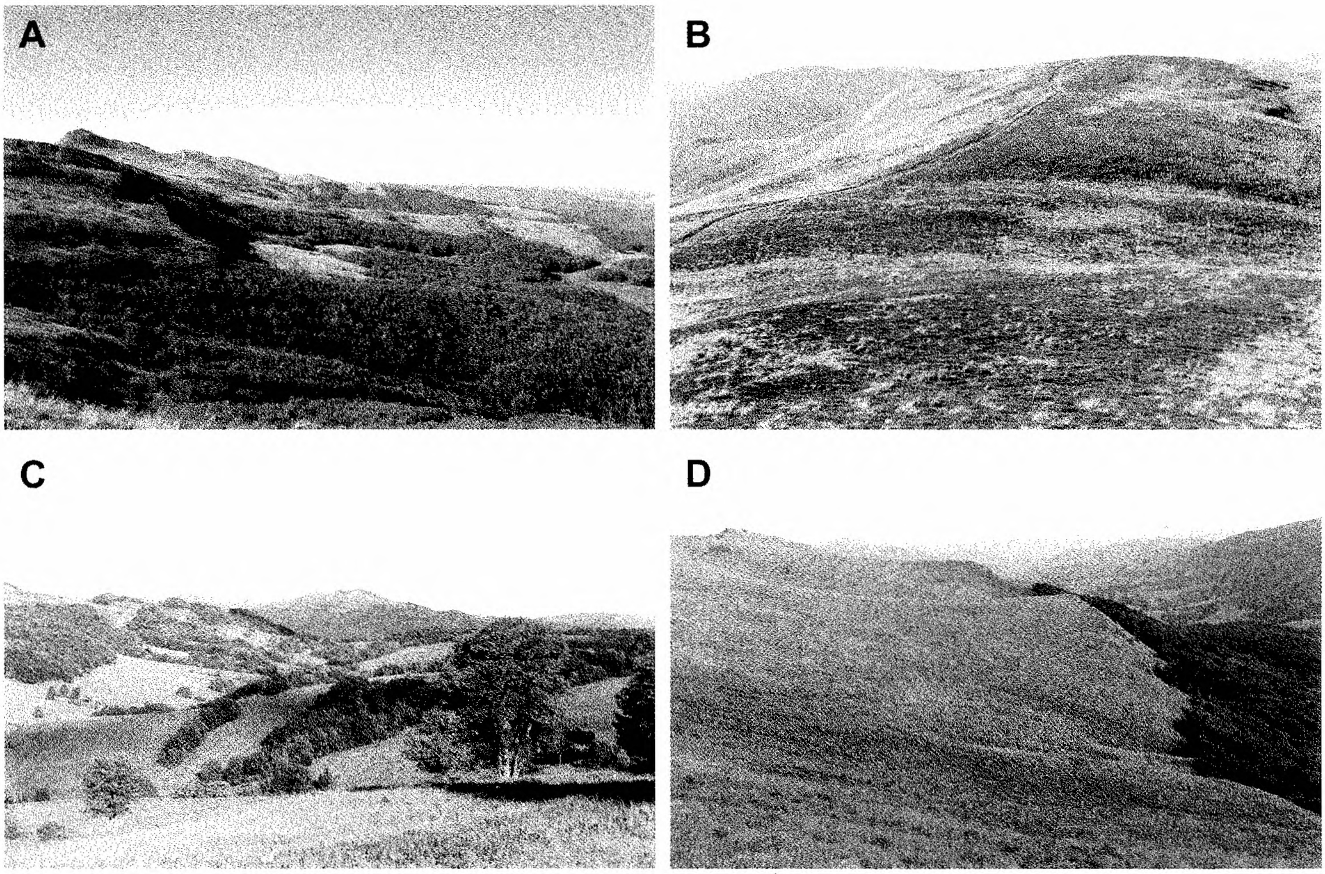

Fig. 5. Examples of planated surfaces in the High Bieszczady Mts.: **A** – intramontane level upon the NE slopes of Halicz and Kopa Bukowska (Połoniny Range) mountains; **B** – ridge-top surface of the northern part of Szeroki Wierch (Połoniny Range), as well as Wielka and Mała Rawka mountains (Pasmo Graniczne Range in the background on the left); **C** – flat surfaces related to the foothills level around Wyżniańska Pass (intra-Bieszczady Depression). Szeroki Wierch and Tarnica mountains visible in the background; **D** – structurally-controlled flat surface upon a sandstone ridge in the Połonina Wetlińska Range. Note Pasmo Graniczne Range showing a flat base of slope (foothills level) on the left. (Fig. 5A – by G. Haczewski)

These surfaces show features typical for a pediment, are up to 0.5 km wide, and inclined towards the neighbouring valleys at 4–8°. The surfaces are separated from the San and Wołosatka River valleys by a distinct erosional escarpment. The morphology of such surfaces is characterised by rows of rocky steps or minor monadnock ridges that have been denudationally exhumed during earlier phases of their development. The best preserved fragments of such a pediment occur on the NE slopes of Kopa Bukowska-Halicz-Wołowy ridges (Fig. 5A). A pass between Tarnica and Krzemień Mts. (1,150–1,200 m a.s.l.) belongs to the same level. In the Pasmo Graniczne Range, this level includes flat ridges of Dział-Mała Rawka, Kańczowa (1,115 m a.s.l.), Semenowe (1,123 m), Chresty (978 m), and Beskid Wołosacki Mts. (1,105 m). The highest-elevated parts of both the ranges (exceeding 1,200 m a.s.l.) are of monadnock-type, and rise up to the ridge-top (Połoniny) level (Teisseyre, 1928; Demediuk, 1983). The ridge-top level includes, *i.a.*, flat ridge surfaces upon Wołowy (1,248 m a.s.l.), Szeroki Wierch (1,243 m) and Wielka Rawka (1,304 m) ridges (Fig. 5B). Erosional remnants, in turn, are represented by cone-like culminations of Halicz (1,333 m a.s.l.), Kopa Bukowska (1,320 m), Tarnica (1,346 m), Krzemień (1,335 m), and Bukowe Berdo (1,313 m; cf. Figs. 4, 6).

The *foothills level* is lower than the intramontane level by *ca.* 150–200 m, and rises at 800–950 m a.s.l. (up to even 1,000 m a.s.l.). It is composed of flat areas occurring upon interfluves of transversal ridges of the Pasmo Graniczne and Połoniny Ranges (200–270 m; Fig. 4), as well as upon interfluves in the intra-Bieszczady Depression (Nad Berehami and Wyżniańska Passes; 150–250 m.; cf. Fig. 5C). Fragments of this level can also be found upon Jeleniowate (850–900 m a.s.l.), Muczne (850–880 m a.s.l.), and Piniaszkowy Mts. (900–950 m a.s.l.), as well as numerous flat segments upon the W–E-orientated slope of the Połonina Bukowska and Kińczyk Bukowski Mts. (900–950 m a.s.l.). Its inclination towards the San River valley averages at 5°, increasing slightly above the Wołosatka River headwaters up to 7–10°.

The most extensive and numerous are remnants of the *riverside level* (740–850 m a.s.l.). They occur on the Wołosatka and Rzeczyca River valley sides, between Beskid and Wyżniańska Passes, as well as in the Upper San River valley, between headwaters and the mouth of the Roztoki stream. Its extensive fragments are preserved upon the NE slopes of Jeleniowate range (Fig. 6). Traces of this level protrude along the Wołosatka and San River valleys up to two transversal passes in the Bieszczady Mts., *i.e.*, the

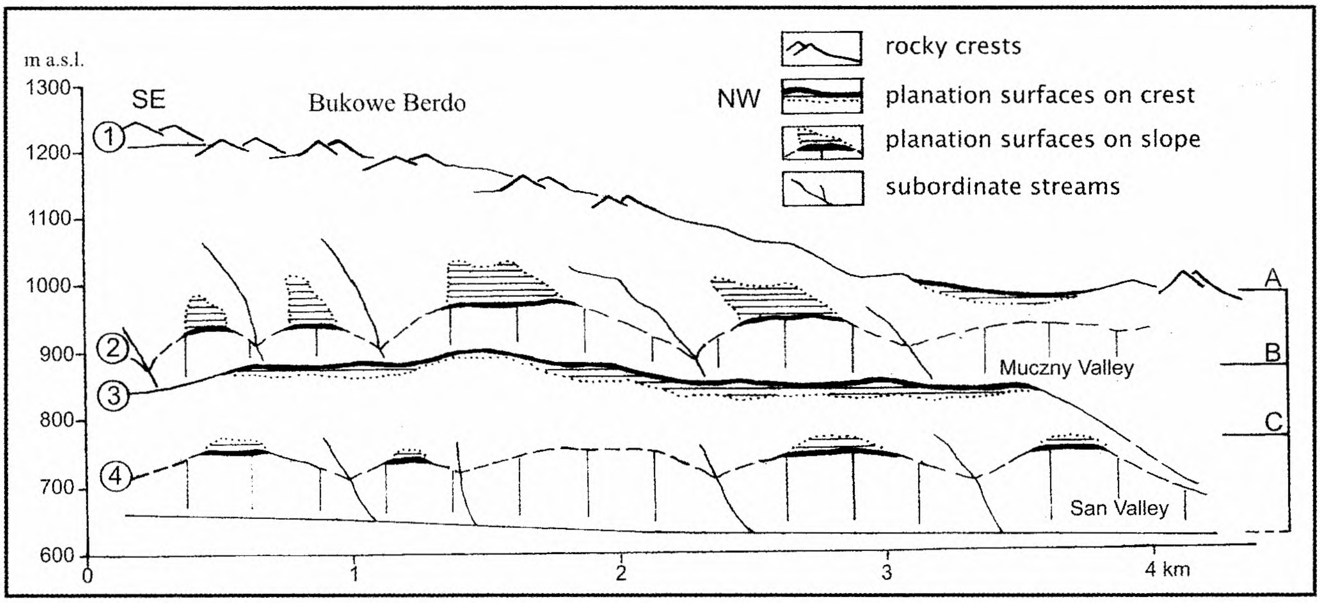

Fig. 6. Planated surfaces upon the ridges of Bukowe Berdo (1) and Jeleniowate (3), and on their slopes (2, 4). Levels A, B, and C as on Fig. 4

Użocka Pass (858 m a.s.l.) and Beskid Pass (785 m a.s.l.). Narrow shelves of this level can also be found within major transveral valleys (Wołosaty, Roztoki, Muczny), their inlination usually attaining 3–6°, and dropping to 2–4° close to the Użocka Pass only. Elevations above river valley bottoms are variable (30–100 m), diminishing towards thalwegs and passes. Higher elevations occur in a gap section of the Wołosaty River in the Połoniny Range, whereas within subsequent valleys the level attains lower elevations. At Wołosate, the riverside level has been transformed in the Pleistocene into a *"glacis"*, whereas at Ustrzyki Górne it was overlain in Elsterian time by fluvial sediments (Pękala, 1966, 1971; Henkiel, 1972).

The hypsometry of planated surfaces along the 15-km-long segment of the Wołosatka-Wołosaty River valley is shown on Figure 7. Elevations of individual levels are different in transversal water-gaps (upper Wołosatka, Wołosaty), basin-like segments (Ustrzyki Górne Depression), and within a subsequent segment of the valley between the Beskid Pass and Ustrzyki Górne. Longitudinal profiles of the levels show concave-down lowering around the Ustrzyki Górne Depression, and minor upwarping in the Wołosaty water-gap. Such a tendency is better portrayed by relative elevations of individual levels. As far as the subsequent valley segment is concerned, the riverside level becomes gradually lower, whereas the higher levels maintain comparable elevation, irrespective of the valley slope. Increased concentration of higher levels is to be noted above the Upper Wołosatka River valley. The highest peaks, situated far away from valley bottoms, bear the most extensive and highest traces of ancient landscape.

Relief energy of individual planated levels is clearly greater within older landforms, attaining 50–60 m in the riverside level to 100 m and even 150 m within the foothills and intramontane levels (Figs. 4, 7). Remnants of the foothills level are higher upon the left-hand valley side, whereas the other levels do not show any relationship to the slope aspect. In the San River valley, absolute altitudes of the levels gradually diminish from Halicz Mt. towards the NW. For instance, the foothills level upon the slopes of Kińczyk Bukowski and Halicz Mts. rises at 940–960 m a.s.l., whereas upon the San and Wołosaty (near Stuposiany) River interfluve it slopes down to 840–880 m a.s.l.

PLANATED SURFACES AS STRUCTURALLY-CONTROLLED LANDFORMS

It has been suggested that flat slope segments in the studied portion of the Bieszczady Mts. are purely structurally-controlled, having nothing in common with planation surfaces (Tokarski, 1970, 1975). A good example of step-like arrangement of such flat slope segments is provided by the SW slope of Bukowe Berdo Mt. (Tokarski, 1970). These segments are situated behind cuesta-like landforms that strike parallel one to another on the steep SW slope. Frontal parts of these steps are developed upon exposures of resistant, thick-bedded sandstones and are frequently accompanied by tors. Flat or pan-like stoss sides have been cut into less resistant shale-sandstone flysch beds, and represent subsequent landforms that are separated from the Terebowiec River valley by exposures of sandstone complexes. Longitudinal profiles of such steps on Bukowe Berdo Mt., however, display considerable relief, so flat areas shaped on their stoss sides cannot be linked into coeval levels. Moreover, it is commonly accepted that strong structural control on the morphology of the High Bieszczady Mts., the latter still being in the process of exhumation of the pre-existing structures, is not favourable for preservation of planation surfaces (Starkel, 1969, 1972).

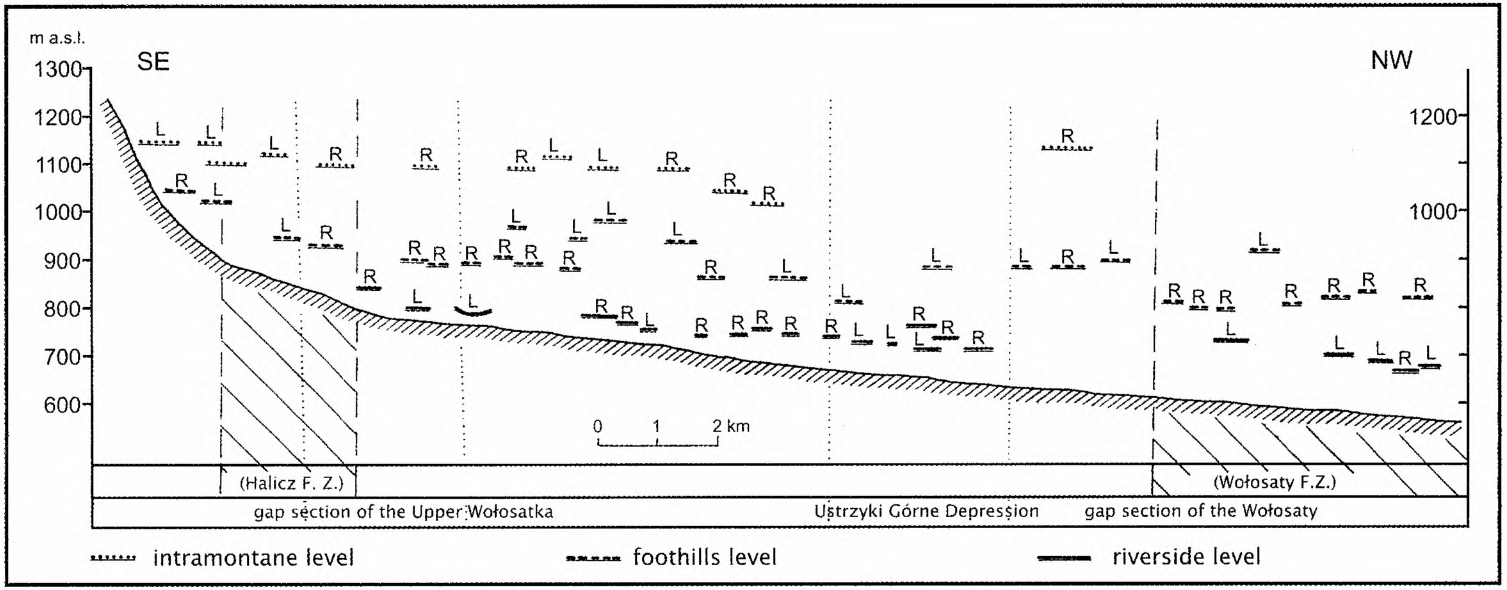

Fig. 7. Hypsometry of flat surfaces occurring on the Wołosatka-Wołosaty River vally sides. L – left-hand valley side; P – right hand valley side; F.Z. – fault zone

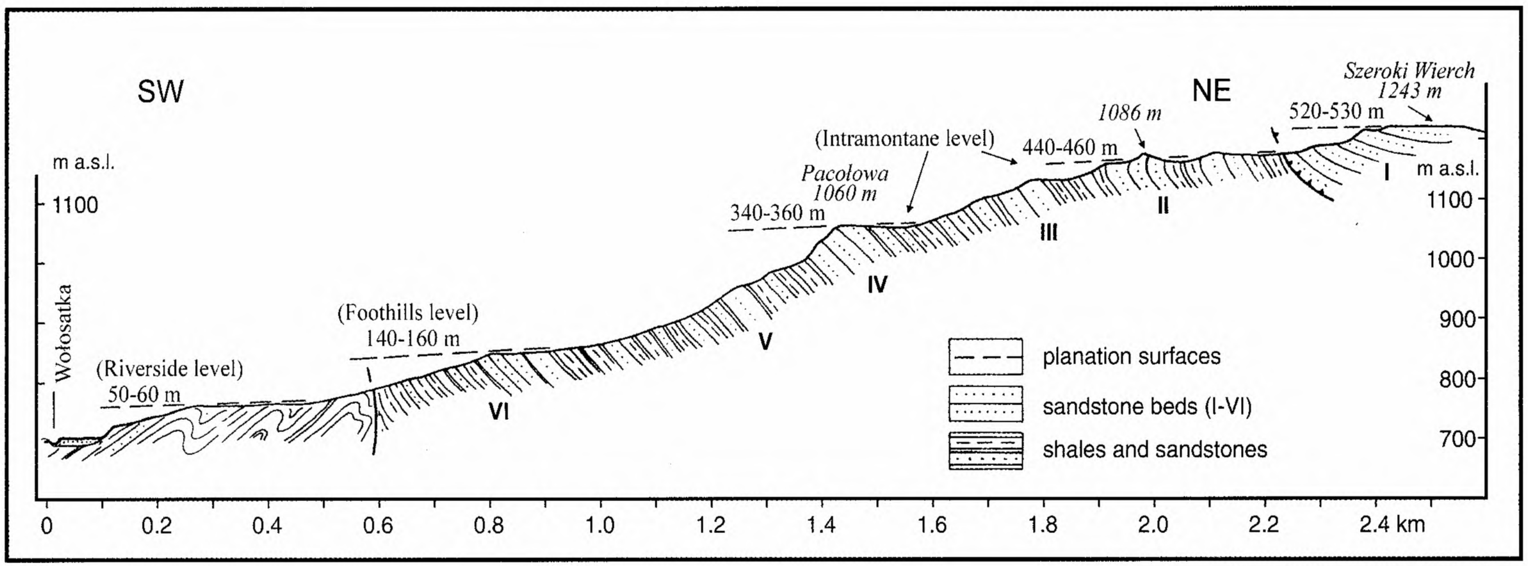

Fig. 8. Profile of the Szeroki Wierch slope (9)

Most of contemporary flat slope segments in the Bieszczady Mts. are indeed structurally controlled like, for instance, those occurring on the SW slope of Szeroki Wierch Mt. (Fig. 8). There occur five thick-bedded Otryt sandstone complexes, separated by sandstone-shale strata (Tokarski, 1975), and unconformably overlain by another sandstone complex that builds the top of the mountain. The latter complex composes an open syncline; the lower sandstone complexes dipping steeply (45–70°) towards the NE. Sandstone beds are marked upon the slope by steep steps being followed farther upslope by gently inclined flat slope segments, whose width depends on the thickness of sandstone complexes, their dip, and position within the lithostratigraphic section. Flat areas become wider with increasing stratigraphic separation and decreasing dip, as those occurring above complexes III and V on Figure 8. At higher dip angles and decreasing stratigraphic separation, flat slope segments become narrower and less smoothed (for instance those above complexes I, II, and IV; Fig. 8). Gentle dip of strata is probably responsible for the presence of extensive ridge top of the Szeroki Wierch Mt. (Fig. 5B). Individual flat steps upon sandstone complexes are elevated at: 150–170 m (up to 100 m in width), 230–240 m (poorly marked), 340–360 m (20–120 m wide), 460–480 m (up to 200 m in width, including tors), and 520–530 m (200–300-m-wide interfluve). Hence, the number of flat slope segments exceeds that of commonly distinguished "planation surfaces". Moreover, beneath flat levels developed upon sandstone complexes, another, 50–60-m-high level occurs which truncates different strata of the Fore-Dukla zone (Pękala, 1969; Henkiel, 1972). This level probably represents a planation episode associated with te so-called riverside level. Therefore, it is difficult to assign all the higher-elevated flat slope segments to a given "planation surface". The SW slope of Bukowe Berdo Mt. also shows a composite profile (Tokarski, 1970), being dominated by flat segments developed upon thick-bedded sandstone complexes which have been exposed by selective erosion. The number of such segments is greater than that of planated levels. However, the increased number of flat surfaces versus planated levels upon the slope of Szeroki Wierch Mt. is of different origin than in case of Bukowe Berdo Mt. (see Discussion below).

Elevation differences observed in longitudinal profiles of planated surfaces need not have to be a result of young faulting. Examples described by Tokarski (1970, 1975) from slopes of the Bukowe Berdo Mt. clearly document structural control. Flat slope segments, shaped upon thick-bedded sandstone complexes, could have developed along the exposures of the latter; hence, altitudinal position of "planated levels" is a mere result of intersection of sandstone complexes with the slope surface (Fig. 5D). Since the continuity of sandstone strata is disturbed upon fault zones, elevation differences of flat slope segments are also the greatest along these faults, what does not necessarily imply fault reactivation. This applies to places indicated by Henkiel (1977, 1997) and Pękala (1997), where elevation differences on either side of a fault attain 80–100 m. The alleged young throws of 100 m would then be greater than relative elevation of the riverside level. Moreover, the older levels in the same fault zone do not show comparable differences.

DISCUSSION

The remnants of flat surfaces preserved upon ridges and slopes in the study area show a step-like arrangement, individual steps being represented by both planation surfaces and gentle, stoss sides of structural cuesta-like steps. The latter compose a denser pattern of steps which attain the highest elevations in the upper parts of slopes (NE slopes of Kińczyk Bukowski, Halicz, SW slopes of Połonina Wetlińska and Połonina Caryńska Mts.), and upon very steep, isoclinal slopes (*i.a.*, SW slopes of Bukowe Berdo, Szeroki Wierch, Magura Stuposiańska Mts.). The shaping of structurally-controlled steps has been aided by different bedrock resistance to denudation, and the entire set of cuesta-like landforms could have easily developed at the same time (Fig. 9). Therefore, flattened stoss sides of the majority of

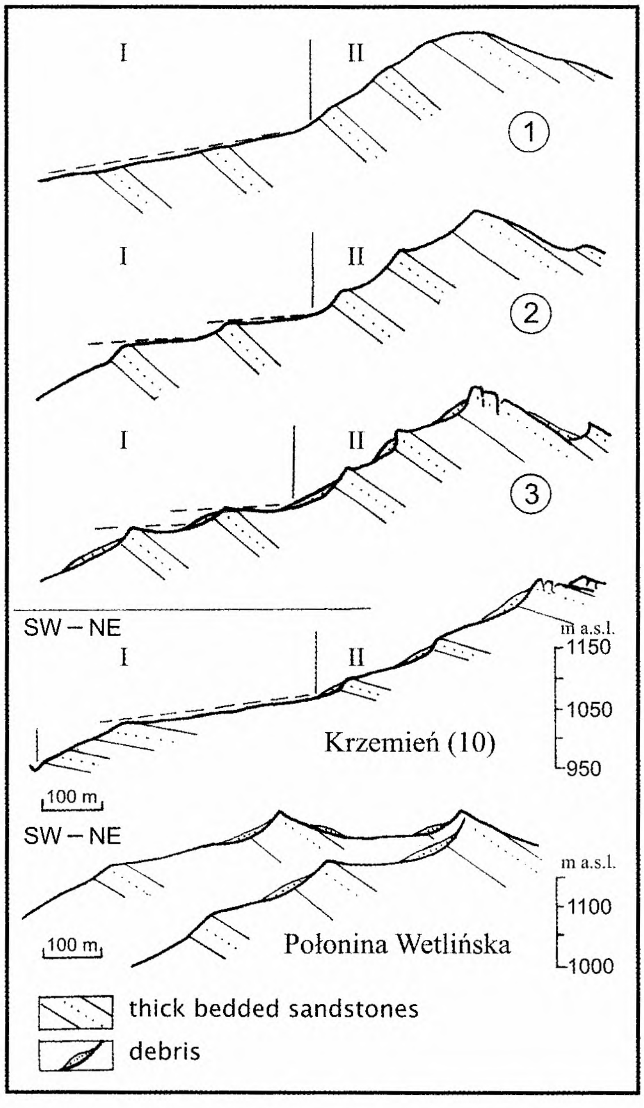

Fig. 9. Morphological evolution of the planated surface (I) and monoclinal ridge (II), starting from an incipient stage (1), through a phase of exposure of more resistant rocks (2), up to their Pleistocene transformation (3). Contemporary slope profiles of the Krzemień (10) and Połonina Wetlińska ridges (close to the NW corner of Fig. 1) are also shown

cuestas occurring on Kińczyk Bukowski and Bukowe Berdo Mts. cannot represent coeval planation surfaces.

The processes of selective denudation have also been ubiquitous within planated surfaces themselves. Small inclination of such surfaces has delayed the rate of exhumation of more resistant rocks; hence, the resulting landforms are usually small-scale ones. Most of these surfaces have largely been modified by minor, structurally-controlled landforms. Planated surfaces underlain by isoclinal sandstone complexes reveal the presence of low monadnock-like ridges; although the surfaces tend to attain comparable elevation (Halicz-Kopa Bukowska Mts.; cf. Fig. 5A). Gentle dip of strata favoured formation of cuesta-like landforms which subdivide the primary surface into two levels. One can explain in this way the uneven surface of the "intramontane level" and its locally marked two-tier arrangement. A good example is provided by a fragment of the intramontane level preserved upon Szeroki Wierch Mt. This level originally represented an accordant pediment, whose surface became subsequently remodelled by exposing resistant sandstone beds and shaping cuesta-like steps. At present, the former pediment surface forms two levels (340–360 m and 460–480 m above the Wołosatka River valley) that are separated by young steps underlain by sandstone complexes I and II (Fig. 8). The lower level (340–360 m) shows a more denuded surface, although replacing the initial landform and, despite lower elevation, constituting a part of the ridge-top level. Comparable origin and profile reveal flat surfaces of similar elevation on the NW slope of Wołowe ridge.

The younger, foothills level displays similar relief modification, although of smaller dimension (e.g., upon the SW slopes of Rozsypaniec-Połonina Bukowska ridges. Flat surfaces of the riverside level have largely preserved their original shape. They are relatively smooth and build only one level, being only locally covered by alluvial sediments deposited during the first Pleistocene cooling, or altered into glacis-like surfaces (Pękala, 1966; Henkiel, 1972). Despite relief rejuvenation, such surfaces can be considered planation surfaces, since they have not lost their identity upon slopes of the Bieszczady Mts. Their rejuvenated parts are not exactly the original planated surfaces, but showing similar development throughout the entire level, and still marked in the slope relief. At present, the most extensive and nearly horizontal are interfluves of the northern part of Szeroki Wierch (1,240–1,243 m a.s.l.), Chresty-Kańczowa (980–1,000 m), Jeleniowate (860–880 m), and Kiczera Sokolicka (780–820 m) Mts. These landforms can be considered hypsometric representatives of the Połoniny (ridge-top), intramontane, foothills, and riverside levels.

When analysing the present-day pattern of planated ridges and slopes, one should also take into account the time that has elapsed since their formation. During this timespan, denudation-controlled separation of more resistant sandstone complexes took place (Fig. 9), together with general lowering of the pre-existing landscape. The older and more longer remodelled planated surfaces are, the more uneven they become. It is commonly accepted that planated surfaces originated before the first Pleistocene cooling (Fig. 3), although periglacial remodelling must have had a bearing on their development. Denuded steps and sandstone minor ridges provide material accumulated within grus covers, and solifluction processes transported weathering material down the slope. At that time, another type of flat surfaces could have been formed in the highest parts of the Bieszczady Mts., *i.e.* cryoplanation terraces (Baumgart-Kotarba, 1971; Ziętara, 1995).

It seems likely that lithological differentiation of the bedrock has markedly controlled not only the preservation of planated surfaces, but also their subsequent rejuvenation. Flat surfaces of the intramontane level have only been preserved due to the presence of underlying thick-bedded sandstones, whose exposures formed a barrier to degradation proceeding from the surrounding valleys. Resistant bedrock exposures build frontal parts of steps, behind which poorly remodelled fragments of a planated surface could have survived. This applies particularly to long, gentle, and sparsely drained slopes, *i.a.*, in the upper parts of Szeroki Wierch, Halicz, and Wołowy Mts. Older planated surfaces could have not survived upon exposures of less resistant rocks or at places which have not been protected by thick sandstone complexes.

Relief energy of the planated ridges and slope fragments can also result from their present-day position in respect to the ancient valley axis. Planated surfaces which have developed laterally, progressively away from the axes of large valleys, were inclined towards the thalwegs. Proceeding farther upslope and upstream, their elevation tends to increase. The preserved remnants of planated surfaces did not have to be the most distant ones in respect to the ancient valleys. Proceeding upstream, these planated levels display convergence, particularly well visible close to the majority of the Bieszczady passes. For instance, the riverside level protruding upstream the San, Wołosatka or Rzeczyca River valleys shows increasing absolute altitudes, approaching those of the foothills level.

CONCLUSIONS

1. The slopes and interfluves of the High Bieszczady Mts. bear flat surfaces representing fragments of both planation surfaces (intramontane, foothills, riverside levels), and numerous flat areas developed on stoss sides of structurally-controlled steps. Planated surfaces are better preserved upon the side transversal ridges, whereas structural steps tend to dominate upon steep slopes and highest-elevated parts of the main longitudinal ridges.

2. The topography of planated surfaces, and particularly of the intramontane level, has been largelly remodelled by denudation. Relief rejuvenation has been structurally-controlled, depending on local differences in bedrock resistance to erosion and the attitude of beds. Smooth surfaces have only been preserved upon the riverside level.

3. As a result of rejuvenation of older planated surfaces, detailed reconstruction of altitudinal changes of their long profiles is difficult. Local changes in relief energy could have resulted either from young tectonic movements, poor preservation upon the slope, or bedrock structure (e.g., changeable attitude of sandstone complexes).

4. Proceeding downstream the Wołosatka-Wołosaty River valley, only the riverside level tends to diminish its elevation, whereas the other levels do not show such a trend displaying, in turn, higher vertical extent of individual planated fragments.

5. The most extensive and elevated are planated surfaces overtopping the upper reaches of the Wołosatka River valley, surrounding the highest summits of the Bieszczady Mts., and situated most distant to erosional bases of the San and Wołosatka Rivers.

An analysis of morphological properties of the studied flat surfaces upon ridges and slopes of the Bieszczady Mts. leads to a general conclusion that traces of young tectonic processes are very difficult to recognise. These surfaces are mostly structurally controlled. It seems likely that neotectonic impact upon morphology of the area can only be reconstructed on a regional and not local scale.

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REFERENCES

Baumgart-Kotarba, M., 1971. Cryonival features of flysch ridge crests in the Carpathians. *Studia Geomorphologica Carpatho-Balcanica*, 5: 199–210.

Baumgart-Kotarba, M., 1983. Channel and terrace formation due to differential tectonic movements (with the eastern Podhale basin as example). (In Polish, English summary). *Prace Geograficzne IGiPZ PAN*, 145: 1–119.

Cys, P. N., 1966. Geomorfologiya. (In Russian). *Gieologia SSRR*, 48: 441–464.

Demediuk, N. S., 1983. Planation surfaces in the Ukrainian Carpathians and in their promontories. (In Russian, English summary). *Studia Geomorphologica Carpatho-Balcanica*, 16: 3–14.

Gofshtein, I. D., 1979. Neotektonika zapadnoy Volhyno-Podolii. (In Russian). *Naukova Dumka*, Kiev: 1–158.

Haczewski, G., Bąk, K. & Kukulak, J., 1998. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, arkusz Dźwiniacz Górny (1069).* (In Polish). Unpublished explanations to geological map. Polish Geological Institute, Warszawa- Kraków.

Haczewski, G., Bąk, K., Kukulak, J., Mastella, L. & Rubinkiewicz, J., 2001. *Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, arkusz Ustrzyki Górne (1068).* (In Polish). Unpublished explanations to geological map. Polish Geological Institute, Warszawa-Kraków.

Henkiel, A., 1972. Pleistocene denudation flats in the Carpathians. (In Polish, English summary). *Annales UMCS, Sec. B*, 27: 47–66.

Henkiel, A., 1977. The origin of the relief of the Polish Flysch Carpathians. (In Polish, English summary). *Annales UMCS, Sec. B*, 32-33: 1–35.

Henkiel, A. 1980. Structural relief of the Carpathian Mountains. (In Polish, English summary). *Annales UMCS, Sec. B*, 32/33: 37–88.

Henkiel, A., 1997. Geomorphological microregions of the Polish Bieszczady Mountains. (In Polish, English summary). *AnnalesUMCS, Sec. B*, 52: 133–145.

Klimaszewski, M., 1948. Polish West Carpathians in the Ice Age. (In Polish, English summary). *Acta Univ. Vratisl.*, Ser. B, 7: 1–236.

Klimaszewski, M., 1987. O rozwoju geomorfologicznym Karpat Polskich. (In Polish). *Przegląd Geograficzny*, 41: 405–419.

Klimaszewski, M., 1988. *Rzeźba Tatr Polskich.* (In Polish). Państwowe Wydawnictwo Naukowe, Warszawa, 660 pp.

Koszarski, L., Ślączka, A. & Żytko, K., 1961. Stratygrafia i paleogeografia jednostki dukielskiej w Bieszczadach. (In Polish). *Kwartalnik Geologiczny*, 5.

Książkiewicz, M., 1972. Karpaty. (In Polish). In: Pożaryski, W. (Ed.), *Budowa geologiczna Polski*, T. 4, cz. 3, *Tektonika.* Wyd. Geol., Warszawa, 228 pp.

Kukulak, J., 1991. Influence of tectonics on ridge levels development in the western Podhale. (In Polish, English summary). *Folia Geographica, series geographica-physica*, 22: 87–102.

Opolski, Z., 1933. O stratygrafii warstw krośnieńskich. (In Polish). *Sprawozdania Państwowego Instytutu Geologicznego*, 7 (4): 565–636.

Pękala, K., 1966. The influence of local base levels of the formation of terrace systems (as exemplified by the Wołosaty river basin). (In Polish, English summary). *Annales UMCS, Sec. B*, 21: 185–219.

Pękala, K., 1971. The pre-Quaternary relief elements in the Upper San Basin in the Bieszczady. (In Polish, English summary). *Annales UMCS, Sec. B*, 26: 219–230.

Pękala, K., 1997. Rzeźba Bieszczadzkiego Parku Narodowego. (In Polish). *Roczniki Bieszczadzkie*, 6: 19–38, Ustrzyki Dolne.

Starkel, L., 1965. Geomorphological development of the Polish Eastern Carpathians (upon the example of the Upper San basin). (In Polish, English summary). *Prace Geograficzne IG PAN*, 50: 1–160.

Starkel, L., 1972. Karpaty Zewnętrzne. (In Polish). In: Klimaszewski, M. (ed.), *Geomorfologia Polski*, T. 1. Państwowe Wydawnictwo Naukowe, Warszawa: 52–115.

Starkel, L., 1985. Controversial opinions on the role of tectonic movements and climatic changes in the Quaternary evolution of the Polish Carpathians. *Studia Geomorphologica Carpatho-Balcanica*, 19: 45–60.

Ślączka, A., 1971. The geology of the Dukla Unit. (In Polish, English summary). *Prace Instytutu Geologicznego*, 63: 203–267.

Ślączka, A., 1985. Geology of Polish part of Fore-Dukla Zone and Dukla Unit. *Guide to Exc. 4, 13th Congres Carpatho-Balkan Geological Association.* Geological Institute, Kraków: 64–85.

Ślączka, A. & Żytko, K., 1978. *Mapa geologiczna Polski 1:200 000, ark. Łupków.* (In Polish). Wydawnictwa Geologiczne, Warszawa.

Świdziński, H., 1953. Karpaty fliszowe między Dunajcem a Sanem. (In Polish). *Regionalna Geologia Polski*, t. 1, *Karpaty*, z. 2, *Tektonika.* Polskie Towarzystwo Geolologiczne, Kraków: 326–418.

Teisseyre, H., 1928. La surface des faites des Karpates. (In Polish, French summary). *Prace Geograficzne wydawane przez prof. E. Romera*, 10: 67–112, Lwów.

Tokarski, A. K., 1970. The relief of south-western slopes of the Bukowe Berdo on the background of the geological structure. (In Polish, English summary). *Studia Geomorphologica Carpatho-Balcanica*, 4: 249–258.

Tokarski, A. K., 1975. Geology and geomorphology of the

Ustrzyki Górne area (Polish Eastern Carpathians). (In Polish, English summary). *Studia Geologica Polonica*, 48: 1–90.

Ziętara, T., 1995. Rozmieszczenie i rozwój teras krioplanacyjnych w Karpatach fliszowych. (In Polish). In: Późnoczwartorzędowy rozwój rzeźby i zmiany środowiska przyrodniczego. *Wydawnictwo Uniwersytetu im. Adama Mickiewicza*, Poznań: 42–44.

Zuchiewicz, W., 1983. Neotectonic phases in the Carpathians: a review. *Bulletin of the INQUA Neotectonics Commission*, 6: 14–23.

Zuchiewicz, W., 1984a. Neotectonics of the Polish Carpathians: facts and doubts. *Studia Geomorphologica Carpatho-Balcanica*, 17: 29–44.

Zuchiewicz, W., 1984b. Evolution of views on origin and age of Carpathian planation surfaces. (In Polish, English summary). *Przegląd Geologiczny*, 8-9: 468–477.

Zuchiewicz, W., 1987. Tectonics and climate versus relief evolution: old controversy and new arguments. *Studia Geomorphologica Carpatho-Balcanica*, 21: 183–202.

Zuchiewicz, W., 1991. On different approaches to neotectonics: A Polish Carpathians example. *Episodes*, 14 (2): 116–124.

Zuchiewicz, W., 1995. Selected aspects of neotectonics of the Polish West Carpathians. *Folia Quaternaria*, 66: 145–204.

Zuchiewicz, W., 2000. Morphotectonics of the outer East Carpathians of Poland in the light of cartometric studies. *Studia Geomorphologica Carpatho-Balcanica*, 34: 5–26.

Zuchiewicz, W. & Henkiel, A., 1993. Orientation of Late Cainozoic stress field axes in the light of joint pattern analysis in SE part of the Polish Carpathians. (In Polish, English summary). *Annales UMCS, Sec. B*, 48: 311–348.

Żytko, K., 1968. *Budowa geologiczna Karpat między dorzeczem Strwiąża a Wetliną w Bieszczadach.* (In Polish). Unpublished report, Archiwum Państwowego Instytutu Geologicznego, Oddział Karpacki, Kraków.

Żytko, K., 1985. Some problems of a geodynamic model of the Northern Carpathians. *Kwartalnik Geologiczny*, 29: 85–108.

Streszczenie

NEOTEKTONIKA A POWIERZCHNIE ZRÓWNANIA W BIESZCZADACH WYSOKICH (POLSKIE KARPATY ZEWNĘTRZNE)

Józef Kukulak

Bieszczady Wysokie w dorzeczu górnego Sanu i Wołosatego mają rzeźbę wybitnie strukturalną (Fig. 1). Potwierdza to nie tylko równoległe ułożenie walnych grzbietów (Pasma Połonin i Graniczne) oraz obniżeń (Dolina Sanu, Obniżenie Śródbieszczadzkie), ale również układ form drugorzędnych (grzęd twardzielcowych, progów stokowych, subsekwentnych obniżeń, przełęczy) w ich obrębie. W strefach wododzielnych najwyższych pasm, w znacz- nym oddaleniu od rzek, przetrwały do dziś również relikty rzeźby planacyjnej. Są nimi wyrównane wierzchowiny grzbietów podłuż- nych i spłaszczenia na grzbietach poprzecznych, rzadziej na sto- kach. Mają one układ schodowy, nawiązując do 3 (4) poziomów dawnej planacji Bieszczadów (Fig. 2, 3).

Najliczniej występują spłaszczenia stoków w poziomie dolinnym (30–100 m), które w profilu podłużnym poziomu ujawniają najmniejsze deniwelacje (50–60 m). Poziom ten wnika w górę doliny Sanu i jego większych dopływów (Wołosatki-Wołosatego i Rzeczycy) aż do transkarpackich przełęczy (Użocka, Beskid). Poziom pogórski (150–270 m) zachował się obszernie na poprzecznych garbach w Obniżeniu Śródbieszczadzkim i na grzbiecie Jeleniowatego, a na stokach nawiązują do niego wąskie spłaszczenia (Fig. 4). W poziomie śródgórskim (350–500 m) występują spłaszczenia wokół najwyższych szczytów Bieszczadów (Fig. 4–6). Deniwelacje profili podłużnych obu wysokich poziomów sięgają 100 m, pojedynczo nawet 150 m (Fig. 7). Nachylenie obu poziomów wykazuje niewielką zgodność z obecnym kierunkiem spadku Wołosatki.

Rozmieszczenie spłaszczeń na stokach wykazuje znaczne uwarunkowania strukturalne. Na stokach Pasm Granicznego i Połonin większość spłaszczeń zachowała się na pakietach piaskowcowych lub na warstwach łupkowo-piaskowcowych, ale za zasłoną tych pakietów. Powierzchnie planacyjne mają rzeźbę odmłodzoną. Przekształcenie tych powierzchni przez procesy degradacyjne w czwartorzędzie przebiegało głównie w nawiązaniu do lokalnego zróżnicowania litologiczno-odpornościowego i położenia warstw. Pakiety gruboławicowych piaskowców zostały wypreparowane w postaci grzęd lub progów typu kuest, powodując lokalny podział starszych powierzchni (śródgórskiej i pogórskiej) na dwa poziomy (Szeroki Wierch; por. Fig. 8). Usytuowanie spłaszczeń strukturalnych na stokach stromych (Bukowe Berdo, Magura Stuposiańska) i w partiach szczytowych (Kińczyk Bukowski) nawiązuje do wychodni pakietów piaskowcowych na powierzchniach stoków.

Ślady ruchów neotektonicznych w obecnej konfiguracji płaskich wierzchowin i spłaszczeń stoków są mało przejrzyste, ponieważ struktura wydaje się być czynnikiem decydującym o rozwoju rzeźby tego obszaru (Fig. 9). Postulowane przez wielu autorów wypiętrzanie neotektoniczne Pasm Połonin i Granicznego przejawia się głównie ich wyniosłością nad doliną Sanu i Wołosatki (400–600 m).