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RELIEF AND DEPOSITS OF EROSIONAL-DENUDATIONAL VALLEYS IN THE CARPATHIAN FOOTHILL REGION – THE WIŚNICZ FOOTHILLS

Abstract: The paper discusses variances in the relief of erosional-denudational valleys that are scattered across the woodland areas of the threshold of the Carpathian foothill region – in the Wiśnicz Foothills. Relief in the study area was characterized via geomorphological mapping and analyses of cartographic materials such as a LIDAR DEM. The paper also discusses valley types and valley morphometry along with the diversity of morphogenetic processes occurring in the study area. Deposits forming the floors of the studied valleys were also characterized through the use of 12 geologic drilling sites. The resulting data included the deposit grain size range and degree of deposit sorting. In the section on the analysis of present-day relief and relief evolution, the research focuses on the joint action of landslides and fluvial erosion. The following sequence of valley types is discussed for the main valleys presented in the study: denudational trough or gully, active V-shaped valley, V-shaped valley with a flat accumulation floor – found near the mouth of the watercourse. Active V-shaped valleys are characterized by the presence of short but numerous valley sections featuring predominant downcutting erosion or small, local accumulation zones. In this case, the presence of these sections is determined by the intensity of landslides on hill slopes in the studied valley, influx of material from tributary valleys, erosional capacity of local streams, and the presence of woody or rock steps in stream channels. The characteristics of deposits composing valley floors, described in the present study, indicate large differences in deposition process energy and short-distance transport of mineral-type material in stream channels. Research has shown significant complexity of regional factors and local factors affecting the evolution of small erosional-denudational valleys in forested areas in the southern part of the Wiśnicz Foothills. The location of the study area in the Silesian unit overthrust associated with the presence of a visible morphologic threshold, the middle foothills threshold, leads to significant, local differences in elevation, high degree of hill slope fragmentation, high activity of morphogenetic processes, and also affects the impact of these processes on deposits forming the floor of the studied valley.

Keywords: erosional-denudational valleys, geomorphologic mapping, deposits, Carpathian Foothills

INTRODUCTION

Erosional-denudational valleys are at present an important element of mountain and upland relief as well as Old and Young Glacial areas. Some of the valleys are dry and some feature intermittent runoff, while still others experience a constant but low runoff. These valleys are constantly or periodically shaped and reshaped by linear erosion, in conjunction with other processes such as land sliding, creeping, piping, and windfall. The occurrence and origin, as well as evolution of these valleys have been studied by geomorphologists for many decades since the early 20th century, usually in the course of broader geomorphology research in areas featuring relief shaped under periglacial climate conditions. Interest in the subject increased substantially upon the publication of H. Schmitthenner's (1925) "Della". Geomorphologists began to look more frequently at erosional-denudational valleys (Büdel 1944; Lehmann 1948; Poser 1948; Tricart 1952; Lembke 1954). Polish geomorphologists initially associated these landforms with mass movements in periglacial climate conditions (Dylik 1953, 1956; Jahn 1954, 1956; Klatkowa 1954). Subsequent analysis of previously existing periglacial regions by workers at the University of Łódź focused on the important morphogenetic role of episodic water runoff (Klatkowa 1958, 1964, 1965).

Other studies on areas in northern Poland focused on small valleys slitting moraine plateaus, valley slopes and edges of high terraces, walls of terminal moraines, slopes of paleo-valleys, as well as slopes of subglacial troughs (i.e. Marsz 1964; Churska 1966; Kostrzewski 1971; Paluszkiewicz 2009; Paluszkiewicz, Ratajczak-Szczerba 2013). The abovementioned research studies showed multiple stages of the evolution of small valleys in their key morphometric characteristics and variances in the deposit structure of their floors as well as in proluvial fans. As research methods evolved and improved and new knowledge became available, it became common to focus on the evolution of Holocene erosional-denudational valleys; in particular on the high significance of human impact on valley evolution (i.e. Twardy 2008; Tylman 2011; Tylman et al. 2011; Jaworski, Juśkiewicz 2014; Micun 2015; Paluszkiewicz 2016; Jaworski 2018; Karasiewicz et al. 2019).

Researchers focused on the evolution of small valleys due to the low resistance of their soil cover and significant human impact, especially in loess areas in Poland as well as Europe in general. Studies focused on these themes are usually dedicated to the subject of denudational troughs in agricultural areas as well as gorges. Papers on the said problems discuss main stages of evolution, key determinants of selected characteristics (i.e. valley slope asymmetry, role of extreme events), and human impact in its various forms (see

Maruszczak 1956; Widacki 1966; Wolnik 1981; Buraczyński 1989; Śnieszko 1995; Rutkowski 1997; Dotterweich et al. 2003; Stankoviansky 2003; Valentin et al. 2005; Vanwalleghem et al. 2006; Kołodyńska-Gawrysiak 2008; Zgłobicki et al. 2014).

Both the characteristics and evolution of small erosional-denudational valleys in the Polish Flysch Carpathians were initially described in the course of research work on other types of landforms and processes. For example, W. Schramm (1925) described the presence of small valley landforms in the upper San river catchment. He called them "gorges," and their origin he associated mostly with piping. H. Teisseyre (1929) noted the role of mass movement processes in the shaping of the relief of slopes and floors of small valleys. The emergence and deepening of small valleys following intense precipitation were described by M. Klimaszewski (1935) and K. Figuła (1955). However, the evolution of small, erosional-denudational valleys in forest zones in the Polish Flysch Carpathians remained a side issue in mainstream research in the Polish geomorphology community for many decades.

A more detailed analysis of these landforms became possible after geomorphologic mapping performed by researchers at Jagiellonian University and the Polish Academy of Sciences (Klimaszewski 1956). One great advantage of the geomorphologic maps created was the presentation of landforms in the context of their origin and chronology of evolution. In the years that followed, more detailed information on the origin, age, and variability of small valleys emerged and helped yield holistic analytical perspectives on the evolution of relief in the Polish Flysch Carpathians (Starkel 1960a, 1972a), other geographic regions (Starkel 1960b, 1965; Lach 1984), and the morphologic effects of extreme events or the activity of selected processes (Ziętara 1968; Galarowski 1976; Bober et al. 1977; Kotarba 1986; Starkel 2011). Research studies showed very large diversity in the type and intensity of processes shaping small valleys at the present time, which is reflected in valley type, valley morphometry, and varying degrees of valley maturity.

However, there exist few papers on the evolution of, and variances in, erosional-denudational valleys across the Carpathian Foothills, and especially their threshold region characterized by large local differences in elevation and lithologic contrasts. Thus far, the only studies that provide a characterization of small valleys in the threshold region of the Foothills are regional papers by L. Starkel (1957, 1960a). The author described a variety of types of erosional-denudational valleys and identified two fundamental stages of their evolution – Pleistocene and Holocene. He also argued that some small valleys fragmenting the slopes of the Polish Flysch Carpathians may be the outcome of the rejuvenation of preexisting periglacial valleys. Furthermore, he noted the presence of joint effects of erosion and mass movement processes in the Holocene evolution of small valleys – and underscored the complexity of the evolution of these landforms, as determined by key local environmental characteristics and the effects of human impact.

The threshold zone of the Carpathian Foothills is a rarely studied region in terms of its relief and evolution of small valleys, especially those in woodland areas. While some older, regional studies do exist, there is a lack of more current studies that would examine this subject in detail. Their results could serve as the starting point for further research on themes in the Quaternary evolution of relief in this particular geographic region.

The aim of the study was to learn about the relief of small erosion-denudation valleys in the southern part of the Wiśnicz Foothills. The goal was to characterize in detail each valley's morphometry, describe the sequence of valley types along longitudinal profiles, and learning about the diversity of the deposits in the valleys floors. Moreover, the joint effects of erosion and mass movement processes were examined in the evolution of each studied valley.

STUDY AREA

The study area consisted of a small system of erosional-denudational valleys in the Wiśnicz Foothills in the southern part of the catchment of the Stara Rzeka – a right-bank tributary of the much larger Vistula river (Fig. 1A). The studied area had a surface area of 0.51 km^2. The studied system of valleys consisted of four larger valleys, numbered I to IV, and numerous, smaller tributary valleys. Small watercourses drain the valleys permanently or intermittently and subsequently join the main river channel of Stara Rzeka. The examined valleys cut through the morphologic threshold of the middle foothills at the front of the Silesian unit overthrust. The maximum elevation of the studied area is 336 m a.s.l., while the lowest elevation is 228 m a.s.l., which is also where the studied small watercourses join the main river channel of Stara Rzeka. Characteristic features of the relief of the study area are landslides that remain active today as well as large differences in hill slope gradients and valley slope gradients (Fig. 1B). Landslide landforms present in the study area discussed in the paper have not been examined until now. Landslide landform types occurring in the Wiśnicz Foothills were discussed in earlier papers on the relief of the Carpathian Foothills threshold – the section between the valleys of the Raba and Uszwica rivers (Michno 1995). Studies on the activity level of a small landslide were also performed in a valley adjacent to the current study area (Zielonka et al. 2014).

In the Stara Rzeka catchment, the threshold of the Carpathian Foothills is composed of two levels. The upper level is situated at elevations from 320 to

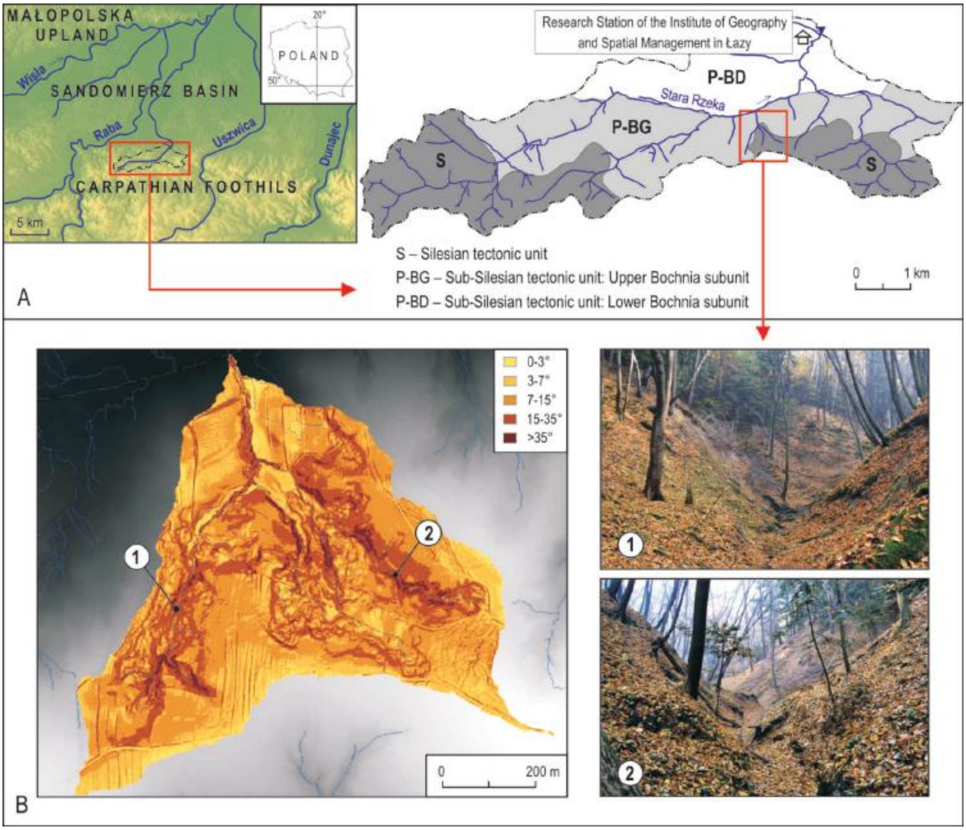

Fig. 1. Location of study area: A – location of study area in the Carpathian Foothills and in the Stara Rzeka catchment area in the context of tectonic units present in the region, B – map of gradients and selected photographs of the studied valleys

340 m a.s.l., with relative heights ranging from 80 to 110 m. It is formed atop resistant sandstone of the flysch Silesian and Sub-Silesian tectonic units, and represents middle foothill relief (Starkel 1972b, 1988; Gilewska, Starkel 1988). The lower level is found at 280 to 300 m a.s.l., with relative heights at 50 to 60 m. Its extent matches that of the Sub-Silesian unit (also known as the Bochnia subunit) which is further divided into two parts – an upper flysch part and a lower, folded flysch and Miocene formations part (Olewicz 1968, 1973). The lower level represents low foothills relief. The study area's Cretaceous-Tertiary parent material is covered with clayey weathering material (regolith) and Quaternary soil cover that includes the following: loess-like deposits (up to 9 m thick), deluvial and proluvial material at the base of a hillslope and on the valley floor, colluvial matter commonly encountered

on hill slopes and on valley slopes affected by landslide activity. The floor of the Stara Rzeka valley is formed of silt and – to a lesser degree – sediments of larger grain size such as sand and gravel. Their total thickness equals 5 to 7 meters (Pietrzak 2002; Stępień 2018).

Loess-like parent material features poorly differentiated soil cover. About 80% of the Stara Rzeka catchment area is covered with *Haplic Luvisols* and *Stagnic Luvisols*. The remaining 20% is covered with deluvial *Cambisols* and *Cambic Fluvisols*. *Eutric Gleysols* occur across small, moist inner-forest areas (Skiba 1992; Skiba et al. 1995). The catchment is dominated by the presence of complex hill slopes with an irregular longitudinal profile featuring an array of concave, convex, and straight sections. The average gradient of hill slopes strongly varies across the study area: 3–10° in the northern section of the catchment, 10–25° in the southern section of the catchment (Święchowicz 1991). Hill slopes herein are fragmented by denudational troughs, V-shaped valleys, gullies, and gorges. The density of the valley network in the Stara Rzeka catchment is 6.0 $km \cdot km^{-2}$.

Hill slopes characterized by higher gradients are covered with complex forest communities (41.86% of the catchment area): mostly oak and hornbeam stands, beech stands, mixed forest dominated by pine stands, riparian forests consisting mostly of alder and ash stands found across valley floors (Stachurska 1995). 14.92% of the studied catchment is occupied by meadows and pastureland, 36.25% is arable land, 2.45% consists of orchards, and 4.52% consists of built-up areas (Żelazny 2005).

The hydrogeology of the study area is very complex, which manifests itself in low groundwater levels. The Stara Rzeka river and tributaries draining its sub-catchments are characterized by a complex discharge regime with culminations in the spring (snowmelt) and summer (rainfall) as well as high fluctuations in river discharge and shortage of river recharge from groundwater sources (Żelazny 2005). Mean monthly discharge in the Stara Rzeka at the Łazy gauging site (Fig. 1A) is 0.18 $m^3 \cdot s^{-1}$. The climate conditions of the study area may be characterized using measurement data from the IGIGP UJ Research Station in Łazy (Fig. 1A). The mean annual air temperature is +8.8°C, while the highest mean air temperature is noted in July (+19°C), and the lowest in January (−1.4°C). The atmospheric precipitation total (averaged over the long term) is 691.6 mm. The highest mean, monthly precipitation totals are recorded in summer (July – 101.4 mm), while the lowest in winter (December and February – 27.3 mm each).

MATERIALS AND METHODS

The research literature was surveyed and cartographic materials were examined as part of the study. The latter were obtained from the Cartography Collection at IGiGP UJ. A LIDAR DEM with a resolution of 0.5 m was used to analyze valley morphometry, create a number of longitudinal profiles and cross sections, and generate gradient maps (Fig. 1B). The DEM was produced using a LAS point cloud in ArcGIS. Fieldwork included mapping of the study area's geomorphology, verification of longitudinal profiles and cross sections, and the drilling of geologic profiles. A total of 12 geologic drillings were performed in the study area (Fig. 2). Each site was drilled to a depth of a maximum of 5 meters (Maciejczyk 2017). The drilling sites – described herein as profiles – were located across local accumulation zones, present close to the mouths of gullies slitting main valley slopes (profiles no. Ł1, Ł2, Ł10), at the base of landslide-affected hill slopes (profiles no. Ł4, Ł7, Ł8), across the floors of active V-shaped valleys (profiles no. Ł6, Ł9), as well as in V-shaped valleys featuring a flat accumulation floor (profiles no. Ł3, Ł5, Ł11, Ł12). Profiles no. Ł1, Ł5, Ł6, Ł7, and Ł9 were selected for the purpose of illustrating differences between deposits as well as the role of erosional and landslide processes in the evolution of the studied valleys. A total of 138 mineral deposit samples were collected from the 12 profiles for laboratory analysis. Granulometric composition was examined using a sieve (with deposits larger than 0.5 mm) and via optical diffraction in the case of deposits smaller than 0.5 mm using a Malvern Mastersizer 3000 device. Next, several basic sedimentological indices were calculated (after Folk, Ward 1957): mean grain diameter (Mz), standard deviation (δ_1), skewness (Sk), kurtosis (KG). Granulometry calculations were done using GRADISTAT 5.11 PL beta software (Blott, Pye 2001). Calcium carbonate and organic material content were also assessed in the studied samples. A field determination method was used for the former – a $CaCO_3$ content approximation based on the intensity of the chemical reaction of the collected deposits with 10% HCl (Konecka-Betley, Czępińska-Kamińska 1978). Organic matter content was determined via a Vario Micro Cube CHNS element analyzer. All the geomorphologic laboratory work was performed at IGIGP UJ in Kraków. The paper focuses only on selected deposit profiles extracted from the floor of the studied small valleys. The climatology and hydrology data for the period 1987–2017 were obtained from the IGiGP UJ Research Station in Łazy near the town of Bochnia.

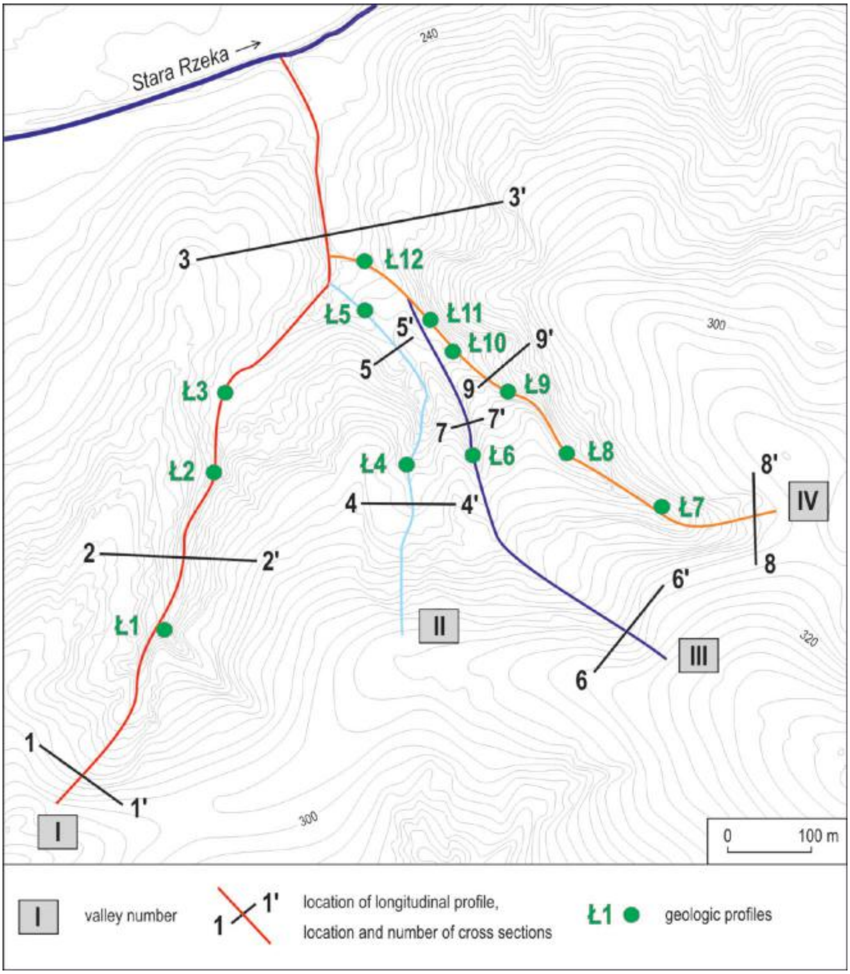

Fig. 2. Documentation map: numbers of main valleys, location of longitudinal profiles and cross sections as well as geologic drilling sites

CHARACTERIZATION OF RELIEF IN EROSIONAL-DENUDATIONAL VALLEYS

In the studied area, broad and rounded ridges gently transition into hill slopes and slopes of valleys. The studied ridges are usually smoothed out along their axis (gradient: 3–5°). At some locations, denudational flats 70 to 150 m wide remain atop the ridges. Ridges and flats are undercut by the niches of active landslides or valley slopes (Fig. 3). A characteristic feature of the study area is the occurrence of parallel landslide landforms with readily observable niches

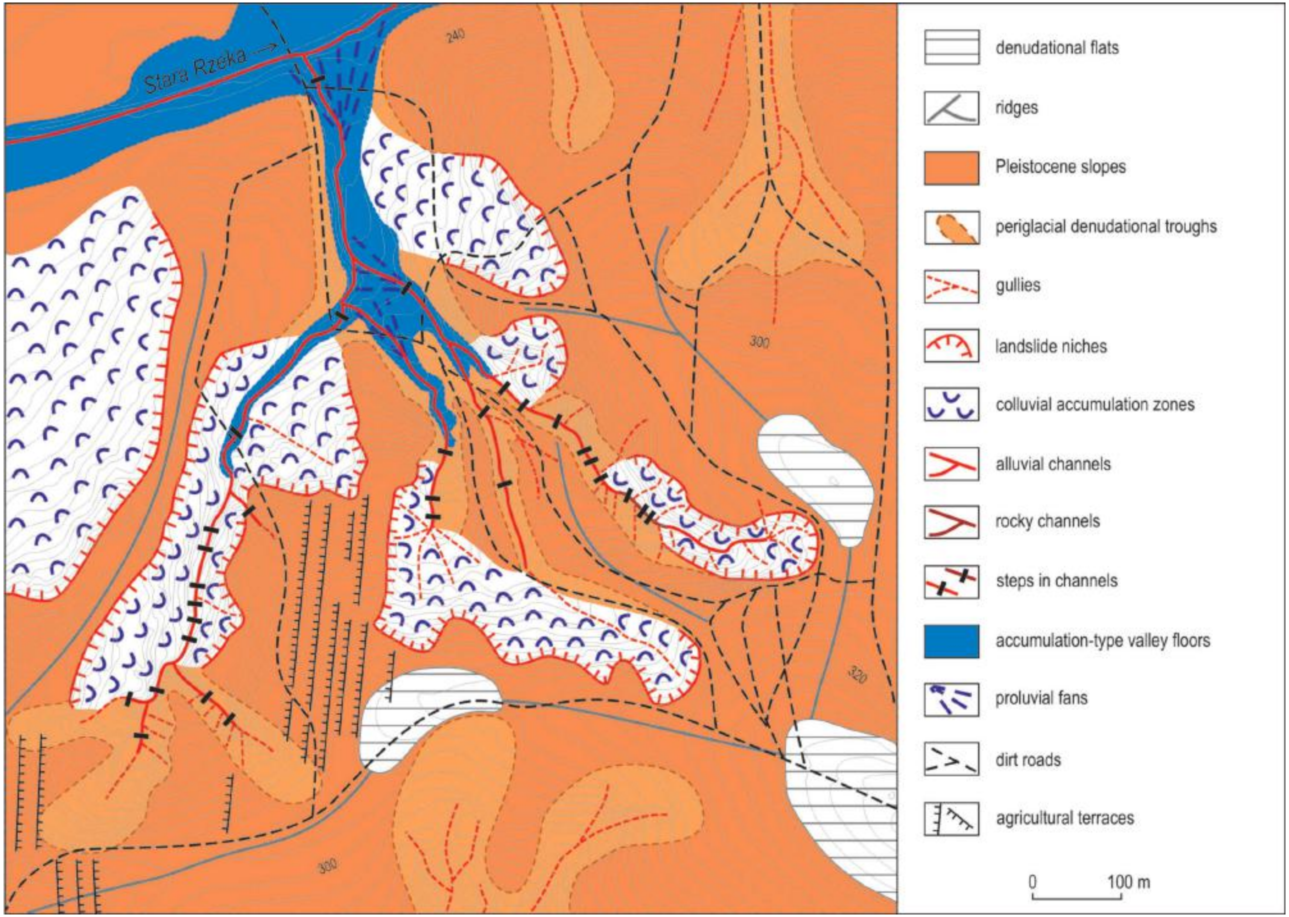

Fig. 3. Geomorphologic map of the study area

2 to 10 m high as well as colluvial headwalls. These include frontal landslides affecting slopes of valleys (e.g. valley no. I) in addition to convergent landslides observed in headwater areas (valleys nos. II and III), where the pattern of colluvial masses is concentric. The surface of colluvial areas is slit by multiple erosion rills associated with periodic linear erosion as well as V-shaped valleys 30 to 207 m long and 1 to 4 m deep (Fig. 4). When the surface area of a colluvial area is undercut by permanent or intermittent watercourses, its mouth section area becomes activated by a large number of lateral erosion undercuts and breakaways. Landslide niches and larger colluvial tongues are also shaped by creeping processes. Tree overturns are also quite common in the area.

A key characteristic of the longitudinal profile of the studied main valleys (nos. I to IV) is their highly variable morphometry: depth, gradient, and width of valley floor. The analysis of these characteristics made it possible to identify valley sections with different relief in the longitudinal profile of each studied main valley.

Three of the studied main valleys begin with a shallow gully (1.5 to 2.7 m) located within a large landslide landform (Fig. 3). Only valley no. I begins its overall length with a denudational trough, now occupied by fallow fields. Its floor is also dissected by a dry gully with a maximum depth of 1.9 m, which then transitions into a shallow V-shaped valley along its mouth section (2.8 to 3.3. m). In valleys no. II and IV, gullies splitting colluvial areas (Fig. 5) follow a concentric pattern and occur directly above V-shaped valleys with a readily discernible channel landform. The splitting of colluvial areas by a system of short, concentric gullies usually occurs tens of meters from the edge of the landslide niche. On the other hand, in valley no. III, colluvial areas are split by a single gully that is quite long – 207 meters.

The middle sections of the studied main valleys take the shape of a V-shaped valley that may be classified as active (Starkel 1957, p. 73). The V-shaped valleys are 13 to 38 m deep, and the gradient of their floor ranges from 6.9 to 17.3%. The length of active V-shaped valleys ranges from 93 to 395 m. Watercourses draining the active valleys cut into colluvial areas as well as small alluvial and proluvial accumulation zones to a depth of 1.2 to 3.4 m. Active V-shaped valleys are characterized by a sinuous longitudinal pattern and uneven channel profile linked with landslide relief. At some locations, their channels also cut into parent material over distances of tens of meters (valley no. IV, Figs 3, 6). The colluvial material periodically becomes slit apart and transported by fluvial processes. Its deposition occurs upstream of steps that populate the floors of active V-shaped valleys in large numbers. Steps usually form around uprooted trees (Fig. 7) and even smaller woody debris. Woody steps reach a height of 2.3 meters, while rocky steps up to 20 cm high are

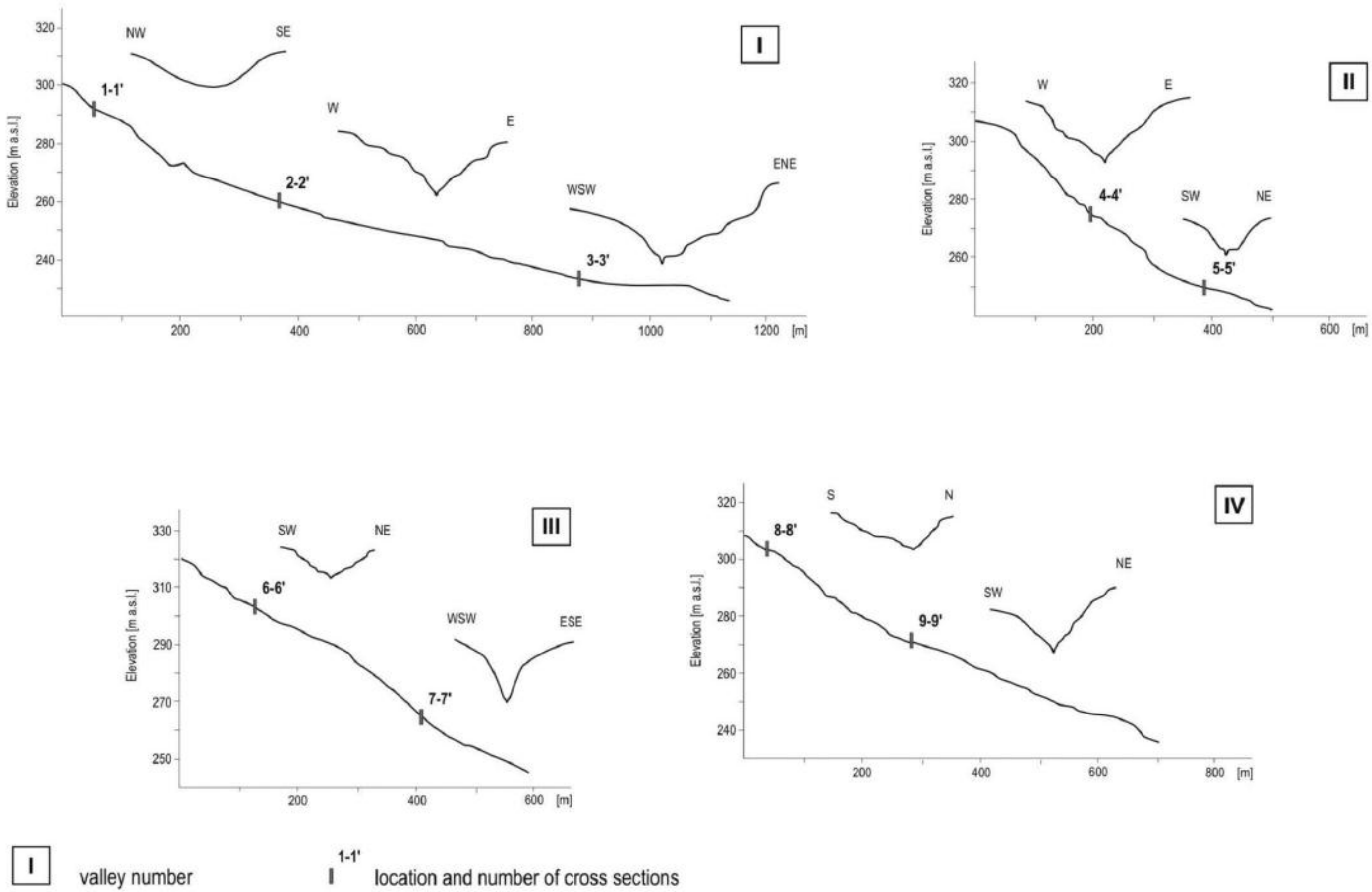

Fig. 4. Longitudinal profiles and cross sections of main valleys.

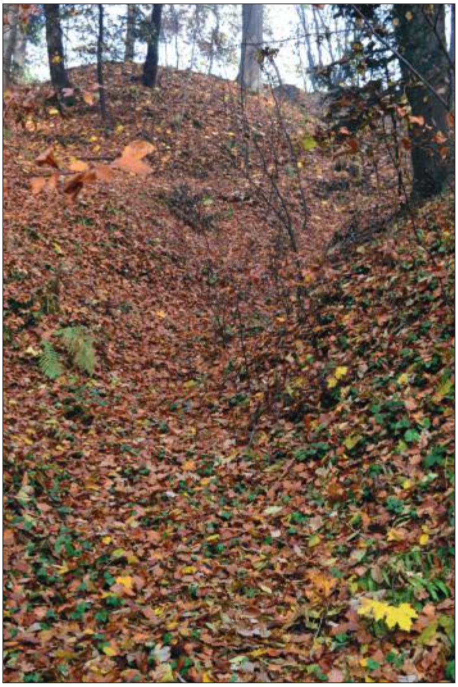

Fig. 5. Gully cutting colluvial material in the headwater area of valley no. II

Fig. 6. Rocky channel floor in valley no. IV

found only in valley no. IV (Maciejczyk 2017). Material halted upstream of steps – zones up to 3.7 meters long – is gradually released into the fluvial system in the course of subsequent flood events. Periodic deposition of mineral material upstream of steps is a sign of material movement occurring in stages along the longitudinal profile of so-called active V-shaped valleys – characterized by alternating sections of predominant erosion and short sections of accumulation.

Local accumulation zones also occur downstream of the mouths of tributary valleys, and this suggests periodic inflows of material into main valleys (active V-shaped valleys). The slopes of active V-shaped valleys usually have a gradient ranging from 15 to 49°. In the case of the presence of rock outcrops (thick-layered sandstone), the gradients of slopes are higher, for a maximum of 75° (Fig. 8). The slopes of active V-shaped valleys are slit by straight-line and shallow gullies (up to 3 to 5 m) with a length of 37 to 84 meters. Proluvial fans may be found at the mouth of the valley, which significantly reduces the longitudinal gradient of these valleys in the mouth section. The slopes of gullies with gradients of 18 to 39° are shaped by creeping processes, while their floors are populated by shallow rills and erosion kettles implying periodic

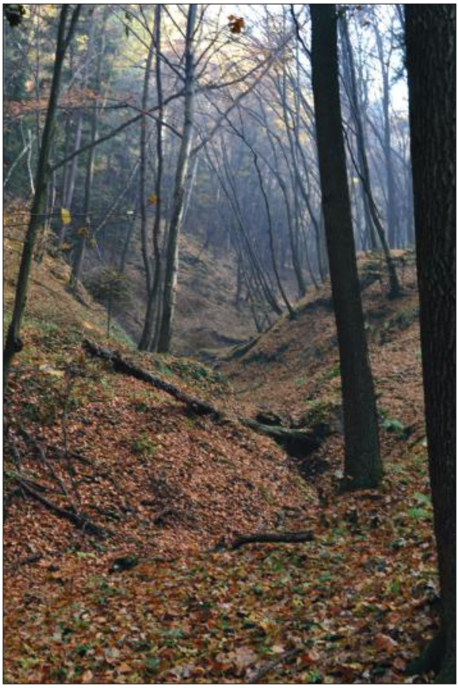

Fig. 7. Uprooted tree blocking the channel in valley no. IV

Fig. 8.Rock outcrops on slopes in valley no. I

linear erosion. Larger differences in depth and gradient over the longitudinal profile are encountered in gullies cutting across landslide surfaces; moreover, their length is greater at 76 to 115 meters.

Downstream sections of active V-shaped valleys transition into valleys with a flat accumulation floor with a smaller gradient and smaller height of slopes (6 to 8 m). These may be described as V-shaped valleys with an accumulation floor (Starkel 1957, p. 74). These valleys are 46 to 230 m long and their floors are 6 to 28 m wide. Channels cut across their floors to a depth of 1 to 2.3 meters. At the point where the main valleys join the accumulation zone clearly becomes wider – 50 to 94 meters of width (Fig. 3). Flat and wide alluvial fans are found in the mouth areas of main V-shaped valleys. The same is true at the point where the valleys converge in the contact zone with the floor of the Stara Rzeka valley. Lateral erosion undercuts revealing the structure of the valley floor are found on the floors of V-shaped valleys characterized by accumulation.

The study area also features agricultural terraces with a height of 0.8 to 1.1. m that serve as proof that the area used to consist of farmland including farmland in flatland areas and upper parts of hill slopes. There are numerous of dirt roads used by forest management vehicles. These affect the content of precipitation water and locally serve as sources of mineral material, eventually reaching lower valley elevations.

The pattern of change in flatland areas found in the study area – denudational flats and ridges – as well as the upper portions of hill slopes is associated with the intensity of landslide processes reshaping headwater areas and slopes of main valleys, and with periodic linear erosion in lateral gullies in terms of dirt roads and landslide surfaces. The processes mentioned above lead to local undercutting of flatland areas and the fragmentation of hill slopes. In addition, fluvial erosion across the floors of active V-shaped valleys leads to the activation of landslides and the emergence of secondary gravitational landforms therein.

The following sequence of valley types is provided in the paper for every examined valley: (1) denudational trough or gully, (2) active V-shaped valley, (3) V-shaped valley with a flat accumulation floor. On the other hand, for the longitudinal profiles of active V-shaped valleys, alternating sections were identified with a predominance of deep-cutting erosion along with small accumulation zones impacted by the intensity of landslides and the erosive power of watercourses flowing across valley floors. The joint action of mass movement processes and either permanent or periodic linear erosion across the floors of active V-shaped valleys and gullies is reflected mostly in variation in longitudinal profiles and cross sections of valleys as well as in the formation of local deposition zones or small landslide gorges.

Differences in local relief including local differences in elevation, degree of valley and hill slope fragmentation, and combined effects of erosion and landslides strongly differentiate the study area into two distinct parts. The upper and middle parts of the valley system described in this paper are characterized by a linkage between erosion occurring along the axis of each active V-shaped valley (fluvial processes) and gully (periodic linear erosion) and landslide processes shaping hills and slopes. On the other hand, in the mouth section of main valleys, fluvial erosion acting across wide accumulation floors of V-shaped valleys and landslide processes do not act in unison. These sections are characterized today mostly by lateral erosion as well as local aggradation in deeply incised channels, and the material transported by the channel comes from side incision made by erosion and from the upstream parts of the channel. The study area is divided into two parts differing in terms of relief energy and relationship between gravitational and erosional processes. All of this is related to the extent of the Silesian unit overthrust featuring the morphologic threshold of the studied middle foothills range. This threshold is fragmented by the studied system of erosional-denudational valleys.

Profile Ł1 had a depth of about 1.2 m and was located on a proluvial fan situated at the mouth of a shallow gully slitting a denudational trough in a headwater area of valley no. I (Figs 2, 3). The lithologic profile contained silt and sand deposits including fine gravel (up to 17%) as well as interlayered thin layers of fine gravel (Fig. 9A). The mean grain diameter (Mz) ranged from –1.89 phi to +5.88 phi. The deposits throughout the entire profile were very poorly or extremely poorly sorted (δ_I = 2.12–5.16). A large kurtosis range (KG = 0.51–1.02) and large skewness range (Sk = –0.32 to +0.69) underscore differences in the dynamics of the environment depositing sediments of various grain size. Low values of kurtosis characterizing larger-grained deposits imply their rapid deposition. Variances in deposits in profile Ł1 are most likely related to differences in the rate of linear erosion periodically impacting the floor of the studied gully.

Profile Ł5 had a depth of 3.78 m and was located in the mouth section of valley no. II – a V-shaped valley with an accumulation floor (Figs 2, 3). This lithologic profile was formed primarily of silt-type deposits or sandy-silt deposits containing fine gravel (Fig. 9B) – and interlayering at various depths consisting of gravel and sandy gravel deposits characterized by 39% to 45% grain sizes less than –1 phi. The extensive range of the granulometric composition is also shown by the mean grain diameter: Mz = –1.41 to +5.88 phi. The entire profile is characterized by very poorly sorted deposits (δ_I = 3.15–3.79) and extremely poor sorting in gravel and sandy gravel layers (δ_I >4). The skewness range (Sk) also distinguishes deposit layers of larger grain size, for which Sk values are positive, while for small grain size samples, Sk values are negative. It is important to note that at the location where the drilling was performed, the floor of the V-shaped valley was elevated due to the presence of a small proluvial fan; hence, the large thickness of deposits and large diversity of grain sizes forming the deposits found at the site.

Profile Ł6 had a depth of 1.8 m and was located on the narrow floor of an active V-shaped valley (valley no. III; Fig. 2). There are no woody or rock steps upstream of this site, and the channel itself begins immediately downstream of a large landslide zone, which is fragmented by a long gully (Fig. 3). The bottom part of the lithologic profile at a distance below 1.53 m is formed by sandy deposits (Fig. 10A). The middle part is formed of silt including fine gravel or sandy silt with fine gravel. At a depth of 0.28 meters, the profile includes interlayering of silt with sandy silt that also contain grains of fine gravel. The mean grain diameter (Mz) ranged from 2.18 to 5.85 phi. The entire profile is characterized by poorly sorted deposits (δ_I = 2.62–3.83). Sk values (skewness) ranged from –0.25 to +0.68. The negative value of skewness associated with the deposits that form the upper and middle part of the profile may indicate multiple redeposition events. In addition, large variances in kurtosis values obtained for this profile indicate large differences in the energy of the associated deposition environment.

Profile Ł7 had a depth of 2.45 m and was located at the base of the right side of the valley (no. IV), which was affected by active landslide processes, and its colluvial material was fragmented by emerging gullies (Figs 2, 3). The entire lithologic profile was formed of deposits of variable grain size.

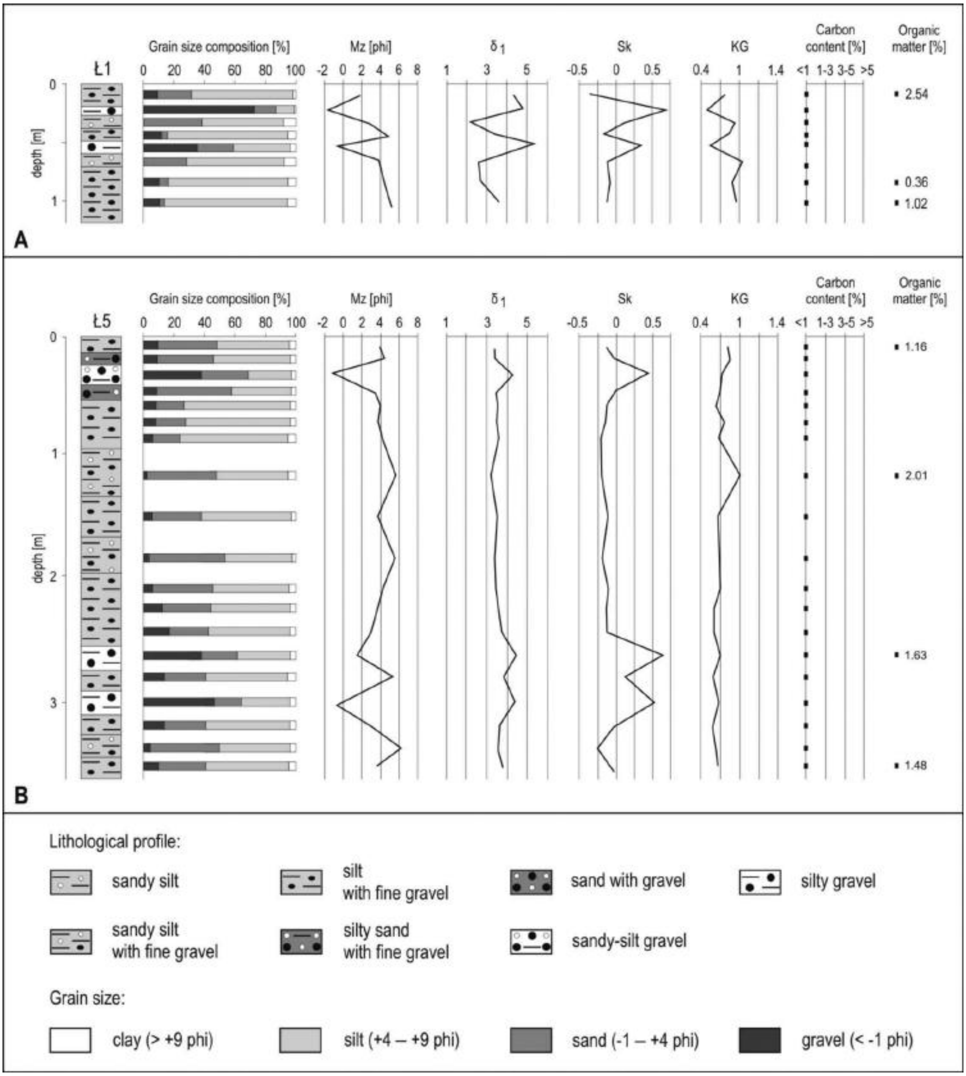

Fig. 9. Diversity of deposits forming the floors of valleys – profiles Ł1 and Ł5

It may be divided into three parts: (1) bottom part (1.59 to 2.45 m), which was formed of sand – with some gravel – interlayered with two layers of silt deposits, (2) middle part (0.78 to 1.59 m), which was formed of silt with some fine gravel, (3) top part (0.0 to 0.78 m), which was the most diverse part in terms of grain size and thickness of available layers (Fig. 10B). Gravel-size deposits were found throughout the entire profile; however, their content varied considerably with depth from 0% to 38.7%. The largest differences in the content of the largest grains occurred between the sandy deposit layer and silt deposit layer in the top part of the profile.

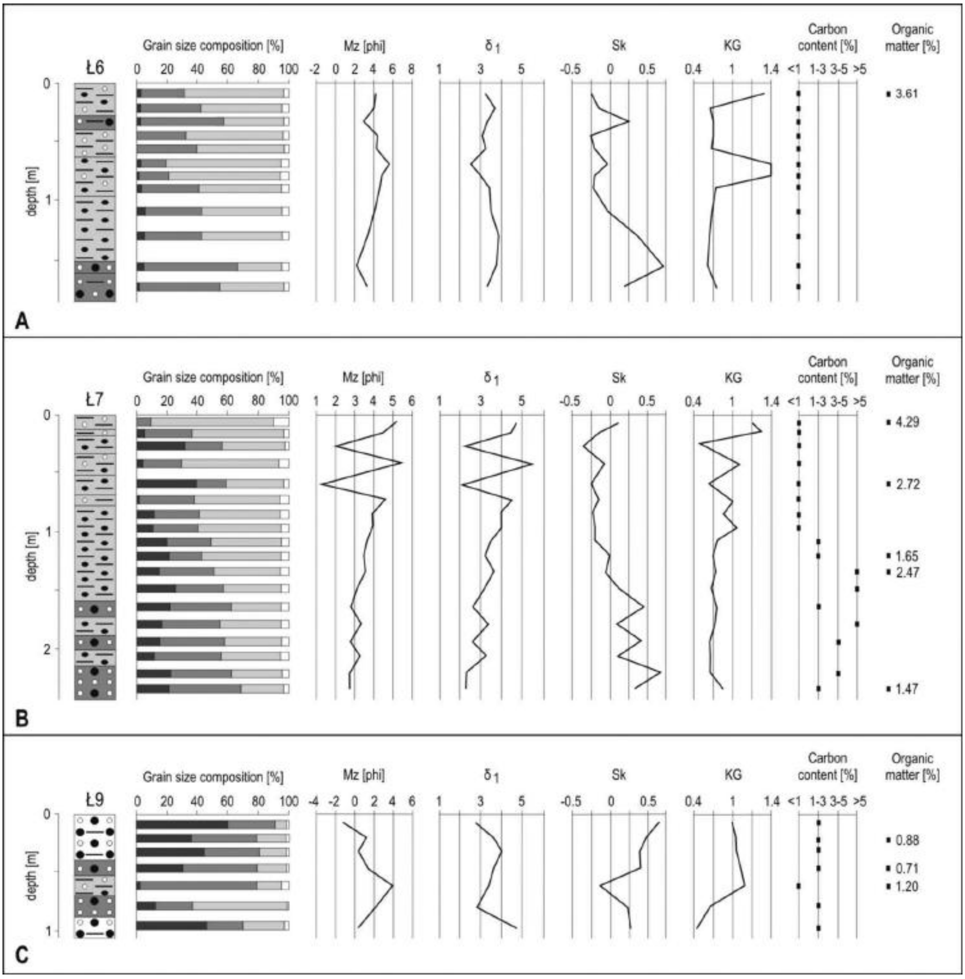

Fig. 10. Diversity of deposits forming the floors of valleys – profiles Ł6, Ł7, and Ł9 (legend as in Fig. 5)

This is also shown by the large range of the mean grain diameter in the deposits forming this part of the profile (Mz = 1.23–5.46 phi). In the middle and bottom parts of the profile, the Mz values are not as variable. Differences between various deposits forming profile Ł7 at its different depths are also illustrated by the values of other leading sedimentological indices used in the study. Deposits found throughout the entire profile are characterized by very poor or extremely poor sorting (δ_I = 2.39–5.10). This may indicate short-distance transport – characterized by varying rates of transport. In addition, kurtosis values (KG = 0.42–1.32) and especially their variances in the top part of the profile, tend to suggest rapid changes in the level of energy of the ambient depositional environment. Sk values (skewness) ranged from –0.31 to +0.63. Negative Sk values were found to be most characteristic of deposits in the top and middle parts of the profile, while negative values were characteristic of the bottom part.

Profile Ł9 had a depth of 1.06 m and was created inside the floor of the active V-shaped valley (valley no. IV; Fig. 2) in a small deposition zone (max. length of 2.3 km) that had formed upstream of a woody steps. Further upstream, the channel of the valley is carved in solid rock along a 68-meter section, and also features 7 steps: 4 steps formed on overturned trees and other woody debris, and 3 rock steps (Fig. 3). Sandy-silt gravels are found in the top and bottom parts of lithologic profile Ł9. The middle part (0.8 to 1.79 m) consists of sand with gravel and sandy silt and fine gravel (Fig. 10C). The mean grain diameter (Mz) ranges from –1.47 to +4.0 phi. This is a larger range than that for profile Ł6 – located also in an active V-shaped valley, but one that does not have steps in its channel. The coarsest deposits form the top part of the profile and contain about 60% gravel-size grains less than –1 phi.

The deposits found throughout the studied profile are very poorly sorted (δ_I = 2.82– 3.91) and extremely poorly sorted in its bottom part (δ_I = 4.95) including 25.89% coarse gravel. Skewness (Sk) ranges from positive 0.25 to positive 0.68. Skewness is negative for the interlayering of sandy silt with fine gravel (Mz = 4.0 phi, Sk = –0.17) at a depth of 1.06 to 1.42 meters. Positive skewness values indirectly indicate grain immobilization following traction (Mz <0.5 phi) or saltation (Mz = 0.5–2.0 phi). The latter is forced by the presence of a woody threshold yielding the creation of a zone of deposition upstream of the threshold. Kurtosis values (KG) varied from 0.38 to 1.18. Low kurtosis values for gravel deposits in the bottom part of the lithologic profile and their extremely poor sorting indirectly indicate rapid deposition of material. The entire profile is dominated by deposits characterized by a polymodal grain size distribution. The deposits are transported primarily in a high energy environment. The stoppage of deposits above a woody steps in the channel and their characteristics clearly indicate material transport in the channel based on distinct stages – mostly in the course of higher energy events.

Variances in the deposits forming the floors of V-shaped valleys and small, local accumulation zones indicate large differences in the energy of deposition processes as well as periodic redeposition. The deposits obtained from the studied profiles are very poorly or extremely poorly sorted, which suggests short-distance transport and lack of homogeneity of the starting material. All the studied profiles contain some gravel-sized grains, while the clay fraction is small. Analysis of the relationship between mean grain diameter and the degree of sorting indicates that as mean grain diameter increases, the degree of sorting is on the decline. This type of relationship is characteristic of sedimentation environments affected by fairly variable rates of deposition. The largest differences in grain size were noted in deposits forming a proluvial fan at the mouth of a gully (profile Ł1). This confirms the occurrence of periodic material influx from tributary valleys to the main valley, especially in the course of higher precipitation events, where linear erosion cuts into the gully floor.

The largest grain size was found for deposits situated upstream of woody steps (profile Ł9). These deposits are much more coarse and more poorly sorted than deposits in profile Ł6 situated in a small depositional area in an active V-shaped valley. This valley does not feature steps, established on overturned trees or woody debris, upstream of the studied profile. The thickest deposits are found in the floor of a V-shaped valley with a flat accumulation floor (profile Ł5). In this profile, as in profile Ł1 found at the mouth of a gully, there are several strata of deposits associated with a higher energy of the deposition environment. Deposits found in profile Ł7 are also quite thick. This profile is located in a headwater area affected by active landslides, where downcutting erosion is not very strong, and colluvial deposits only experience slitting and redeposition from time to time.

CONCLUSIONS

The diversity of relief in the study area suggests a large complexity of local and not local determinants and their important role in the evolution of small erosional-denudational valleys in the woodland areas of the Foothills threshold zone in southern Poland. The relief of the study area is shaped mainly by landslides as well as permanent or periodic linear erosion. The intensity and joint action of these processes depend on local differences in elevation, characteristics of hill slope cover, and the intensity of precipitation events. The relationship between these processes is based on the periodic incision of colluvial matter by the fluvial processes in effect across the floors of V-shaped valleys, linear erosion in tributary valleys, and the activation of secondary landslide movements by lateral erosion in streams. The combined action of landslide processes and erosion is reflected in valley type and the morphometry of valleys as well as in the diversity of deposits forming valley floors and local zones of accumulation. Tree uprooting processes can also play an important role in the variation of longitudinal gradients of valley floors as well as in the transport and local deposition of matter. The high rate of present-day processes shaping the studied valleys is determined by differences in the resistance of bedrock and location of the study area atop a morphologic threshold in a middle foothills area straddling two tectonic units.

The present-day evolution of small erosion and denudation valleys in the woodland areas of the Wiśnicz Foothills is complex in the same way that the evolution of similar landforms in both Old and Young Glacial areas and loess uplands is complex. However, differences in soil cover and degree of forest cover in the Wiśnicz Foothills favor landslide processes and a lesser role of present-day human impact in the evolution of these small valleys. The common occurrence of active landslides in the headwater areas and on the slopes of these valleys favors the emergence of lateral valleys and a variable cross section as well as variable longitudinal profile of main valleys. Valleys characterized by stable discharge that dissect the threshold of the Wiśnicz Foothills are an important element of the channel system in the Stara Rzeka catchment. On the other hand, small dry gullies and denudational troughs were found to be more stable in terms of morphogenetics – and the same was found in the case in postglacial areas.

Characteristics of deposits forming the floors of V-shaped valleys and small zones of accumulation downstream of the mouths of tributary valleys or upstream of steps in the channel indicate large differences in the energy level of deposition processes. The deposits are characterized by variable grain size and a low degree of sorting that suggest mineral material transport over short distances and a lack of homogeneity of the source material (i.e. colluvial matter, weathering material). The characteristics of the deposits forming the local accumulation zones, especially in the upper and middle sections of valleys, reflect the activity of hill slope processes and permanent or periodic erosion occurring across the floor of V-shaped valleys and tributary valleys. Local characteristics of relief such as the gradient of valley slopes, gradient of valley floors, degree of hill slope fragmentation, and activity level of natural processes determine the rate of delivery of mineral material to main valleys and the stage-based transfer of deposits along the longitudinal profile of valleys.

A similar, differential pattern of characteristics was noted for deposits forming the floors of small valleys in other areas – despite the parent material being different. This suggests a high variability of transport energies and rates of material deposition as well as short material travel distances along the axes of erosion and denudation valleys.

The present study made it possible to learn more about the relief and evolution of small erosion-denudation valleys in the southern part of the Wiśnicz Foothills. The results did show that a detailed analysis of small valleys and the deposits that populate their floors can serve as a starting point for broader research work on the evolution of relief in the region. However, it will be necessary to learn more about the age of the studied deposits. Present-day morphogenetic processes will require an analysis of the relationship between their rate of occurrence and physical outcomes and also available meteorologic and hydrologic data.

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