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DEVELOPMENT OF RELIEF OF THE VELYKY LUKAVETS RIVER VALLEY NEAR STARUNIA PALAEONTOLOGICAL SITE (CARPATHIAN REGION, UKRAINE)

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Abstract: In Quaternary sediments filling the Velyky Lukavets River valley, at the abandoned ozokerite mine (= Ropyshche) in Starunia, perfectly preserved carcasses of large mammals were discovered in the first half of the 20th century. The study area includes a fragment of the valley between Molotkiv and Starunia, and its close vicinity. The area belongs to several morphostructural and geomorphic units of the Outer Eastern Carpathians and the Carpathian Foreland. The asymmetric, subsequent valley is a part of the Mizhbystrytska Upland, where flattened ridges and flat bulges represent fragments of planation surfaces: the upper (the Krasna level), elevated 170 m above the valley bottom and linked with the Late Pliocene, and the lower one (the Loyova level), rising at 100 m and linked with the Eopleistocene. Several flat surfaces are visible on valley slopes, probably representing river terraces formed before the Late Pleistocene. The valley attained its maximum depth during the Eemian Interglacial (OIS 5e). In the Ropyshche area, probably three terrace steps built of Weichselian and Holocene sediments (OIS 5d – 1) were developed, but their top surfaces are almost completely destroyed by mining operations. The recent, meandering river bed follows the zones of decreased cohesiveness of rocks resulting from mining activity and is becoming somewhat deepened during inundations. The transported material is mostly coarse-clastic one. The two latter factors may suggest that the river is underloaded due to declining agriculture and decreasing intensity of outwash. The top surface of the sub-Quaternary basement is deformed by subsidence and collapse of mine workings, but the relief of valley bottom allows for further exploration for remnants of large mammals not only in the Ropyscche area but along the whole studied segment of the valley, as well.

Key words: geomorphology, river terraces, Starunia, Carpathian region, Ukraine.

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INTRODUCTION

The discovery of large mammal remains in the Pleistocene deposits at Starunia (SW Ukraine) in the first half of the 20th century was recognized as an event of special importance in geological sciences. Previous researchers were concerned mostly with the excellent state of preservation of the remains, which was linked with their saturation with brine and petroleum ascending from Cainozoic strata (*e.g.*, Kotarba, 2002; Duliński *et al.*, 2005; Koltun *et al.*, 2005). Less attention was paid to other components of the environment, including the relief and the Quaternary deposits themselves, in which the large mammal carcasses were hosted. For this reason, the hundredth anniversary of the first discovery has become a good occasion to undertake interdisciplinary research, the aim of which was to reconstruct the changes of environmental conditions at the Starunia site. That is why the objective of the present study is the analysis of landform features and lithology of Pleistocene sediments, which, together with geochemical factors, decisively controlled the accumulation of animal remains at Starunia and their perfect preservation.

Although geomorphological research in Starunia and its surroundings, including the Carpathian Mountains, has begun over 100 years ago, data pertaining to the relief and to Quaternary sediments of the Velyky Lukavets River valley are still insufficient. A general description of the relief as well as the development of Quaternary sediments of larger geomorphological and physico-geographical units can be found in Czyżewski (1934), Karandeeva (1957), Raskatov (1966), Tsys (1966), and Kondracki (1978). The geological structure of older formations and Quaternary sediments, as well as the problems of planation, development of fluvial terraces and the connections between the relief and the neotectonics of smaller geological and geomorphic units in the area of Starunia are discussed in the papers by Zuber (1885, 1888), Rogala (1907), Łomnicki (1914), Nowak *et al.* (1930), Teisseyre (1933a, b) Gofshtein (1964, 1979), and later in other publications (Alexandrowicz, 2004; Alexandrowicz *et al.*, 2005; Koltun *et al.*, 2005; Korin, 2005; Stelmakh, 2005).

The following study aims at characterizing the relief of the Velyky Lukavets River valley and its close vicinity, and to indicate geomorphic controls on further exploration for large mammal fossils.

In order to show a broader environmental background of the Starunia surroundings, an overview study of the relief and the sediments was carried out outside the palaeontological site investigated in detail. The study covered the area of the Velyky Lukavets River valley between Molotkiv and the northern proximities of Starunia, as well as the valleys of the Dashevets Stream and the Maly Lukavets River (Fig. 1). The methods involved field reconnaissance, including the recording and description of outcrops, the geomorphological sketch and the analysis of topographic maps, and morphometric analysis as well as examination of images published at the website http://earth.google.com.

GEOLOGICAL SETTING

The source area of the Velyky Lukavets River valley and its tributaries, including the longest Stavyshche River, is situated in the range of the Skyba Unit belonging to the Outer Eastern Carpathians. The most widespread here are the Menilite and Polyanytsya beds (see Bujalski, 1938), which represent the Oligocene and Early Miocene (Andreeva-Grigorovich *et al.*, 1997). The former are developed as bedded black shales, mudstones and sandstones, with a locally developed sandstone member (the Kliwa Sandstones). Up the section, sandstones of the Polyanytsya beds dominate. Much less extended are the outcrops of Eocene sandstones of the Vygoda beds, which locally pass into carbonates of the Pasichna beds (Zuber, 1885; Koltun *et al.*, 2005).

The above-mentioned flysch strata are unconformably overlain by the Miocene molasse formations of the inner zone of the Carpathian Foredeep (the Boryslav-Pokuttya Unit) and form a few slices thrust one over another to the northeast. In the surroundings of Starunia, the Lower Miocene molasse is represented by the Polyanytsya beds, up to 600 m thick, which include dark shales with sandstones intercalations. The higher part of the molasse succession is occupied by the salt-bearing Vorotyshcha beds, up to 2,000 m thick, which are Egerian (Korin, 2005) or Ottnangian (Andreeva-Grigorovich *et al.*, 1997) in age. The majority of these strata are developed as sandstone-shale-marl breccias with clayey-salty cement, and are cut by veins of gypsum and impregnated with single crystals of sodium-potassium salts. Locally, thin (usually a few centimetres long) lenses of bluish-grey, medium- and coarse-grained sandstones with a poor clayey-carbonate cement are found. Zuber (1885) mentioned also the blocks of quartzite, limestones as well as crystalline schists in the breccias.

Locally, these formations are replaced by the Sloboda Conglomerates and the Dobrotiv beds, occurring mainly in the slopes of the Velyky Lukavets River valley (Zuber, 1885; Bujalski, 1938; Koltun *et al.*, 2005). In the Sloboda Conglomerates, variably rounded boulders and pebbles of limestones, phyllites, quarzites and schists, including exotic chlorite and crystalline schists, sometimes several metres in diameter, are embedded in clayey-silty cement with occasional sand admixtures. The Dobrotiv beds are dominated by bedded, compact sandstones accompanied by shale intercalations.

The Skyba Unit is thrust over the Boryslav-Pokuttya Unit. The latter is displaced northeastward and represents a complex of superimposed nappes. Frontal parts of the nappes built the anticlines, *i.e.*, the Gvizd, Starunia, Dzvinyach and Monastyrchany folds with steep northeastern and gently dipping southwestern limbs (Adamenko *et al.*, 2005; Koltun *et al.*, 2005; Korin, 2005). This unit is cut by a number of strike-slip faults, which bound a series of blocks. Four systems of regional to local faults were distinguished in the Starunia vicinity: (i) the NW–SE (sub-Carpathian) and NE–SW (transverse) systems, genetically related to the Alpine tectogenesis and reflected in the Mesozoic–Cainozoic successions, (ii) the sub-latitudinal/sub-meridional systems, which require further studies. All of them have been permanently active during the Quaternary (Stelmakh, 2005).

Unfortunately, the scale of published geological maps (Adamenko *et al.*, 2005; Koltun *et al.*, 2005, Korin 2005) is too small and their topographic sheets are very generalized, hence, it is impossible to link the structural elements with the particular morphostructures and landforms.

To the northeast of the Boryslav-Pokuttya Unit, two other tectonic units appear: the Sambir and Bilche-Volytsya (*cf.* Koltun *et al.*, 2005). Both of them are situated outside the study area.

MORPHOSTRUCTURAL AND GEOMORPHIC UNITS

Individual regions of the Carpathian Mountains and the Carpathian Foreland are variously named in morphostructural, geomorphic and physico-geographical subdivisions (Fig. 2). As both the range and the names of principal morphostructural and geomorphic units are consistent, these are discussed together. In some particular cases the terminology used in physico-geographic subdivisions is applied.

This part of the Outer Eastern Carpathians, including the Velyky Lukavets River catchment, according to Ukrainian divisions, is situated in the Skyba (Skyb) Beskid Mts. (Ermakov, 1948), the Beskid-Gorgany area (Tsys, 1966), Skibovi Gorgany Carpathians – low-mountain relief of the Skibovi Gorgany region and Manyavsko-Bitkivskiy subregion (Kravchuk, 2006), or – in morphostructural division – the Border morphostructure of the 2nd rank, and Manyavsko-Bitkivskaya morphostructure of the 3rd rank (Kravchuk & Ivanyk, 2006). In physico-geographical subdivisions, this fragment is called the Border Beskid Mts., which is a part of the Forested Beskid Mts. (Kondracki, 1978).

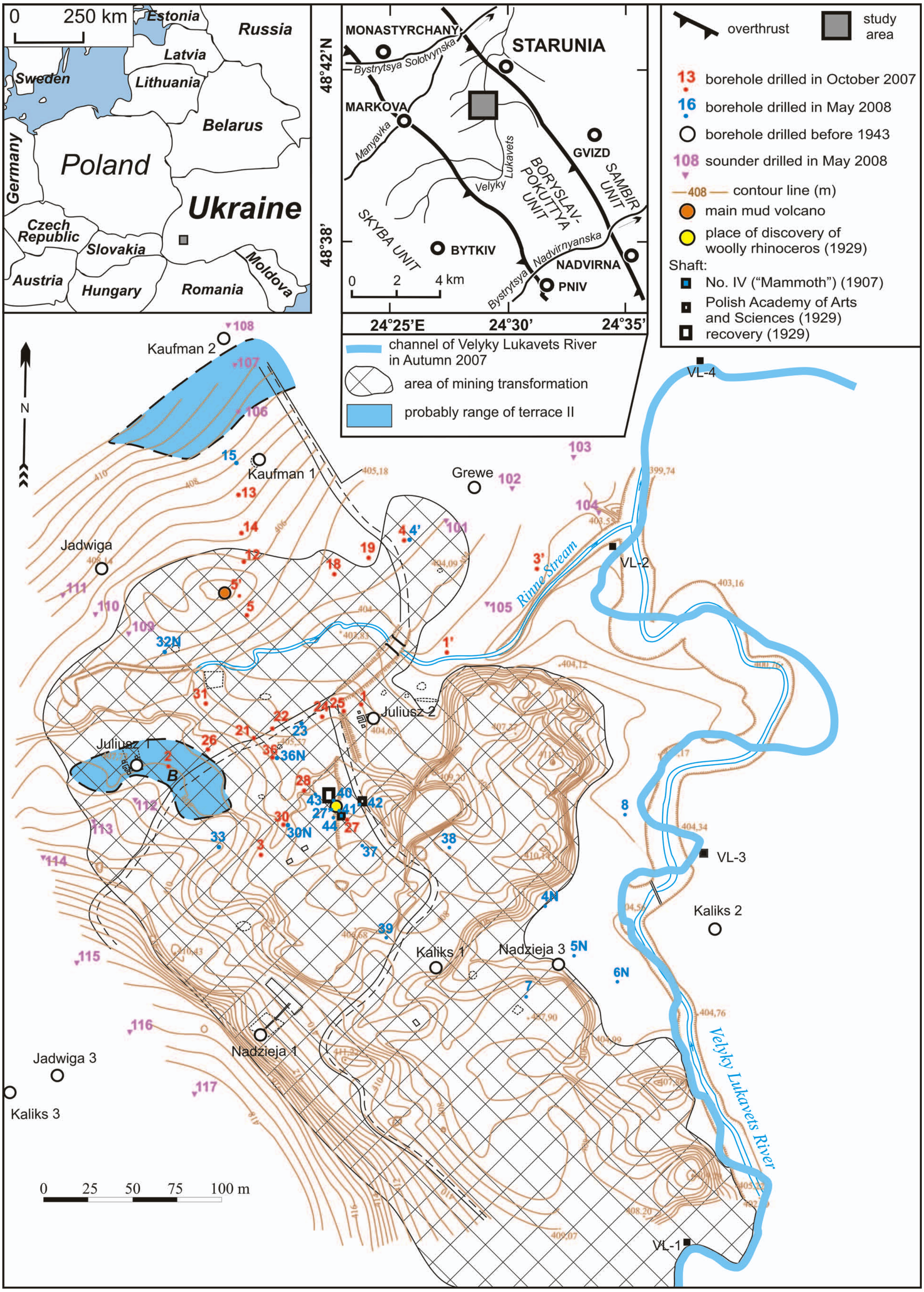

Fig. 1. Sketch map of the vicinity of Starunia (Carpathian region, Ukraine) with the location of study area

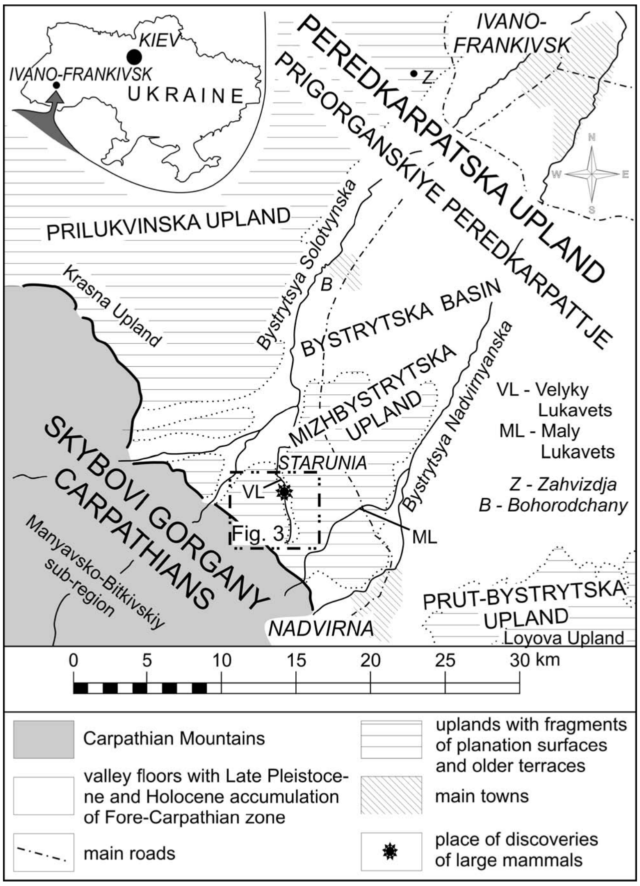

Fig. 2. Geomorphological units of the vicinity of Ivano-Frankivsk

The quite regular, approximately parallel ranges form a landscape typical of low mountains, with altitudes not exceeding 960 m a.s.l. The slopes are often inclined at >20° and locally transformed by landslides.

In the Fore-Carpathian zone built of the Boryslav-Pokuttya, Sambir and Bilche-Volytsya units, Tsys (1966) and Kravchuk (1999) distinguished morphostructural units of various ranks. The 1st rank unit is the Peredkarpatska Upland, which extends along the margin of the Carpathian Mountains and is separated from the mountain ranges by a distinct boundary developed along the overthrusts of the Carpathian nappes. It is divided by transversal dislocations into several tectonic blocks, which form the 2nd rank units, *e.g.*, the Stryi-Stanislav Foreland (Czyżewski, 1934), also called the "accumulative terraces and valleys of the Central Peredkarpattje" (Tsys, 1966) or the Prigorganskiye Peredkarpattje (Kravchuk, 1999). A series of basin depressions occurs within this unit, separated by upland areas (3rd rank units) of tectonic origin (Czyżewski, 1934; Gofshtein, 1962; Tsys, 1966; Kravchuk, 1999). In the basin depressions the isolated summits are rather rare, while common are broad, flat ridges with well-developed denudation-erosional or denudation-erosion-accumulational or only denudational (pediments) planation surfaces or river terraces dissected by valley depressions.

Both the 3rd rank morphostructure and morphologically elevated area in the surroundings of the Velyky Lukavets, Manyavka, and Bystrytsya Solotvynska river valleys (Fig. 2) belong to the Prilukvinska Upland. The part situated to the east of the Bystrytsya Solotvynska River valley is named the Mizhbystrycka Upland (Kravchuk, 1999). In physico-geographical subdivisions, both units were combined into the Black Forest Upland (Czyżewski, 1934).

The Prilukvinska Upland is the most prominent morphological elevation of the Fore-Carpathian area with the culmination along the Halitch-Maydan line (Tsys, 1961, 1966; Kravchuk, 1999). As a morphostructure, it is related to the transversal Maydan – Ivano-Frankivs'k elevation of the Palaeozoic basement. Its denudational surfaces are covered with Pliocene–Quaternary sediments. Differences in elevation allowed for distinguishing the Krasna Upland in the southern part (Fig. 2; Kravchuk, 1999). The plateau of the former, with culmination in the Krasna Hill (589 m a.s.l.), is developed on the planation surface elevated 160–180 m above the valleys bottoms. This surface was linked by Teisseyre (1933b) to an older planation surface, distinguished later also by Gofshtein (1962) as the Late Pliocene Krasna level. Below (140–150 m above the valleys bottoms), another, younger planation surface exists (Eopleistocene in age; Gofshtein, 1962; Kravchuk, 1999). It was distinguished by Teisseyre (1933b) as the Loyova level.

To the north, Łanczont and Boguckyj (2002) found two morphological steps located at 150–170 and 120–130 m above the valleys bottoms and related them to the Loyova level. The same authors reported on the results of drillings, which revealed that the steps are covered with gravels underlain by Miocene sediments and overlain by loess-like loams. Moreover, Łanczont and Boguckyj (2002) found another step located 60–70 m above the bottom of the Bystrytsya Solotvinska River valley and placed it between the Loyova level and the terrace V distinguished in the Upper Dnister River valley. In this step, alluvial gravels, sands and muds are covered with loess, up to 20 m thick, which, together with soil horizons (Solotvyn II, Solotvyn I, Sokal, Lutsk and Korshiv), represent the Elsterian I – Saalian (Drenthe) and the Sula – Dniper 2 stages in the Ukraine.

The unit named Mizhbystrytska Upland, to which the Velyky Lukavets River valley belongs, includes the 4th and 5th rank morphostructures which, according to Kravchuk (1999), are related to the above mentioned Gvizd, Starunia and Molotkiv anticlinal folds (the latter presumably corresponds to the Dzvinyach and/or Monastyrchany folds after Adamenko *et al.*, 2005; Koltun *et al.*, 2005 and Korin, 2005). The Mizhbystrytska Upland reveals erosional-tectonic and denudational relief (Kravchuk, 1999) with accumulation horizons. In its culminations, both planation surfaces – the Krasna and the Loyova levels – are quite distinct. Moreover, numerous gullies occur there, which are interpreted by Kravchuk (1999) as one of the signs of neotectonic uplift. Simultaneously, the presence of such landforms points to intensive washout processes.

To the east of the Prilukvinska Upland, a relatively vast depression occurs, called the Stanislav Basin (Czyżewski, 1934; Tsys, 1966) or the Bystrytska Basin (Kravchuk, 1999), which is filled almost completely with up to 15 m thick sediments of fluvial terraces of the Vorona, Bystrytsya Nadvirnyanska and Bystrytsya Solotvynska rivers, and their

Table 1

Heights and ages of fluvial terraces

Age	Terrace	Upper Dnister (Raskatov, 1966)	Bystrytsya Solotvinska (Kravchuk, 1999)	Bystrytsya Nadvirnyanska (Kravchuk, 1999)	Velyky Lukavets		
		height (m)	height (m)	height (m)	terrace	height (m)	age
					floodplain	<1.5	Recent
Holocene	I	1-2, 4-5	2.5-3.5	2.5-3	I	<4.0	Neo-Holocene
Neo-Pleistocene	II	10-12	7-10	6-8	II	7-8	Late Weichselian
Neo-Pleistocene	III	13-25	20-25	13-15	III	25-30	Meso-Pleistocene
Meso-Pleistocene	IV	30-40	40-45	28-35	IV	35-50	Meso-Pleistocene
Eo-Pleistocene	V	70-90	60-70	50-60	V	60-80	Eo-Pleistocene
Eo-Pleistocene	VI			100-130	VI (LL)	90-110	Eo-Pleistocene
Late Pliocene	VII (KL)	120-140160			VII (KL)	160-170	Late Pliocene

LL – Loyova level, KL – Krasna level

tributaries. The vast and flat basin bottom shows local elevations up to 30 m high. Teisseyre (1933b) related its origin to erosion, while Zglinnicka (1931) and Czyżewski (1934) proposed downwarping tectonic movements. The latter concept was supported by, *e.g.* Gofshtein (1964, 1979) and Kravchuk (1999).

In the southeast, the Stanislav Basin is surrounded by the Delatin-Nadvirna Subcarpathians (Czyżewski, 1934), the South-Pokuttya Upland (Tsys, 1966), or the Loyova Upland, which is a fragment of a larger unit, the Prut-Bystrytska Upland (Kravchuk, 1999). In its northwestern part, about 110 m above the valley bottom, a planation surface of the Loyova level is present. Above this surface gravel horizons were encountered, which document the flow of the Bystrytsya Nadvirnyanska River to the east, towards the Prut River valley.

PRESENT-DAY RELIEF OF THE VELYKY LUKAVETS RIVER VALLEY AND ITS SURROUNDINGS

In the study area, the Velyky Lukavets River valley is rimmed from the east by an almost meridional ridge of the Bzovach Hill (579 m a.s.l. – Fig. 3). Farther eastward, a nearly parallel range of the Dilok Hill (512 m a.s.l.) occurs. One of its broad, flattened ridges surrounds the Dashevets Stream valley from the north. On the western side, the ridge of the Pohorylets Hill (483 m a.s.l.) – Pasovyshche Hill (512 m a.s.l.) extends far to the southwest, up to the Krepa (715 m a.s.l.) summit, which already belongs to the Skyba Beskid Mts. Its long and broad, gently inclined ridges slope down to the Velyky Lukavets River valley.

In the Starunia area, the Velyky Lukavets River valley is asymmetric (Fig. 4). A distinct, though quite narrow, flat surface on the culmination of the Bzovach Hill (Figs 3, 4, Table 1), 170 m above the valley bottom, was linked by Teisseyre (1933a) to an older planation surface, distinguished later also by Gofshtein (1962) as the Late Pliocene Krasna level. The slopes descending from here to the Velyky Lukavets and Dashevets stream valleys are steep, locally with inclinations even around 30° and, in many sites, are dissected by gorges, which are even recently shaped by intensive rainfalls. The slopes have concave profiles in their lower parts, with traces of solifluction and/or slopewash covers. Farther to the south of the valley as well as in the Rinne Stream valley, the lower fragments are undercut and on the scarps the clayey-rubble sediments crop out.

The lower (80–100 m above the valley bottoms) and younger (Eopleistocene, see Gofshtein, 1962; Kravchuk, 1999) level cuts the Pohorylets-Pasovishche Ridge (Loyova level; Teisseyre, 1933a). Loess-like deposits found on its culmination rest upon the gravels uncovered from the side adjacent to the Manyavka River valley (see Bujalski, 1938). On the side ridges, sloping down at gentle angles towards the Lukavets River, as well as on the ridge surrounding the Dashevets Stream valley from the north, several flat surfaces are visible. Although not supported by direct evidence, like the presence of alluvial deposits, these surfaces are regarded as higher terraces of the Velyky Lukavets River. Their heights do not differ from those of the terraces of the Fore-Carpathian rivers (Table 1), including the adjacent Bystrytsya Solotvynska and Bystrytsya Nadvirnyanska rivers (Tsys, 1961, 1966; Kravchuk, 1999).

Particularly distinct is the elevation level 60–80 m, which corresponds very well to the loess-covered level distinguished by Łanczont and Boguckyj (2002) and Łanczont *et al.* (2003) in the Prilukvinska Upland at Zahvizdya, at an elevation of 60–70 m. Below, the next two, less distinct, levels occur at elevations of 35–50 and 25–30 m above valleys bottoms.

The present-day valley bottom shows quite significant changes in width. Below a distinct broadening (almost 600 m) in the area of Molotkiv, the valley maintains an almost constant width, 200 m on average, and only near a cone-like rise, at the junction of the Velyky Lukavets River and the

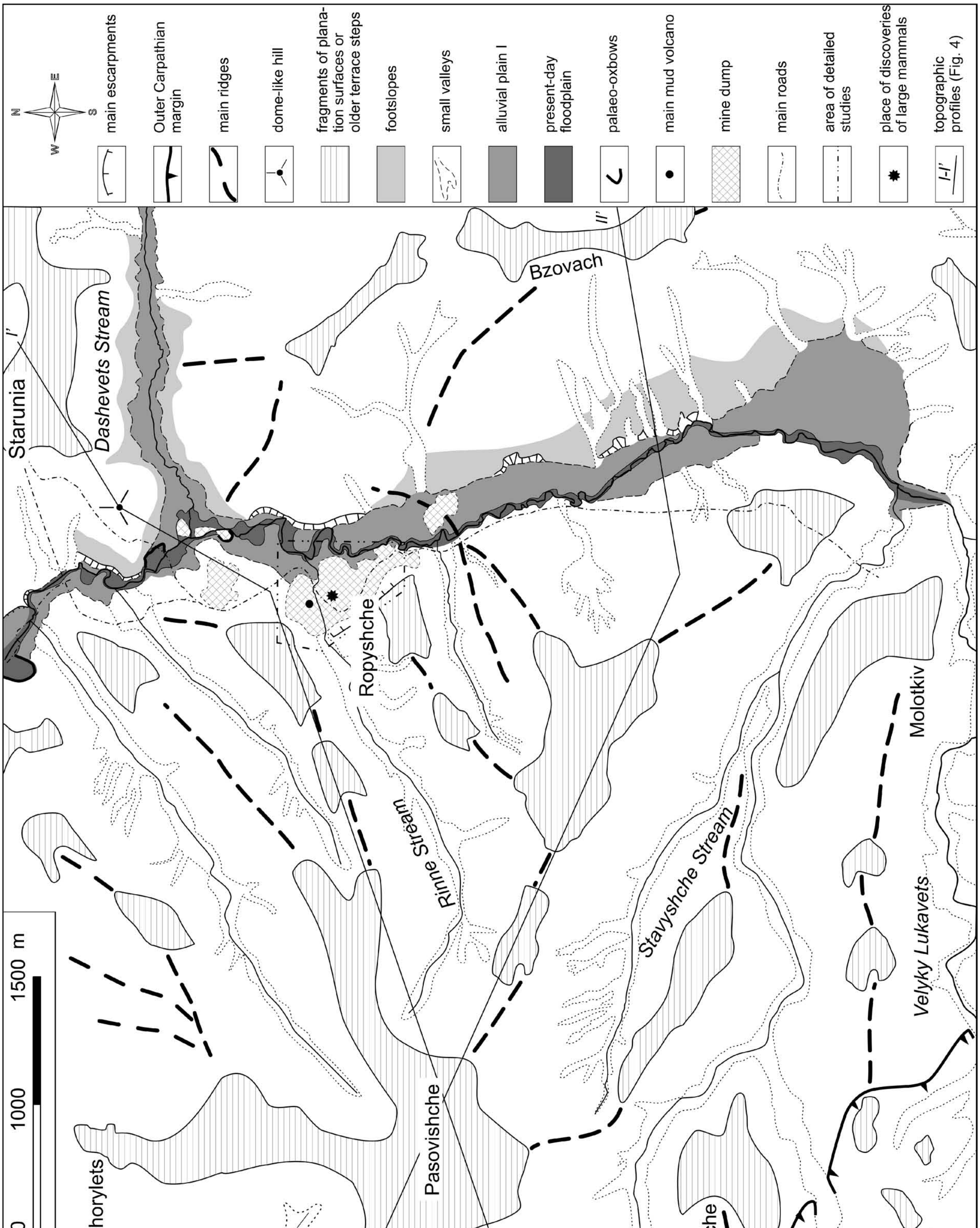

Fig. 3. Geomorphological sketch of the Velyky Lukavets River valley near Starunia

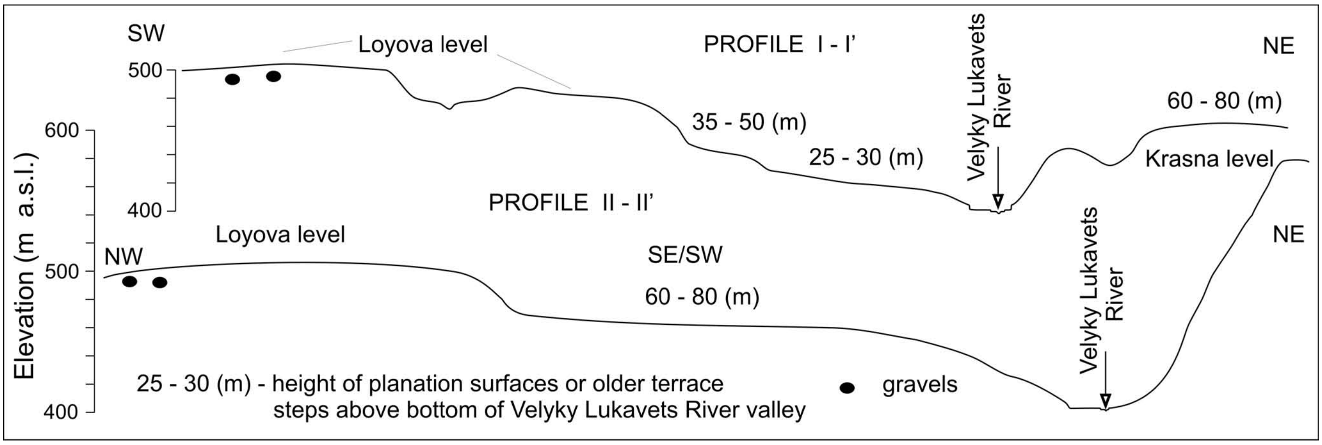

Fig. 4. Topographic profiles of the Velyky Lukavets River valley near Starunia. Location of profiles – see Fig. 3

Dashevets Stream, it narrows to less than 100 m. Probably, three terrace levels occur there. The highest one (terrace II) is practically blurred except for a very vague, strongly anthropogenically transformed flat surface inclined towards the axis of the Velyky Lukavets River and the Rinne Stream. However, as concluded from the differences in geological structure and age (Sokołowski *et al.*, 2009; Sokołowski & Stachowicz-Rybka, 2009), it corresponds to the 8-m-high terrace found in the Bystrytsya Solotvynska River valley (Kravchuk, 1999), or – alternatively – to the 10-m-high (Gofshtein, 1962) or 10–12-m-high (Raskatov, 1966) terrace distinguished mostly in the upper Dnister River valley. The next, up to 4-m-high high terrace I, covers the larger part of the valley between Molototkiv and Starunia, and probably penetrates also the lower segment of the Rinne Stream valley. Its monotonous, flat surface is locally overlain by post-mining embankments (Fig. 1), several metres high. An interesting formation, adding some variety to the terrace surface, is a small, flat cone of a mud volcano. The presence of other mud volcanoes of the same type was mentioned by Mishchenko (2008); however, the other ones are not visible in the relief and rather resemble old mine shafts. The terrace surface is locally boggy. It seems likely that in the past the fens occupied a larger area, as indicated by horizons of iron precipitates visible in outcrops of terrace scarps.

The textural and structural diversity of fine-grained sediments (Sokołowski *et al.*, 2009) allowed for the distinction (following Zwoliński, 1992) of the proximal and distal parts of floodplains (alluvial ridge and flood basin, after Bridge, 2003).

Below the Ropyshche area, the present-day floodplain is about 150 m wide and up to 2 m high. It usually forms alternating patches of variable shape and size along the river bed. Sometimes, the floodplain is marked by sinuous palaeo-oxbows. In the remaining segment of the valley the floodplain is narrow (up to 40 m) and lower.

The top of this landform is transformed by mine dumps or slope deposits. A few hundred years of mining activity led to considerable changes in the relief. Therefore, it is assumed that the top of alluvium hidden under the mine wastes did not have to coincide with the natural surfaces of fluvial terraces. Consequently, in the map (Fig. 1) only inferred contours of particular terraces are drawn (Fig. 1) in the Ropyshche area instead of well-documented boundaries. It must be emphasized that these contours do not correspond to those presented by Stelmakh (2005).

The present-day Velyky Lukavets River bed between the Stavyshche River tributary and the northern boundary of the area presented on the map (Fig. 3) has a sinuosity index of about 1.51 and is mainly of alluvial character. In several places, however, the bedrock is exposed, mostly the salt-bearing Vorotyshcha beds. The 19th-century maps of the mine's vicinity show that at that time the Velyky Lukavets River bed was even more sinuous. The channel gradient adjacent to Ropyshche amounts to about 3.4 m/km. In the escarpments close to the present-day river bed, mine wastes, wooden linings of shafts, and woven linings of galleries are quite often uncovered. This suggests that such zones of weakening in the rocks have been used by the river bed. Probably, also in this zone an increased supply of both natural and anthropogenic material to the river bed took place.

Among other signs of human activity important is the disappearance of farmlands, which covered a significant part of the area even a dozen of years ago. Recently, the large cropfields, typical of the past political system, are vanishing, whereas pastures and meadows are replaced by wastelands.

During the most recent floods in the years 2007 and 2008, intensive relief shaping processes took place. Comparison of photographic documentation of the same sites after floods revealed a 20–30 cm incision into some valley sediments, bank cutting and destruction of terrace scarps within the zone up to 8 m wide. In a short, straight segment downstream of the confluence with the Rinne Stream, the river bed was shifted by about 20 m and a bar was deposited.

The deepening of river bed seems to be relatively high considering the fact that a trunk of *Abies alba* cut below the Ropyshche before the year 1298 AD (Alexandrowicz *et al.*, 2005) was protruded from alluvium less than 50–60 cm above the recent river bed (M. Krąpiec, *pers. comm*. 2009).

The recent river flow apparently takes advantage of the zones of low cohesiveness in Quaternary sediments caused by mining operations. It is documented by fragments of timber lining found in scarps of terraces.

Moreover, downstream from Ropyshche, crevasse splays and deltaic cones were formed on the recent flood plain as well as tree trunks were transported, both resting on bars near the river bed and even eroded from the alluvium.

Dominance of channel lithofacies in the accumulated material can be an effect of declining agriculture in the valley and resulting deficit in supply of finer detrital fractions. It may also decrease the sediment load carried by the river, which results in more advanced deepening of the river bed. Gravel lithofacies were redeposited from older terraces and from the salt-bearing Vorotyshcha beds. The main components of gravels are flysch and Miocene sandstones derived from the Vorotyshcha beds, Dobrotiv beds, and Sloboda Conglomarates (Sokołowski *et al.*, 2009).

SUB-QUATERNARY RELIEF

The shape of the top of Miocene strata reconstructed on the basis of detailed geological mapping is generally conformable with the present-day relief of the Velyky Lukavets River valley and its peripheries, although the course of the fossil landforms does not coincide accurately with the present-day one. The axis of the fossil valley bottom is locally shifted by about 100 m to the west compared to the present-day river bed (Fig. 5). Nearby the present-day Rinne Stream bed and to the north of it, a flat area occurs, the central part of which is occupied by a bedrock high accompanying the above-mentioned mud volcano.

The major part of the south-eastern Ropyshche area, situated below 406 m a.s.l., is the centre of the highest density of underground workings (see Mitura, 1944). A very diversified relief (with alternating highs and lows of the top of Miocene strata) suggests that the substantial factor in its development was subsidence. Similarly, the south-western valley slope in the area of Nadzieja-1 well is certainly the result of human activity, which reached the top of Miocene deposits. This is indicated by a considerably larger inclination of the valley slope in this area, compared to the slopes of adjacent highs on the left side of the valley. It must be mentioned that Stelmakh (2005) associated rectilinear course of this valley with the effects of neotectonic movements. Only the north-western slope of the valley seems to follow more natural course, only slightly modified by anthropogenic transformations.

AN OUTLINE OF RELIEF DEVELOPMENT OF THE VELYKY LUKAVETS RIVER VALLEY

The pre-Quaternary stage of relief formation is of Late Pliocene age and includes the development of the Krasna level (Gofshtein, 1979), initially related to denudation but later determined as polygenetic one, with undoubtful, significant contribution from fluvial processes, including accumulation (Gofshtein, 1979; Kravchuk, 1999; Kadnichanskiy, 2008). These authors and also Tsys (1966) suggest that the Krasna level corresponds to terrace VII in the Dnister River valley.

In the Eopleistocene, the Loyova level was formed (initially regarded as Pliocene in age; Teisseyre, 1933b; Gofshtein, 1962; Tsys, 1966; Kravchuk, 1999), which corresponds to terrace VI in the Dnister River valley. Its polygenetic origin was accepted as late as in the 1960s (see Kravchuk, 1999), although Bujalski (1938) marked gravels located in the range of this level on his geological map of the area of Pasovishche. Hence, the accumulational character of the Loyova level confirmed in the area of the Prilukvinska Upland (where it is bipartite; Łanczont & Boguckyj, 2002; Łanczont *et al.*, 2003) indicates the pattern known from the Polish Carpathians, where the valley levels form a system of high, Early Pleistocene terraces (Zuchiewicz, 1984, 1995).

If the 60–80 m level present in the upper parts of the Velyky Lukavets River valley corresponds indeed to the 60–70 m level distinguished by Łanczont and Boguckyj (2002) in the Bystrytsya Solotvinska River valley, it should be accepted that the dissection at the Eopleistocene/Mesopleistocene boundary amounted at least to 40 m. Fluvial sediments encountered at the basal part were attributed by Łanczont and Boguckyj (2002) to the Bavelian Interglacial (in Poland – Podlasian Interglacial, in Ukraine Shirokino Interglacial) (22-27 OIS). This stage was followed by deposition of loess, interrupted during climate warmings by formation of soil horizons, which have lasted until the Schöningen Inter- stadial (Lubavian in Poland, Kaydakian in Ukraine – OIS-7).

The next period of relief formation, until the Eemian Interglacial, is poorly recognizable. Apart from progressing incision, both the valley broadening and the formation of flats are visible, accompanied by episodes of deposition.

As revealed by absolute age determinations of coarse-grained channel sediments from the bottom of the Velyky Lukavets River, the river bed attained its lowermost position during the Eemian Interglacial (Pryluky in Ukraine – 5e OIS). Moreover, channel sediments from the Early Weichselian and the Weichselian Early Pleniglacial were preserved at the valley bottom as well, but the formation of flood plain at this stage of valley history is documented for the Weichselian Middle Pleniglacial (Glinde Interstadial; *cf.* Sokołowski & Stachowicz-Rybka, 2009). During the remaining part of the Middle Pleniglacial, a swamp developed on the floodplain with periodical lakes, some of which can be linked with thermokarst depressions. The lakes must have been saline, at least temporarily (Stachowicz-Rybka *et al.*, 2009a, b). It is possible that the beginning of the Weichselian Late Pleniglacial was the time of more distinct aggradation and widening of the valley, during which the terrace II was formed.

Dissection of this level took place during the later part of the Late Pleniglacial (*i.e.*, before 16.1 ka). First, a short period of channel deposition occurred, being followed by formation of swamps with small lakes and ponds filled with muds and biogenic sediments (peats, peat muds and biogenic muds) during the Late Weichselian. The period of dissection and formation of younger covers is perfectly documented in the vicinity of the Rinne Stream bed. At the same time, the valley slopes were shaped by slopewash and

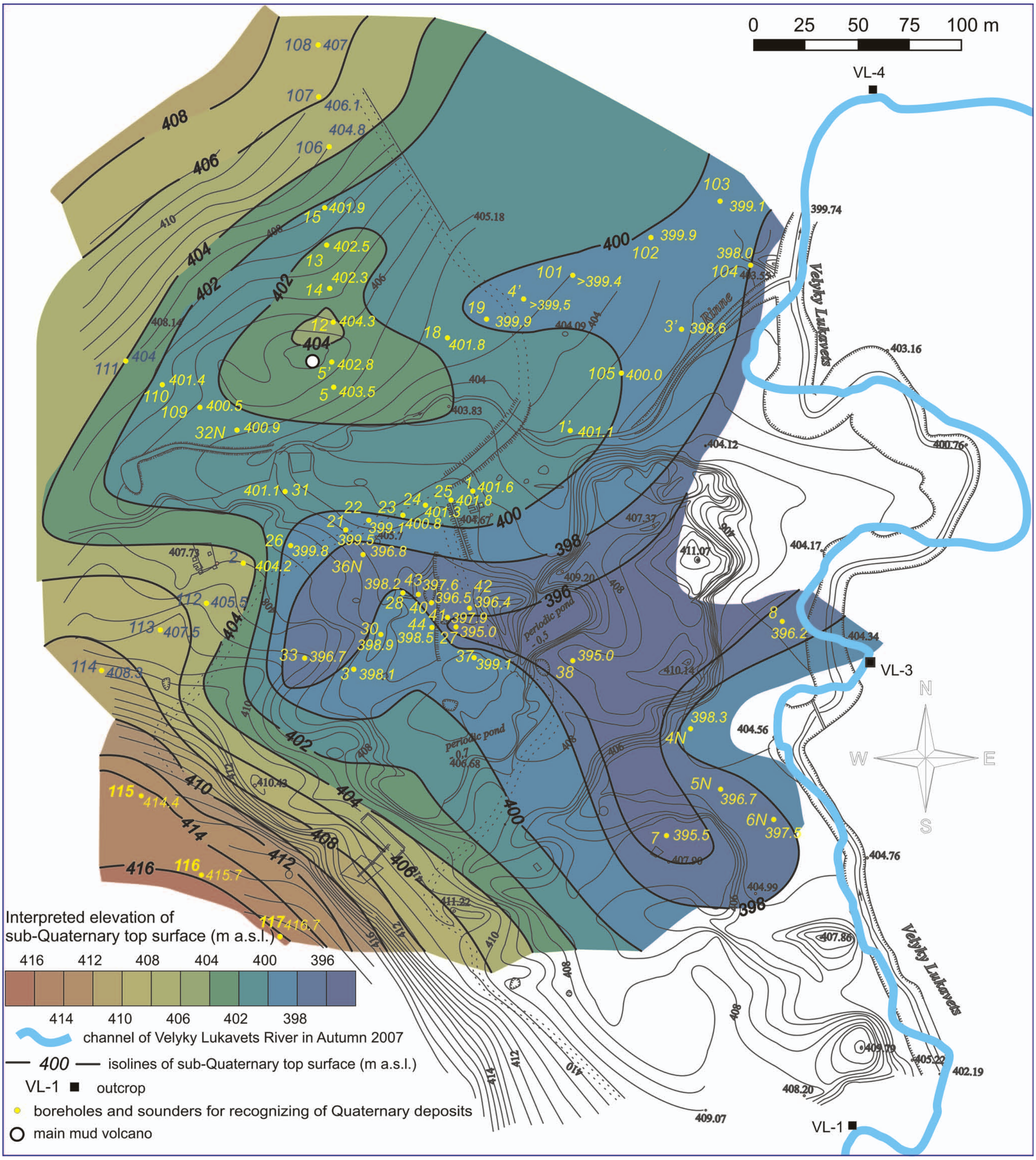

Fig. 5. Top of sub-Quaternary relief in Ropyshche area

solifluction, which led to the development of footslopes. Next, a minor dissection period took place at the turn of the Late Weichselian and the Holocene. Relief and older sediments indicate that in the past the Velyky Lukavets River possessed considerably lower energy than at present, but it was probably a meandering or anastomozing river throughout its history (*cf.* Teisseyre, 1992; Mol *et al.*, 2000; Vandenberghe, 2001).

During both the Eo-Holocene and Meso-Holocene, the environment remained practically unchanged with surviving swamps, lakes and ponds.

Long duration of similar environmental conditions dominated by low-energy flows points out that: (i) the Velyky Lukavets River could have been an anastomosing river even during glacial periods, or (ii) damming of the river bed was probably related to neotectonic movements or to landslides in the vicinity of confluence with the Dashevets Stream (Fig. 3 – Sokołowski *et al.*, 2009; Sokołowski & Stachowicz-Rybka, 2009). A similar situation from the Holy-Cross Mountains was described by Sołtysik (2000).

It is possible that a low-energy depositional environment has survived at the valley bottom until the Middle Ages. In the 7–9th centuries, distinct (about 2 m) deepening of the valley took place and different development processes commenced, maybe due to the breaking of the dam.

After this event, the course of the river channel did not differ significantly from that recently observed, and conditions typical of proximal floodplain have developed. Moreover, the increase of grain size in the overbank deposits was observed (Sokołowski *et al.*, 2009). The next turning point in the history of the valley took place in the 14th century and lasted until the 1960s, when Ropyshche became the centre of mining activity: first of salt, then ozokerite and oil. Mining operations required the sinking of a large number of shafts (Kotarba & Stachowicz-Rybka, 2008), which resulted in excavation of large volumes of mining wastes and their accumulation in the dumps. The rock material combined with anthropogenic components: fragments of bricks, glass, metals and timber was up to now the main component of alluvial sediments. Particularly intensive mining operations took place between the 19th century and the first half of the 20th century. As documented on some old mine and other maps, this was the formation time of the main part of recent floodplain, the outline of which is shown in Fig. 3. The floodplain was probably dissected after the closure of mining operations, when the supply of sedimentary material ceased, *i.e.*, about 40–50 years ago. Today, the river terrace rises about 1 m above the river bed.

Another problem is the link between relief development and neotectonic movements. Presumably, the subsequent character of the Velyky Lukavets River valley north of Molotkiv, its relationship with the thrust of the Starunia fold over the Gvizd fold (the presence of dislocations at the boundary between the valley and the Bzovach Hill was confirmed by gravimetric survey; see Porzucek & Madej, 2009), asymmetry of the valley or dynamics of recent land-forming processes including the activity of mud-volcanoes (Kravchuk, 1999; Stelmakh, 2005; Stelmakh & Pilipenko, 2008; Stelmakh *et al.*, 2008) can be regarded as distinct signs of tectonic movements. Their results are controlled by diversified resistance of rocks to erosion, as revealed, for instance, by the course of the valley along the outcrops of the salt-bearing Lower Miocene Vorotyshcha beds, the resistance of which is low. The more resistant Sloboda Conglomerates or Dobrotiv beds crop out on the valley slopes and on the adjacent culminations of the Bzovach and the Pasovyshche hills (see old geological maps of Zuber, 1885 and Bujalski, 1938). Hence, it cannot be excluded that short ridges of the Bzovach and the Pasovishche are, in fact, monadnocks.

GEOMORPHIC PRINCIPLES OF FURTHER EXPLORATION FOR LARGE MAMMALS IN STARUNIA

The most important geomorphic factor, which led to the accumulation of large mammals' remnants was the depression, into which the animals sunk.

The studies of recent and fossil landforms fully support the shape of both the ground surface and the top surface of the sub-Quaternary basement in the Ropyshche area (Fig. 5), which facilitated the development of swamps and accompanying ponds and lakes. Such morphology occupies most of the southern part of the Ropyshche area. Therefore, factors controlled by the age and lithology of Quaternary strata appear to be more important in this case (Sokołowski *et al.*, 2009), as well as geochemical constraints (Kotarba *et al.*, 2009).

The latter controls undoubtedly resulted in perfect preservation of so many fossils within such a limited area. Other controls remain unknown, although the role of salt licks has been raised. It must be emphasized, however, that both the morphology and lithology of Quaternary sediments provide grounds for the future exploration along the whole valley segment between Molotkiv and Starunia. Such exploration should be preceded by preliminary geochemical survey, as the remnants of historical mining exist also in the right bank of the Velyky Lukavets River as well as in the lower segment of the Dashevets Stream valley. Moreover, it seems likely that the entire segment of the valley might have been the fragment of a seasonal migration trail of animals, whereas the fine-grained, swamp-lacustrine sediments covering the valley bottom might have formed the trap, which was difficult to avoid.

CONCLUSIONS

Along the margins of the subsequent Velyky Lukavets River valley flattened ridges and flat bulges occur, representing the fragments of planation surfaces: the Krasna (170 m) and Loyova (100 m) levels of, respectively, Late Pliocene and Eopleistocene ages. Below, flats of the next, pre-Late Pleistocene levels occur.

The valley attained its maximum depth during the Eemian Interglacial (OIS 5e). Its bottom presumably hosts three terraces composed of the Weichselian and Holocene sediments (OIS 5d – 1), the top of which was transformed by mining operations.

In the southern part of the abandoned mine, the top surface of the sub-Quaternary basement is deformed by ground subsidence and collapse over the mine workings.

The observed recent incision of the river bed and increasing amounts of coarse fractions in the transported material result from the decline of agriculture and decreasing intensity of slopewash.

The relief of the valley bottom enables further exploration for large mammal fossils, also outside the area of the abandoned ozokerite mine in Starunia.

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