

# CHRONOSTRATIGRAPHY AND CHANGES OF ENVIRONMENT OF LATE PLEISTOCENE AND HOLOCENE AT STARUNIA PALAEOONTOLOGICAL SITE AND VICINITY (CARPATHIAN REGION, UKRAINE)

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Sokołowski, T. & Stachowicz-Rybka, R., 2009. Chronostratigraphy and changes of environment of Late Pleistocene and Holocene at Starunia palaeontological site and vicinity (Carpathian region, Ukraine). *Annales Societatis Geologorum Poloniae*, 79: 315–331.

**Abstract:** This paper presents the results of absolute dating and biostratigraphical analysis carried out for alluvial sediments of an abandoned Starunia ozokerite mine located in the Velyky Lukavets River valley, in which large mammal remains were discovered in the first half of the 20th century. The sediments build up three terrace levels. The highest one, up to 8 m high (terrace II), is likely to be associated with a stage of aggradation, as well as with a short episode of valley broadening, which occurred in the Weichselian Late Pleniglacial. The lower one, 4 m high (terrace I), is most likely to be linked with the Holocene, despite a considerable transformation of its top due to mining activity. The lower part of this terrace cover bears coarse-grained channel sediments dated to 120.6–58.9 ka BP (Eemian Interglacial?–Early Pleniglacial – OIS 5e, 4 and 3), and overbank (distal floodplain) mud with intercalations of biogenic deposits (peat, peat mud and biogenic mud). The overbank deposits are dated to 48.2–11.11 ka BP (Glinde Interstadial?–Younger Dryas, OIS 3-2) and are overlain by Holocene (OIS 1) mud and biogenic deposits. In boreholes drilled in the vicinity of the present-day river channel, younger sediments occur more frequently. These include sediments originating from the Late Weichselian overlain by Holocene sediments. However, sediments originating exclusively from the Holocene are infrequent. The deposition of sediments took place in specific conditions of a permanent saturation of the environment with brine, petroleum and thickened bitumen. In the longest period of deposition (48.2–1.27 ka BP), ephemeral swamps, ponds and lakes were developed in different parts of the floodplain. They were marked by the presence of: *Juncus glaucus/effusus*, *J. articulatus*, *Typha* sp., *Batrachium* sp., *Potamogeton filliformis*, *Bidens tripartita*, *Ranunculus sceleratus* and *Phragmites communis*, as well as by halophytic species, like: *Zannichellia palustris*, *Triglochin maritimum*, *Schoenoplectus tabernemontani*, *Puccinellia distans* and *Eleocharis palustris*. Rhythmic oscillations between cold and warm climatic conditions, typical of the Weichselian age and well identified in Western Europe, are here marked by the changes of plant communities (woody assemblages passing into steppe and tundra), but are not noticeably recorded in the sediments of the Velyky Lukavets River. This shows that the greatest part of the discussed period involved the formation of poorly differentiated silty overbank sediments with intercalations of biogenic sediments. However, the variability of sediments provides evidence for extreme events which occurred in the Holocene.

**Key words:** Late Pleistocene, Holocene, fluvial deposits, environment, Starunia, Carpathian region, Ukraine.

*Manuscript received 10 May 2009, accepted 30 October 2009*

## INTRODUCTION

Stratigraphic analysis of Quaternary sediments was part of an interdisciplinary research project conducted in the Starunia area, located about 130 kilometres southeast of Lviv, Ukraine (Fig. 1). The study was carried out between 2006 and 2009 in an abandoned ozokerite (earth wax) mine (= Ropyshche) (Kotarba, 2009), where remnants of a mammoth and three woolly rhinoceroses, with one nearly fully

preserved carcass, were found in 1907 and 1929. The discovery of large Pleistocene mammals in the Starunia ozokerite mine was a spectacular scientific event on a world scale. An unique combination of oil and brine within the Pleistocene mud, into which one of the rhinoceroses had sunk, resulted in a nearly perfect preservation of this specimen.

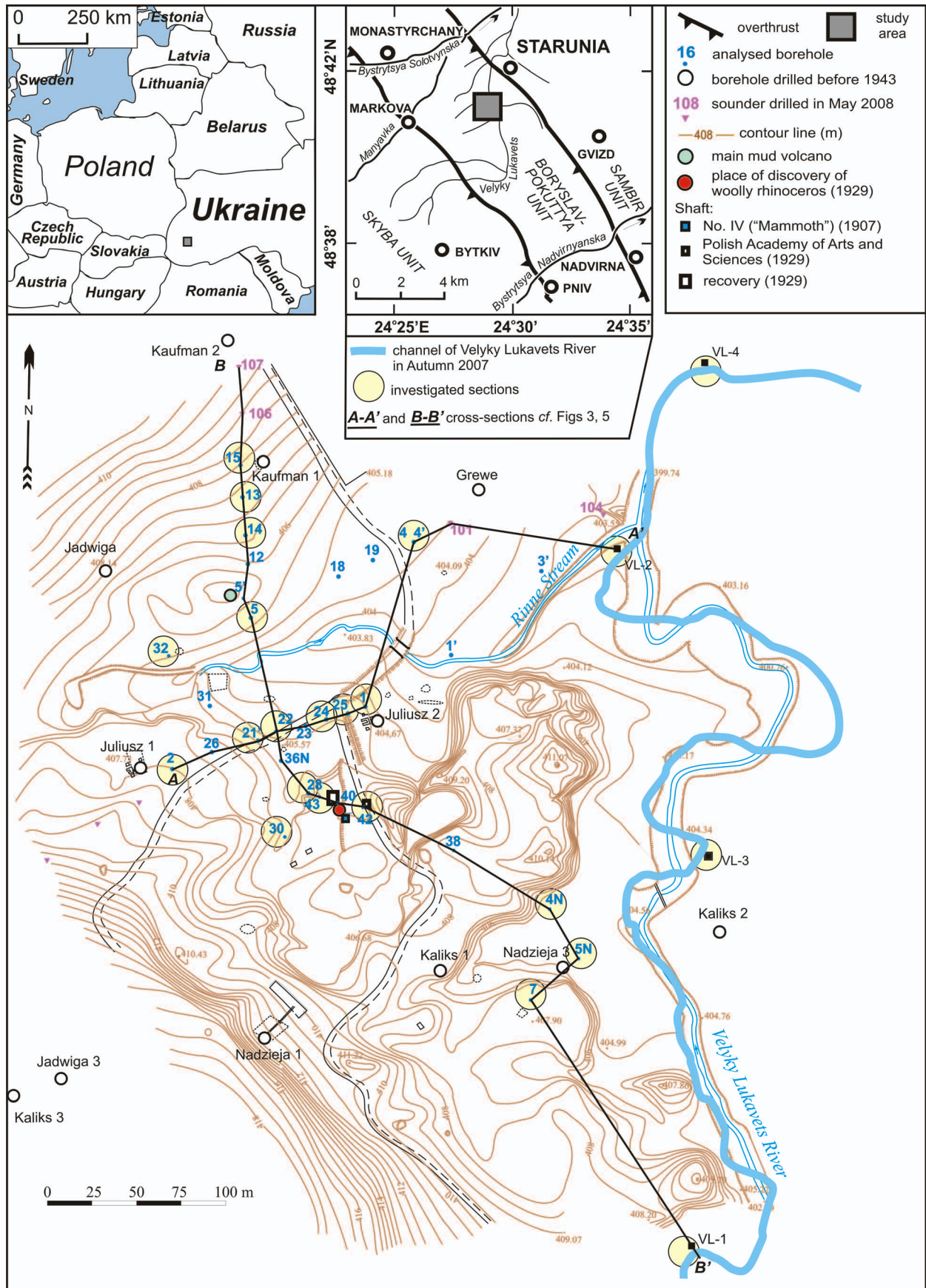


Fig. 1. Sketch map of the vicinity of Starunia (Carpathian region, Ukraine) with location of the study area

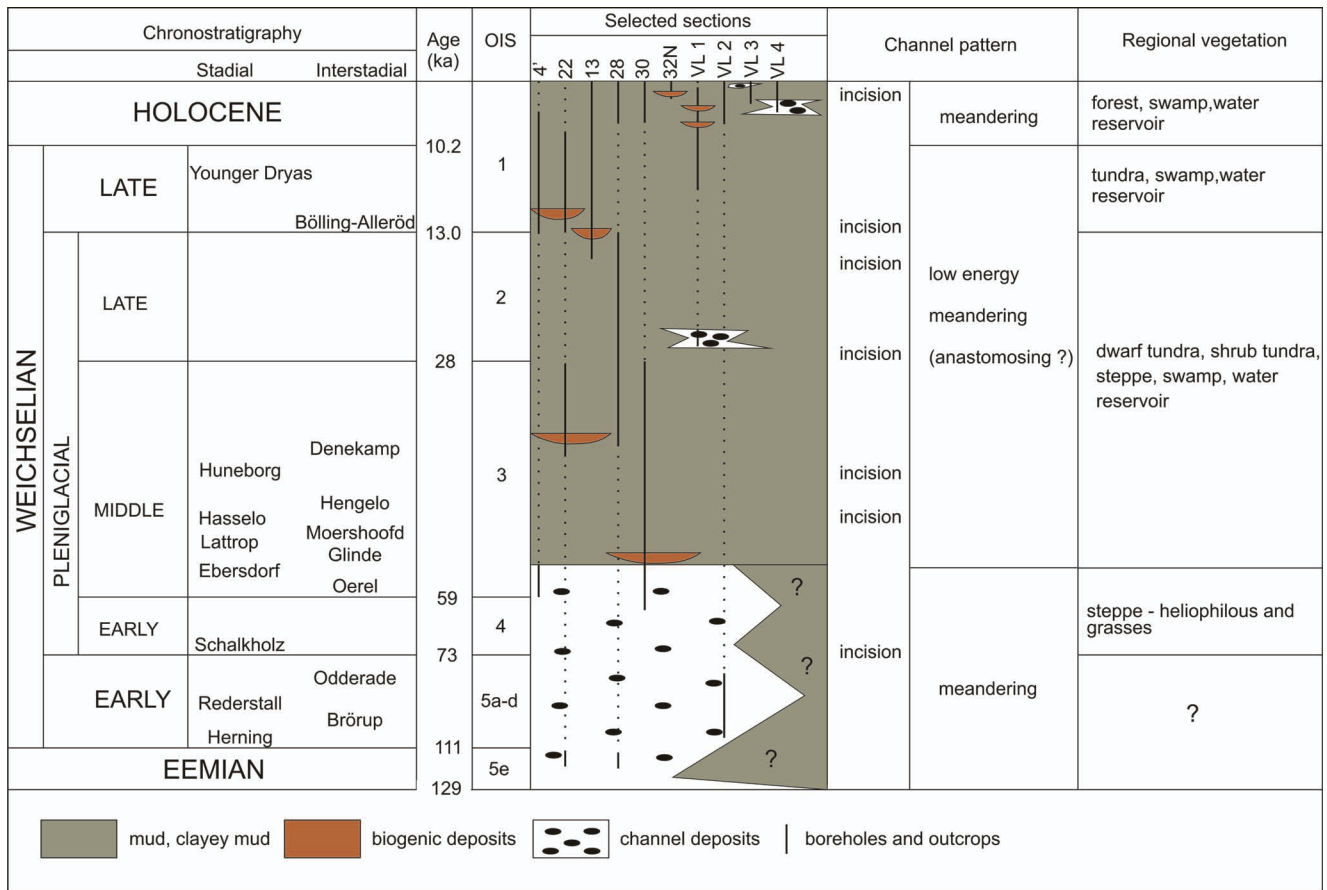


Fig. 2. Chronostratigraphy, channel pattern and regional vegetation of selected sections

The study area is located on the low, left-bank fluvial terraces of the Velyky Lukavets River at its junction with the Rinne Stream (Fig. 1). Although geological survey conducted in Starunia has over a hundred years' tradition, it did not succeed in the recognition of lithology and stratigraphy of Quaternary sediments. Up to now, reports on the development and age of Quaternary deposits filling the Velyky Lukavets River valley, adjacent Maly Lukavets River valley and the surrounding area, as well as studies and dating of the recorded remains of plants and animals, were provided by: Zuber (1888), Rogala (1907), Bayger *et al.* (1914), Nowak and Panow (1930), Szafer (1930), Mitura (1944), Kubiak (1971), and Kuc *et al.* (2005). The above-mentioned papers were also discussed by Alexandrowicz (2004) and Alexandrowicz *et al.* (2005).

During the first stage of excavations (Bayger *et al.*, 1914), the remnants of animals were found in a secondary sediment; hence, it was impossible to determine their age. However, during the second stage of research (Nowak *et al.*, 1930), remains of plants dominated by tundra species were found in the large mammals' surrounding sediments, which allowed Szafer (1930) to associate these findings with the "Cracovien glaciation" (=Elsterian). The conviction about the older age of remains was maintained for a long time. Among Ukrainian researchers, Kravchuk (1999) still related the Starunia flora to the Middle Pleistocene, assuming the similarity of flora to the one representing the

Likhvin Interglacial (=Holsteinian), shown in a relatively well examined section of Quaternary sediments from Krukienice near Sambir (Gerenchuk *et al.*, 1972), although the age of Starunia findings was already associated with the Late Glacial by Raskatov (1966). This was confirmed by the results of absolute age dating conducted on the remains of the mammoth and rhinoceroses (Kuc *et al.*, 2005). Their age is strongly diversified and varies between 14,140 and 47,000 years BP, which, according to the last authors, could result from the contamination of remains with oil. The examination of plant remains was reinterpreted by Granozowski (2002), who narrowed the time range of the death of the animals to the Hengelo Interstadial (39–36 ka BP; Fig. 2). Additionally, the morphological features of some bone and teeth remains of the Ropyshche rhinoceroses, resulting from evolutionary changes of the *Coelodonta* genus, indicate their relatively young age, as they show traits typical of individuals that lived in the Late Pleistocene and originated from the evolutionary line of the Eurasian woolly rhinoceroses (Kahlke & Lacombe, 2008).

The aim of this paper was to determine the stratigraphy of the identified sediments and to reconstruct the Late Pleistocene and Holocene evolution of the Velyky Lukavets River valley at Starunia. This objective was achieved through research conducted by the authors in the years 2007–2009 within a project, the range and topic of which were discussed by Kotarba (2009).

## PRESENT-DAY NATURAL ENVIRONMENT OF ROPYSHCHE AREA

Description of the present-day environment is limited to the following three components, which we consider to be the most important ones: relief, vegetation and aquatic conditions. The deposition of alluvium forming the terraces, as a component regarded as the essential one, was outlined separately.

Although the source area of the Velyky Lukavets River is located in the Outer Eastern Carpathians, the greatest part of the investigated catchment is situated in the range of the Boryslav–Pokuttya Unit, located within the Carpathian Foredeep Basin (e.g., Koltun *et al.*, 2005). The Boryslav–Pokuttya Unit is built up by flysch strata and the Menilite beds, which originated from Oligocene and Lower Miocene and now cover the greatest area of the riverside and are dominated by shales. The above-mentioned strata are accompanied by the Polyanytsya beds, dating from the Lower Miocene and bearing more sandstones (Koltun *et al.*, 2005). The Carpathian Foredeep Basin is dominated by the Vorotyshcha beds, also dating from the Lower Miocene. These beds are composed of salt-bearing clays, laterally passing into the Sloboda Conglomerates and Dobrotiv beds dominated by sandstones and shales (Koltun *et al.*, 2005; Korin, 2005).

The height of fluvial terraces in the vicinity of the abandoned mine usually does not exceed 4 m (Sokołowski, 2009). In the Ropyshche area, the top surfaces of terraces are considerably transformed by the former mining activities; therefore, the distinction of terraces would be inaccurate if based on relief. Due to this fact, we distinguished individual terraces on the basis of variations in their lithology and age of sediments. A few tens of metres to the north of the Rinne Stream channel, a mud volcano occurs, the cone of which is flat and hardly visible. Moreover, the entire study area is marked by the occurrence of small basins filled with water, petroleum and brine, which are probably the remains of abandoned mineshafts or mud volcanoes.

Slopes in the peripheries of the valley are noticeably asymmetric. The steeper one, located on the eastern side, slopes down from the Bzovach Hill (579 m a.s.l.). Its culmination is marked by the presence of a flat top (visible, though of a small surface; Sokołowski *et al.*, 2009), being the remnant of a former levelled surface (Krasna level – Gofshtein, 1962), associated with the Late Pliocene. On the culmination of the Pasovyshche (512 m a.s.l.) – Pohorylets (483 m a.s.l.) ridge, surrounding the valley from the west, a flat top has been retained, being associated with the Loyova level, which is a denudation level associated with the Early Quaternary (Gofshtein, 1962). Recently, several steps have been distinguished in this level (Łanczont & Boguckij, 2002). The ridges, which slope down from this site towards the bottom of the Velyky Lukavets River valley, are inclined at small angles and are marked by the occurrence of several lower and younger flat steps developed in the Pleistocene.

The alluvial bedrock is built by the Vorotyshcha salt-bearing beds (Korin *et al.*, 2005), the top of which is marked by a diversified relief (Sokołowski, 2009).

A characteristic feature of the Ropyshche area is a strong saturation of the sediments with brine, petroleum and bitumens. This saturation took place at least in the Pleistocene and has been going on until to day (Kotarba *et al.*, 2009a, b). At present, such a saturation results, for instance, in the occurrence of plants typical of salt flats. One such species, *Lepigonium salinum* Ser., which is now known as *Spergularia salina* J. Presl. and C. Presl. and is to be found in the investigated area up to the present day forming patches with *Puccinellia distans* (L.) Parl. in the most saline sites (Mościcki *et al.*, 2009), was previously mentioned by Łomnicki (1914) among species representing the meadow flora. *Puccinellia distans* (L.) Parl. is characterized by a very high resistance to soil salinity. It is assumed that 5–10 g of salt per 1 kg of soil is the optimum of this halophyte's requirements. However, as it was stated by Kozłowski *et al.* (2004), even with 73 g of sodium chloride per 1 kg of soil, the existence of the plant is still possible.

From the Middle Pleniglacial up to the present day, the following plants tolerating an increased salinity are to be found: *Triglochin maritimum* L., *Schoenoplectus tabernemontani* (C.C. Gmel.) Palla, and *Phragmites australis* (Cav.) Trin. ex Stued. The sediments are characterized also by the presence of other halophilous species preferring more humid habitats, such as: *Eleocharis palustris* (L.) Roem. and Schult., *Zannichellia palustris* L., and *Potamogeton filliformis* Pers.

At present, brine and petroleum reach the ground surface together with the effluences of water through abandoned mine shafts and boreholes, among which Nadzieja 1 well is a remarkable one, with natural gas still escaping from it. The water of the effluences definitely comes from water-bearing horizons of a deeper location. This is indicated by a generally low rock humidity examined during drilling. Slightly more humid rocks, from which water was occasionally drained, were found infrequently and nearly exclusively close to the Rinne Stream.

The surroundings of Starunia have been penetrated and occupied by people for a long time, what is indicated by the presence of several hunting campsites, the oldest of which originate from the Palaeolithic period and are dated to about 40 ka BP (Matskevych, 2005). According to the above-mentioned author, it cannot be excluded that some of the bone and skin damages observed in the bodies of the discovered animals may be associated with contemporary human activity.

The closest vicinities of Ropyshche are marked by the occurrence of woody areas, usually overgrowing the culminations of greater highs or slopes showing higher inclination, like the Bzovach Hill. Several years ago, a large part of the ground surface was covered by farmlands, meadows and pastures. At present, the areas of farmlands, particularly the large-scale ones typical of the former political system, have decreased. The meadows and pastures are passing into wastelands as well.

## SAMPLING AND METHODS

Large mammals were found in the muds with *Betula nana*, which, according to Nowak and Panow (1930), marked the lowest member of the section of Pleistocene sediments. That is why the fine-grained and biogenic sediments were examined more accurately. Palaeobotanical research (palynology and analysis of macrofossils), malacological and lithological studies, as well as absolute age datings were carried out for sediments sampled from the following boreholes Nos 1, 2, 4, 4', 4N, 5N, 6N, 7N, 13, 14, 15, 22, 24, 25, 28, 30, 32N, 42 and 43, and outcrops VL-1, VL-2, VL-3 and VL-4 (Figs 1, 2). Descriptions of methods of these studies are contained in papers by Stachowicz- Rybka *et al.* (2009a, b) and Sokołowski *et al.* (2009). The OSL (optically stimulated luminescence) dating was carried out at the GADAM Centre (Gliwice Absolute Dating Methods Centre, Silesian University of Technology, Poland), whereas the <sup>14</sup>C dating – at the Poznań Radiocarbon Laboratory. The first method was applied mainly for the dating of coarse-clastic sediments sampled from the river channel. Only in one case was it used to date the fine-grained over-bank sediments. Radiocarbon datings were performed for plant macroremains extracted from fine-grained overbank sediments and biogenic deposits. Details of the radiocarbon method were described in Kuc *et al.* (2009).

## LITHOLOGY

According to a review of previous publications compiled by Alexandrowicz (2004) and Alexandrowicz *et al.* (2005), the Pleistocene and Holocene sediments of the Ropyshe area formed a section described by the following stratigraphic succession: (i) grey clay with plant remains, probably including *Betula nana*, (ii) gravel with sand and sandy-clayey intercalation in the top, (iii) stratified clay and sandy loam with fossil flora, and (iv) loam and silty loam with soil in the top. Up to now, the descriptions of individual sections have not mentioned any biogenic sediments apart from accumulations of plant remains. Such observations are hard to justify, as peat is mentioned in one of letters written by Edward Panow (see the copy of this letter in Alexandrowicz, 2004, pp. 82–83). Peat is also visible in the outcrops of terrace scarps along the Velyky Lukavets River bed. Therefore, the described section cannot be treated as a standard one. The strata probably represent typical subenvironments of fluvial valleys: the river channel and proximal and distal floodplain.

On the basis of the diversity of textural and structural features in each subenvironment, we distinguished a series of lithofacies and assigned them letter codes (Table 1; Sokołowski *et al.*, 2009). In the same paper, we presented a detailed description of lithology, here only outlined. Moreover, due to considerable similarity of the sediments, we do not describe each section separately, but present one generalized description of the examined strata. All these sediments, in each subenvironment, were contaminated with petroleum and salts – halite and gypsum.

### Coarse-grained river channel sediments

The subenvironment of the river channel coarse-grained sediments (CD – channel sediments) is recorded in all terrace levels. Beds of gravel (G), less frequently of sandy gravel (GS) or sand (S), attain a thickness from several centimetres to 7.1 m (Figs 2–5). Structural features of the lithofacies and their genetic interpretation are presented in Table 1.

### Fine-grained overbank sediments

This part of the floodplain (PF) is marked by the occurrence of brown muds, showing various intercalations of sands and locally attaining a thickness of almost 3 m. Particular lithofacies are likely to form changeable sequences (Table 1) and contain admixtures of plant remains and anthropogenic material, including pieces of bricks, material derived from mine dumps, fragments of boards, bottles, plastic wraps, etc. In many areas, the strata are cut by palaeo-oxbows and crevasses. These washouts are usually filled with the following lithofacies: SFr, SFw and FSr. They are also accompanied by abundant plant remains (branches, leaves and seeds).

The fine-grained overbank sediments of the distal floodplain (DF) are dominated by massive silt lithofacies (Fm) of a large scale, attaining a maximum thickness of 10 m (Figs 2–5). Single dropstones and siderite concretions appear frequently.

Most of the sections, particularly their upper segments, bear root hairs, slightly larger root traces (lithofacies Fb), reed rods (lithofacies Frr) and burrows, most frequently covered with a rusty coating.

### Biogenic overbank sediments

Biogenic overbank sediments (C) appear in different parts of the sections sampled from the DF and PF sub-environments, and form lithofacies of a medium or large scale and showing irregular distribution. Their occurrence in the PF subenvironments is infrequent. The peat, being mostly brown or dark brown, however occasionally black (lithofacies Cp), is marked by a various level of decomposition of the plant remains. Locally, it contains a mud admixture (peat mud – lithofacies Cm) or passes into mud with an admixture of small plant remains (biogenic mud – lithofacies Co). In young cuts (palaeo-oxbows?, crevasses?), the segments between silty or silty-sandy lithofacies are typified by accumulations of strongly diversified plant macroremains, not showing advanced humification processes and forming beds of a medium scale (lithofacies Cd).

### Slope deposits

Yellow, grey-yellow and grey muds and sandy muds of slope deposits (SD) appear at the base of slopes surrounding the valley (sections 106, 107, and 112–117; Sokołowski *et al.*, 2009 – Figs 3, 4) and do not exceed 3.6 m in thickness.

Table 1

## Description of subenvironments: a summary

Subenvironments		Lithology of lithofacies	Deposition	Landforms and geomorphic processes
Channel (CD)	Gravel (G)	Usually, maximum particle size - 8 cm, sporadically - 30 cm, sometimes fining-upward sequence and then transition to sandy gravel or sand, grey and after weathering yellow-grey, sandy-muddy matrix, usually horizontally stratified (lithofacies Gh, Sh, vertical succession Gh→GSh), trough-cross-stratified (Gt→GSt), planar-cross stratified (Gp→GSp→Sp), sometimes massive (lithofacies Gm) or low-angle cross-stratified, pieces of wood are often common	Deposition of clastic material in: side bars (Gp GSp Sp), infill of pools (Gt GSt) (Gh, Gh GSh, Sh), washing out of bars (Gt, Gt GSt) and channel pavement ? or short-lived high energy flow ? (Gm)	River channel, bar sand bedforms
	Sandy gravel (GS)			
	Sand(S)			
Overbank	Fine-grained sediments of proximal floodplain (PF)	Brown, grey-brown, muddy sand and sandy mud with ripple-cross lamination (SFr, FSr), or horizontal lamination (Fh), rhythmite with horizontal lamination (SFh, FSh, Fh), in lower members of these deposits wavy (FSw, Fw) and ripple cross lamination of climbing type (SFf, FSf), massive mud (Fm) and sometimes muddy pebbles up to 5 mm are coming up, plant debris and even pieces of wood are very common	Infill of young oxbows and/or crevasse channel ?, vertical accretion depositson proximal floodplain	Washouts, oxbows, crevasse channels (?)
	Muddy sand (SF) Sandy mud (FS) Mud, silt, loam(F)			
	Fine-grained sediments of distal floodplain (DF) Mud, silt (F) Muddy sand (SF) Sandy mud(FS)			
Biogenic (C)	Brown, dark-brown or almost black organic material (lithofacies Cp), in places comprises admixture of mud (muddy peat - lithofacies Cm) or turns to mud with a lot of plant debris (organic mud - lithofacies Co), in young washouts nonhumified plant debris (lithofacies Cd)	Accumulation of plant debris, sometimes with admixture of mud	Lacustrine or wetland areas on distal floodplain or in oxbows	
Slope		Yellow, grey-yellow mud, sandy mud (SD)	Washout on slopes, solifluction	Solifluction and/or wash-out covers

## CHRONOSTRATIGRAPHY AND ENVIRONMENTAL INTERPRETATION

In the paper, the chronostratigraphy (Fig. 2) of Eemian (5e OIS) and Weichselian (in Ukraine = Valdayan, 5a-d, 4-2 OIS) is outlined according to Van der Hammen *et al.* (1967), compared with Woillard and Mook (1982), Martinson *et al.* (1987), Behre (1989), Behre and van der Plicht (1992), Dansgaard *et al.* (1993), Walker (1995), Aalbersberg and Litt (1998), Huijzer and Vandenberghe (1998), and Litt *et al.* (2001). The chronostratigraphy includes modifications pertaining to the area of Poland (Mamakowa, 2003; Latałowa, 2003a; Mojski, 2005). For the Holocene (1 OIS), we applied the divisions by Starkel (2001) and Latałowa (2003b). Previous correlations between the divisions applied for Poland or Western Europe (Lindner *et al.*, 2004; Lindner & Marks, 2008) and the climatostratigraphic units of Quaternary sediments of Eastern Europe were usually limited to the principal units (glacials and interglacials).

The correlated lithological formations were represented mainly by loesses.

Due to considerable transformation of landforms, it was impossible to apply the morphostratigraphic procedures for the Ropyshche area. Additionally, the analysis was hindered by: (i) poor identification of all Quaternary sediments except loesses from the Kolodiiv, Halich and Yezupil sites, located a few tens kilometres away from the study site, and (ii) the location of the studied area. In Western and Middle Europe the climatic conditions were controlled by the Scandinavian ice sheet, the North Atlantic water circulation and the Russian continental air mass (Huijzer & Vandenberghe, 1998). In this part of Europe, the influence of the North Atlantic is not likely to be considerable; however, the Carpathians seem to have a more significant effect on climate. Due to poor identification of Quaternary sediments in the valley and in its closest surroundings, particularly as far as their stratigraphy is concerned, most data are compared to those of Poland.

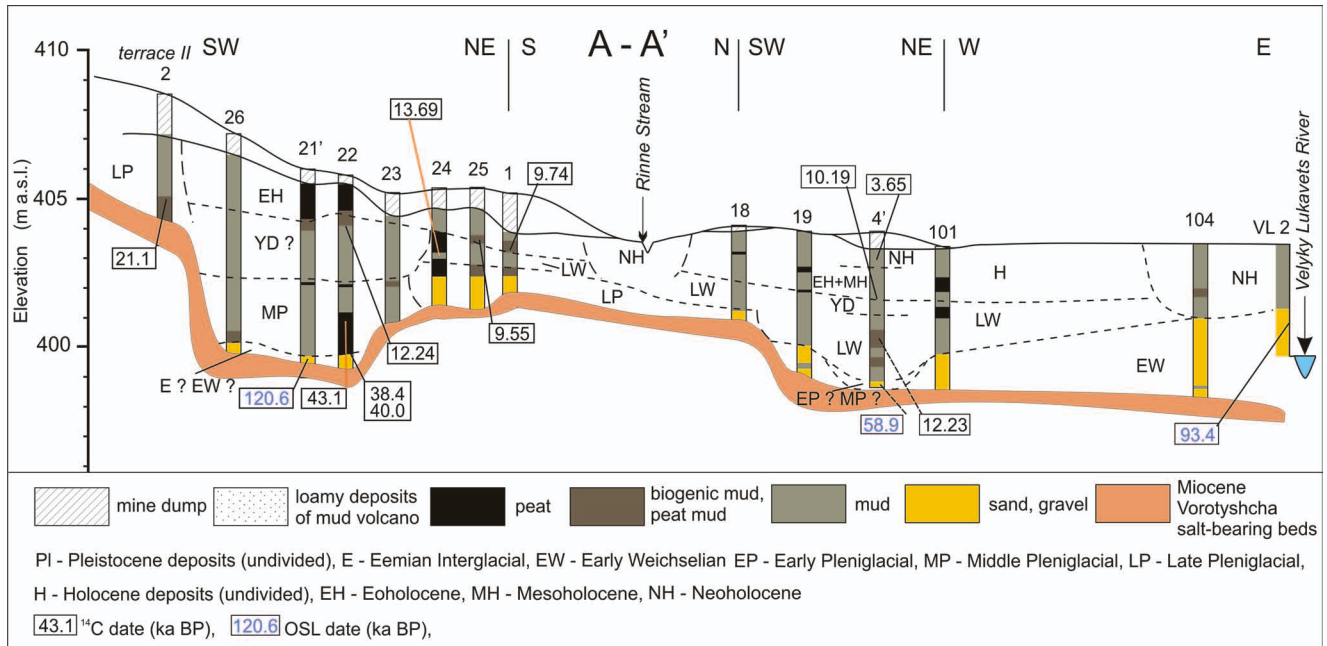


Fig. 3. Geological cross-section A-A'. See Fig. 1 for location

**Eemian–Early Weichselian (OIS 5)**

The results of absolute dating (all dates mentioned in the text are conventional ones) indicate that the oldest sediments examined in the Ropyshche area are the CD ones, sampled in section 21' (Fig. 3, Table 2). The OSL age of 120.6 ka BP allows us to link the sediments with the Eemian Interglacial (OIS 5e). The CD sediments in section VL-2 (Figs 2, 3, Table 2) show younger ages (93.4 ka BP – Early Weichselian, OIS 5a-d); however, scour traces are well marked in the topmost part.

In the Polish Carpathians and Carpathian Foredeep Basin, there are hardly any sites with sediments for which the Eemian Interglacial or Early Weichselian age is documented, or which are associated with these ages (Sobolewska *et al.*, 1964; Laskowska-Wysockańska & Niklewski, 1969; Sokołowski, 2006). The sediments occur in different positions with respect to the river channel.

**Early Pleniglacial (OIS 4)**

In the basal part of section 4, the saturated bitumen of the CD sediments (Figs 2, 3, Table 2) are found, being dated at 58.9 ka BP (Middle Pleniglacial – Late Schalkholz Stadial?/Early Oerel Interstadial? – OIS 4 ?, OIS 3). CD sediments of the Polish Carpathian Foredeep Basin are of comparable age. Gravels found at Radłów on the Dunajec River valley (59 ka BP; Sokołowski, 1995) and at Czaplakówka on the Vistula River valley (67 ka BP; Gębica, 2004) confirm the occurrence of a stage of deposition of fine-grained alluvium during the Early and/or Lower part of the Middle Pleniglacial. The position of the described CD sediments, at a height close to the present-day river channel, proves the appearance of intercalations of different age and shows that the valley bottom was not deepened for a long period of time. On the other hand, this could indicate that

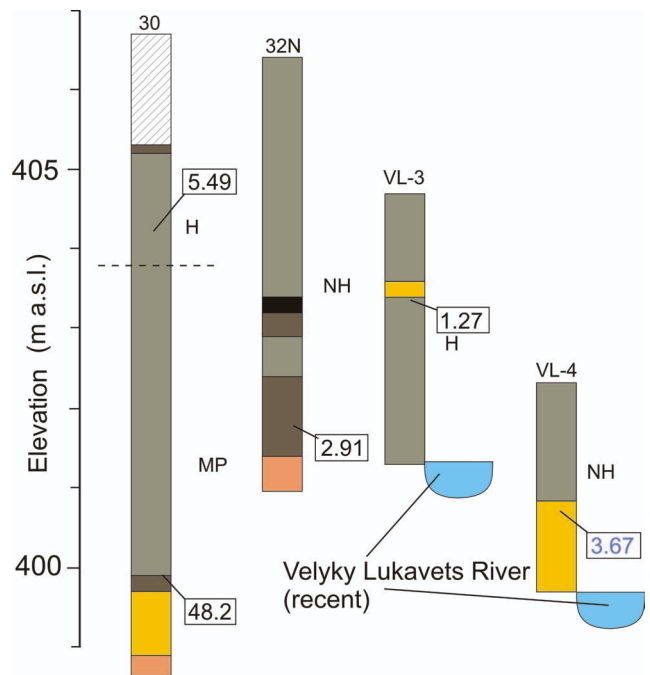


Fig. 4. Lithostratigraphic sections Nos 30, 32N, VL-3, VL-4. See Fig. 1 for location and Fig. 3 for explanation

the river achieved its lowest elevation during the Eemian Interglacial.

It is remarkable that the CD sediments are the only ones retained from the discussed period of time. Overbank sediments were also likely to develop at that time, but they must have been denuded, probably mainly at the end of Early Glacial and the beginning of the Pleniglacial. A marked stage of incision occurring at that time was recorded not only in Poland, but also in Western Europe (*i.a.*, Turkowska, 1988; Krzyszkowski, 1990; Mol *et al.*, 2000; Van

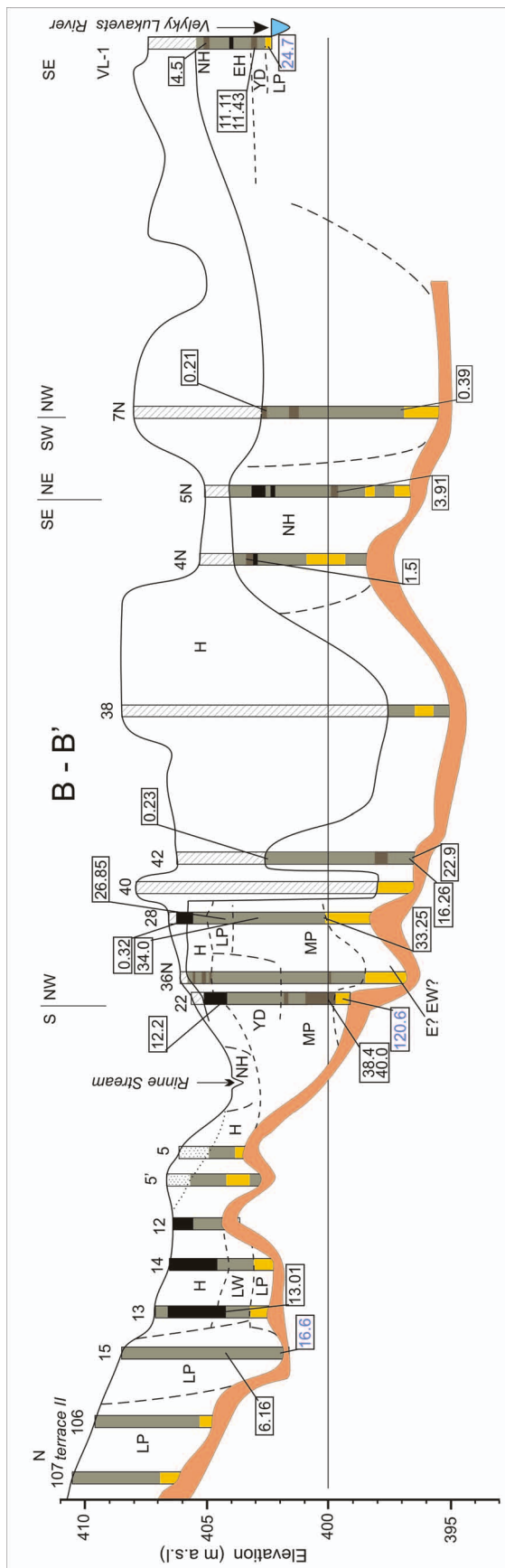


Fig. 5. Geological cross-section B-B'. See Fig. 1 for location and Fig. 3 for explanation

Huissteden *et al.*, 2001). It cannot be excluded that the preservation of CD sediments (found in a relatively good condition, though in minor amounts) could have been supported by the presence of a fine-grained, coherent, filling-cementing mass saturated by bitumens, which could have built up a durable cement, preventing the scour.

The closest sites with sediments of well documented ages of OIS 5e, 5a-d and 4 are the Yezupil and Kolodiiv sites, located a few tens kilometres away to the north. The sites are marked by the occurrence of loesses with the Horohiv pedocomplex being typically developed. It comprises the older lessivé soil formed during the Eemian Interglacial (Horohiv set of soils) and three levels of the younger steppe soils (Kolodiiv set of soils with loess intercalations), originating from interstadials of the Early Weichselian (Boguckij & Łanczont, 2002; Łanczont & Boguckij, 2002; Łanczont & Boguckij, 2007).

At Kolodiiv, the soils were formed with the participation of biogenic deposits which were accumulated in an oxbow lake.

The succession of vegetation, reconstructed on the basis of analysis of pollen grains, corresponds to the development of vegetation in the Eemian Interglacial and Weichselian Glacial (Komar, 2002; Łanczont & Boguckij, 2007; Komar *et al.*, 2009). Pollen zones of the basal part document the presence of assemblages of pine-birch forests with glacial relicts, which serve as evidence for the gradual warming of climate. The further warming resulted in the development of pine-oak forests, followed by the development of multispecies deciduous forests. The subsequent cooling resulted in the growth of herbaceous plants (including xerophytes and halophytes) and a decline in the participation of trees.

### Middle Pleniglacial (OIS 3)

The next stage of development of the Velyky Lukavets River valley falls in the early Middle Pleniglacial time (interstadial complexes – time window 50–41 ka BP; *cf.* Huijzer & Vandenberghe, 1998). This period is indicated by radiocarbon dates, of which the oldest one is 48.2 ka BP (section 30; Fig. 4). However, the type of sediments indicates that this was already the time of development of the floodplain in the Ropyshche area. The floodplain was mainly distal one and was characterized by the occurrence of swamps, ponds or even shallow lakes, in which muds (lithofacies: Fm, Frr and Fb) and biogenic deposits (Sokołowski *et al.*, 2009) were deposited. A younger date of 43.1 ka BP, recorded in section 22 (Figs 2, 3), enables the association of the time of deposition with the Moershoofd Interstadial. Therefore, the dates recorded for the base: 38.4 ka and 40.0 ka BP (Figs 2, 3, 5, Table 2) seem to be slightly rejuvenated.

The assumed interpretation is confirmed by the analysis of pollen spectra and macrofossils, according to which the landscape was initially open, woodless and covered by grassy steppe assemblages of heliophilous herbs and grasses. Vegetation typical to dwarf shrub (low shrub) tundra: *Betula nana* L., *Alnus viridis*, *Salix* sp. and Cyperaceae (Fig. 6), appeared in the areas of a higher humidity. Such a



**Table 2**

Description of the samples and their radiocarbon and luminescence ages

Sections/ Depth (m)	Laboratory code	Laboratory number	Radiocarbon (yr BP) or OSL* (ka BP) age	Calibrated age probability 68.2 % (yr BC) or (AD)	Lithology of samples
43/5.3	St II/43/07	Poz-27168	40 ± 30	1700 - 1720 AD (10.6%) 1810 - 1840 AD ( 7.7%) 1880 - 1920 AD (41.3%) 1950 - 1960 AD ( 8.6%)	Mine dump
43/8.9	St II/43/08	Poz-27169	> 100 pMC		Mine dump
VL-3/0.9	StII VL3/23	Poz-28964	125±30	1680 - 1740 AD (19.8%) 1800 - 1890 AD (39.0%) 1900 - 1930 AD ( 9.4%)	Clayey mud
7/5.7	St II 7/32	Poz-28906	210 ± 30	1650 - 1680 AD (24.7%) 1760 - 1800 AD (31.1%) 1930 - 1960 AD (12.3%)	Clayey mud with plant macrofossils
42/3.9	St II 42/29	Poz-28806	230 ± 30	1640 - 1670 AD (35.8%) 1780 - 1800 AD (26.0%) 1940 - 1960 AD ( 6.4%)	Clayey mud with black mottles and dispersed organic matter
15/3.6	St II 15/28	Poz-28799	240 ± 30	1640 - 1670 AD (45.0%) 1780 - 1800 AD (23.2%)	Clayey mud
28/1.0	St II 28/19	Poz-28801	325 ± 30	1510 - 1600 AD (55.9%) 1610 - 1640 AD (12.3%)	Peat
VL-4/1.7	Starunia VL-4	GdTL-967	3.67 ± 0.18*		Gravel
7/10.8	St II/7/12	Poz-27977	390 ± 30	1440 - 1520 AD (56.0%) 1600 - 1620 AD (12.2%)	Clayey mud with black mottles
4/1.3	ST II 4/34	Poz-28905	625 ± 30	1295 - 1320 AD (27.2%) 1345 - 1395 AD (41.0%)	Clayey mud with black mottles
VL-3/2.1	StII VL-3/18	Poz-28907	1275 ± 30	680 - 725 AD (38.1%) 735 - 770 AD (30.1%)	Peat
4N/2.2	St II 4N/21	Poz-28808	1505 ± 30	540 - 600 AD	Peat
32/4.7	St II/32/05	Poz-27167	2915 ± 30	1200 - 1040	Peat mud
4/0.9	St II 4/24	Poz-28804	3655 ± 35	2130 - 2090 2050 - 1960	Clayey mud with black mottles
5N/5.6	St II/5/06	Poz-27165	3915 ± 35	2470 - 2340	Clayey mud with dispersed organic matter and root traces
VL-1/2.1	St/VL-1/14	Poz-27980	4505 ± 35	3340 - 3310 (11.3%) 3300 - 3260 ( 7.6%) 3240 - 3100 (49.4%)	Clayey mud with dispersed organic matter
30/2.5	St II 30/38	Poz-28903	5490 ± 40	4370 - 4320 4290 - 4260	Clayey mud with dispersed organic matter
15/4.4	St 15/39		6160±40		Clayey mud
4/4.6	St II 4/22	Poz-28803	8460 ± 50	7580 - 7510	Peat
25/1.7	St II 25/17	Poz-28800	9550 ± 50	9130 - 9000 (36.1%) 8920 - 8800 (32.1%)	Peat mud
1/1.8	St II 1/20	Poz-28798	9740 ± 50	9280 - 9195	Peat mud with root traces
4/2.3	St II 4/33	Poz-28904	10190 ± 50	10050 - 9810	Clayey mud with plant macrofossils and dispersed organic matter
VL-1/4.7	St/VL-1/13	Poz-27979	11110 ± 60	11130 - 11000	Peat
VL-1/4.9	St/VL-1/15	Poz-27981	11430 ± 60	11390 - 11270 (68.2%)	Peat
4/3.5	St II/4/03	Poz-27976	12230 ± 70	12230 - 12040	Peat
22/1.7	ST I/22/04	Poz-27164	12240 ± 60	12230 - 12060	Peat mud with plant macrofossils
13/2.9	St II 13/35	Poz-28897	13010 ± 60	13570 - 13250	Peat

Table 2 continued

Sections/ Depth (m)	Laboratory code	Laboratory number	Radiocarbon (yr BP) or OSL* (ka BP) age	Calibrated age probability 68.2 % (yr BC) or (AD)	Lithology of samples
24/2.1	ST II 24/37	Poz-28901	13690 ± 70	14550 - 14130	Clayey mud
42/9.5	St 42/40		16260 ± 80		Clayey mud
15/5.8	Starunia 15/5,8	GdTL-969	16.59 ± 0.71*		Sandy mud
2/4.2	ST II 2/26	Poz-28898	21100 ± 100	24002 (1.4%) 23700 - 23350	Peat
42/9.7-9.8	St II 42/30	Poz-28807	22900 ± 150	21110 - 20800	Clayey mud
VL1/5.2	VLS 1	GdTL-966	24.7 ± 1.1*		Gravel
28/2.5	St II 28/36	Poz-28902	26850 ± 200	25110 - 24700	Clayey mud with plant macrofossils and dispersed organic matter
28/6.0	St II/28/16	Poz-28459	33250 ± 300	31650 - 31000	Clayey mud with plant macrofossils and dispersed organic matter
28/4.0	St II 28/27	Poz-28802	34000 ± 500	32600 - 31500	Clayey mud with plant macrofossils and dispersed organic matter
22/5.8-5.9	St I/22/01b	Poz-26841	38400 ± 1000	37600 - 35400	Peat
22/5.8-5.9	St I/22/01a	Poz-26616	40000 ± 700	38800 - 37300	Peat
22/4.8	ST II 22/31	Poz-28899	43100 ± 1100	42400 - 40100	Peat
30/6.8	St I/30/02	Poz-26617	48200 ± 1800	48500 - 44500	peat mud
4/4.8	4/4,8	GdTL-968	58.9 ± 2.1*		Gravel
VL2/2.4	Starunia VL2		93.2 ± 4.1*		Gravel
21/5.8	21/5,8	GdTL-970	120.6 ± 5.0*		Gravel

Radiocarbon dates according to Kuc *et al.* (2009)

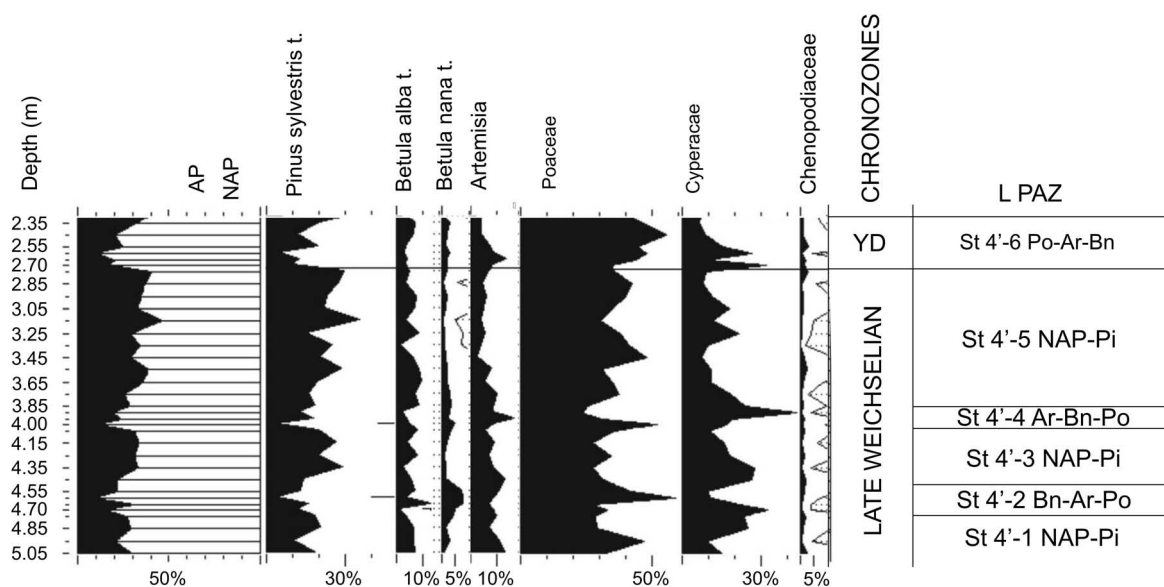


Fig. 6. Pollen diagram from section of borehole No. 4' (according to Stachowicz-Rybka *et al.*, 2009b; substantially simplified). YD – Younger Dryas, PB – Preboreal

type of flora was already suggested by Szafer (1930), who analysed the plant remains sampled from clays, in which the body of the rhinoceros was found. Remains of *Zannichellia palustris* and *Batrachium* sp. prove the existence of a shallow, eutrophic water basin surrounded by a belt of rushes with *Typha* sp and *Juncus* sp. The composition of aquatic flora indicates that the depth of the basin did not exceed 2 m. In fens or on muddy, drying parts of the shores, assemblages with *Bidens tripartita* were found. Up the section, the palynological data suggest a readable though poor expansion of trees like pine and birch, what indicates a slight warming of climate, preceded by an increase in humidity. Among macrofossils, the presence of *Betula nana* (with the minimum temperature of July of 7°C, according to Brinkemper *et al.*, 1987), *Eleocharis palustris* (L.) Roem. and Schult., and *Potamogeton filliformis* (both with the minimum temperature of July of 10°C, as stated by Kolstrup, 1979 and Mamakowa, 1997) as well as *Triglochin maritimum* L. (with the minimum temperature of July of 8°C, following Lambracht *et al.*, 2007) was recorded. The occurrence of the above-mentioned species shows that the contemporary minimum temperature of July amounted to at least 10°C, and it corresponded to temperatures dominating at that time in Western Europe (see Huijzer & Vandenberghe, 1998; Bos *et al.*, 2001). Therefore, contemporary climatic conditions at Starunia could have been controlled by a seasonally frozen ground. The upper part of the section is typified by steppe assemblages showing a rapid increase in the amounts of Poaceae and *Juniperus*, accompanied by a decrease in the quantity of *Pinus* and *Betula* pollen grains. The climate became dry and arctic and was noticeably affected by continental conditions. This is also indicated by the disappearance of aquatic flora, as well as by a poor quantity and species composition of vegetation typical of humid habitats. Upwards in the section, the steppe assemblages disappear. The vegetation is dominated by the low shrub tundra with *Betula nana*, Cyperaceae and arboreal birches, and is likely to indicate the beginning of the next interstadial. Therefore, referring to the data from the lower segment of section 22, the cooling should be associated with the Hasselo Stadial (cold interval, time window 41–38 ka BP; *cf.* Huijzer & Vandenberghe, 1998), and the subsequent interstadial should be linked with the Hengelo Interstadial. The appearance of an erosional cut at the top of the section does not allow for its detailed interpretation and reconstruction of younger events.

The consecutive stage in the evolution of the valley is shown in section 28, which was subject to palaeobotanical studies and radiocarbon dating. The basal sediments of DF (lithofacies Fm; Sokołowski *et al.*, 2009) are typified by a plant succession characteristic of forest-steppes with *Pinus sylvestris* and *Picea* (Figs 2, 5) and by a simultaneous disappearance of tundra assemblages. Such a composition of flora is likely to indicate the drying of climate. As the radiocarbon age of this part of section is 33.25 ka BP (Fig. 2), it can be associated with the Denekamp Interstadial.

The sediments of the Hengelo Interstadial are located *ca.* 2 metres below those of the Denekamp Interstadial. Incisions formed before the Denekamp (Hengelo?) Interstadial are recorded, *i.a.*, at Brzeźnica in the Wisłoka River valley

(Mamakowa *et al.*, 1997) and between Rzeszów and Łańcut in the Wisłok River valley (Szczepanek *et al.*, 2007).

Up the section, the succession of pollen indicates the dominance of steppe assemblages with grasses, wormwoods and Chenopodiaceae. Habitats of a higher humidity were covered by a tundra vegetation including *Betula nana* and other plants representing the Cyperaceae. The tree vegetation was most likely represented by clusters of arboreal birches appearing infrequently (Stachowicz-Rybka *et al.*, 2009b).

It is likely that during freshets the water flow was noticeable, though of low intensity and disappearing upwards in the section, where the macrofossils of: *Juncus* sp., *Carex cespitosa*, *Carex elata*, *Potentilla erecta*, *Plantago major* and *Phragmites australis* were recorded. Their presence suggests a decline of the water level in the basin and the appearance of peat bogs.

It is striking that there were hardly any plant macroremains found in the section. The poor development of vegetation can be explained by a high rate of sediment deposition or by severe climatic conditions, which can be concluded from the results of palynological analysis. In this part of section 28, the termination of deposition is indicated by the next radiocarbon date of 26.85 ka BP.

### Late Pleniglacial (OIS 2)

The first sign of a change in climatic conditions, which occurred between the Middle and Late Pleniglacial, is an incision, the depth of which is difficult to determine. The sediments of an earlier depositional event were intensively eroded, though the exact range of erosion is difficult to reconstruct due to changes resulting from mining activity conducted on a vast area. At the beginning (maximum cold of the Late Pleniglacial, time window 27–20 ka BP, OIS 2; *cf.* Huijzer & Vandenberghe, 1998), the gravel CD sediments were likely to have developed. Their top was dated to 24.7 ka BP in outcrop VL-1. An erosional cut of CD indicates that the deposition lasted for a longer time and occurred in conditions of aggradation, accompanied by lateral changes in the location of the river channel, which were likely to cause local broadenings of the valley. Therefore, it cannot be excluded that the CD sediments of sections 12, 13 and 14, as well as those of sections 106 and 107, originated from the same sedimentation cycle. Later, in the hollows of the floodplain, the biogenic sediments (biogenic mud – section 2) were formed. Their deposition was interrupted at *ca.* 21 ka BP, probably because of the arrival of waves of cooling, which occurred as the ice sheet attained its maximum limit.

The sediments above the CD, located already in the range of the floodplain, are marked by mud deposition. Sediments of sections 106, 107 and 2 are located on relatively narrow ledges, elevated *ca.* 4 metres above the present-day river channel. The natural top of sediments in borehole 2 is placed at *ca.* 7 metres above the river-bed and is overlain by a mine-dump. The layer of yellowish silts, 1.5 m in thickness, appearing in the top of sections 106 and 107, can be recognized as slope sediments. Therefore, the local top of alluvia attains the height of *ca.* 8 metres. The presence of mine dumps and slope sediments, and perhaps also the earth

works conducted in the area of the mine, resulted in the modification of the stepped relief typical of terraces and in the formation of a monotonously inclined slope. A terrace level of the same height (level II), from the nearby Bystrytsya Soltovynska River valley, was described by Kravchuk (1999). It also corresponds to the height of the terrace level distinguished mostly in the Upper Dnister River valley, which attains 10 m (Gofshtein, 1962) or 10–12 m in height (Raskatov, 1966).

While the succession of sediments is likely to be determined for the above-described sections, it cannot be reconstructed for the southern part of the Ropyshche area, between sections 28 and VL-1. Admittedly, the succession of dates can point to the presence of several intercalations of different ages. However, they should be rather associated with phases of very fast, remarkably intensive cutting, which locally reached a depth of even *ca.* 8 m. Moreover, some dates indicate a heavy contamination with anthropogenic material. It must be clearly repeated, that the sections are located in that part of the Ropyshche area which was mostly affected by mining exploitation. The sinking and/or subsidence of the underground headings resulted in vertical displacements. The occurrence of highly intensive anthropogenic disturbances is also confirmed by the strongly diversified type of relief at the top of the Miocene salt-bearing Vorotyshcha beds (Fig. 5).

Once more, the closest sites with sediments of documented OIS 3 and OIS 2 ages are the loess sections from Yezupil, Halich and Kolodiiv. The Yezupil site is typified by the presence of loesses, which accumulated slowly during the Middle Pleniglacial (Łanczont & Boguckij, 2002), and in which several soil horizons developed during warmer interstadials can be distinguished. They are grouped in two sets of soils: the older Dubno 2, and younger Dubno 1. The Late Pleniglacial is represented by a thin (only 2 m thick) loess bed. At Halich, the Weichselian loesses also form a thin bed comprising two pedogenic horizons, Dubno and Rivne, both originating from the Late Pleniglacial. At Kolodiiv, also the youngest horizon, Krasyliv, can be found. At this site, the Middle Pleniglacial is also indicated by a dozen or so climatic oscillations.

### Late Weichselian (OIS 1)

Deposition taking place in the Late Weichselian was most likely interrupted at *ca.* 18–16 ka BP. This is indicated by the date of 16.6 ka BP, related to sandy muds found in the lowest part of section sampled from borehole 15 (Figs 2, 5, Table 2). Although the sediments are actually likely to be slightly younger, they may point to a recognizable stage of incision, generally associated with the next climatic change, which occurred in the final phase of the Late Pleniglacial (time window 20–13 ka BP, part of OIS 2; *cf.* Huijzer & Vandenberghe, 1998). The first deposit filling the cut was probably gravel (sections 1, 24, 25 and 105) and it cannot be excluded that its deposition was fast. Gravel bars became overlain by a distal floodplain with deposition of silts, locally developed in a remarkably homogenous way (section 15; Sokołowski *et al.*, 2009), and with intercalations of

biogenic sediments of different thicknesses (Figs 2, 5). Throughout the entire Late Weichselian, the deposition was retained in the same subenvironment, which is indicated by typical sediments of DF and C, with the dates of 13.69–11.11 ka BP (sections 4, 13, 22 and 24; outcrop VL 1).

The type of succession recorded for pollen and macrofossils of plants sampled from sections 4' and 22 shows that during the Older Dryas–Alleröd land habitats were open and dominated by steppe and steppe-tundra assemblages, developing in conditions of a dry, continental climate. Plant communities are typified by the occurrence of grasses and wormwoods. The open type of landscape is marked by the presence of: *Juniperus*, *Ephedra fragilis*, *E. distachya*, *E. strobilacea*, and *Hippopheë rhamnoides*. The occurrence of *Betula nana*, Cyperaceae, *Selaginella selaginoides* and *S. cf. helvetica* indicates the tundra type of the assemblages. Pine and birch together with larch and spruce formed loose assemblages of boreal forests, likely to be typical of the Alleröd Interstadial. Abundance of damaged sporomorphs and cysts of Dinoflagellata indicate the development of the washing out processes.

Numerous sites close to the present-day river channel of the Rinne Stream were marked by the occurrence of swamps or even periodic aquatic basins, as it is particularly indicated by the presence of plant macrofossils and malacofauna. The macrofossils were typified by the appearance of fruits of *Batrachium* sp. and the occurrence of remains of *Potamogeton filliformis* and *Zannichellia palustris*. The shores were overgrown by a rush with *Schoenoplectus tabernaemontani* and *Eleocharis* sp. The malacofauna, recorded in section 4, at a depth of *ca.* 4 m, was represented by aquatic snails (*Galba truncatula*, Müll. and *Pisidium obtusale lapponicum*, Cless.), a hygrophile land snail taxon (*Vertigo genesii*, Gred.), and small fragments related to the *Vertigo* or *Columella* genus, not qualifying for determination (Stachowicz-Rybka *et al.*, 2009a).

According to the <sup>14</sup>C age of 13.69 ka BP (Epe ?/early Oldest Dryas ?), the oldest sediments are represented by the Fm lithofacies, separating two levels of the Cp sediments. This is likely to indicate that the improvement of climatic conditions, enabling the formation of greater amounts of biogenic sediments, occurred already in the terminal phase of the Late Pleniglacial.

The lower segment of the pollen diagram plotted for section 4' (Stachowicz-Rybka *et al.*, 2009b) is marked by fluctuations in the cool climate. The fluctuation recorded at a depth of *ca.* 4 m is probably associated also with the Oldest Dryas Stadial (zone St 4'-4 Ar-Bn-Po; Fig. 2 in Stachowicz-Rybka *et al.*, 2009b). The decline in the AP/NAP curve is mainly caused by the decrease in the amount of pollen of *Pinus sylvestris*, accompanied by a noticeable increase in the quantity of pollen of *Betula nana* L., Artemisia, Poaceae, and Cyperaceae (Fig. 7). In section 4 (Stachowicz-Rybka *et al.*, 2009b), located less than 2 m away from section 4', a corresponding height is typified by the occurrence of the above-mentioned malacofauna group, being an indicator of cold climate and boggy habitats. According to above-mentioned authors, the group most probably originated from the Younger Dryas Stadial. However, fluctuations in the pollen diagram and the radiocarbon date of

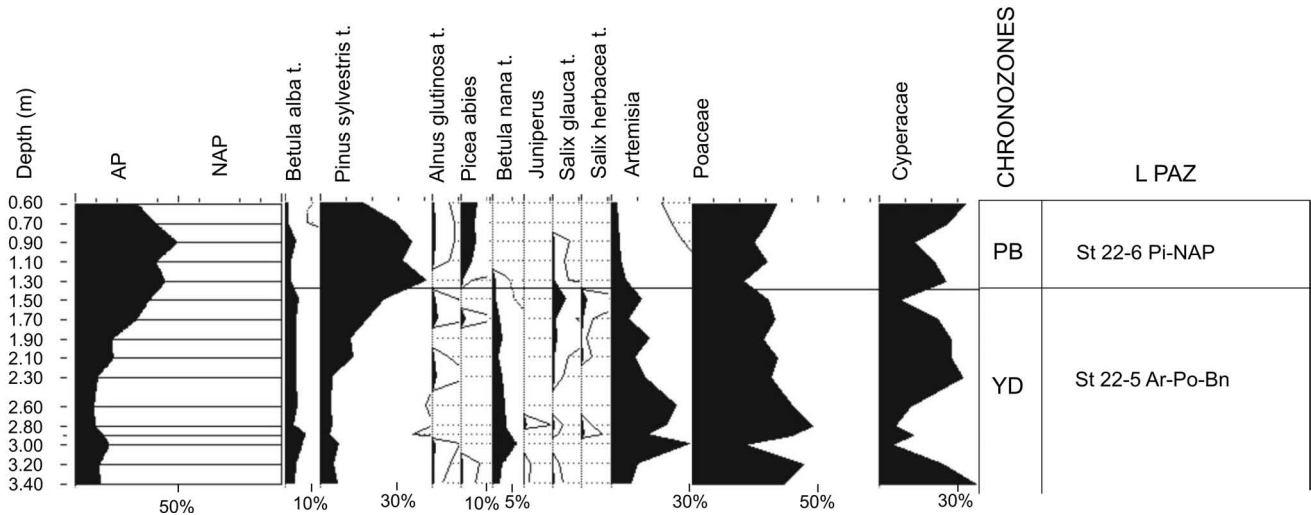


Fig. 7. Pollen diagram from section of borehole No. 22 (according to Stachowicz-Rybka *et al.*, 2009b; substantially simplified). YD – Younger Dryas, PB – Preboreal

12.23 ka BP (Bölling Interstadial), recorded at a depth of 3.5 m in section 4, suggest an older stadial. Credibility of the date may be confirmed by the occurrence of a contemporary water basin with aquatic and rushy flora (*cf.* macrofossil assemblage Star 4'/III; Fig. 2 in Stachowicz-Rybka *et al.*, 2009b).

The next phase is the Alleröd Interstadial, during which the sediments of lithofacies Fm and Frr were deposited in section 4'. The deposition of these lithofacies continued in the Younger Dryas, despite a rapid cooling of climate, visible as a decrease in temperatures recorded in Poland and Western Europe (Goslar *et al.*, 1995; Ralska-Jasiewiczowa *et al.*, 2003; Renssen & Vandenberghe, 2003). It resulted in the spreading of steppe and steppe-tundra assemblages, dominated by Poaceae, Cyperaceae, *Artemisia*, and Chenopodiaceae. The steppe type of landscape in the contemporary Starunia area is marked by the presence of *Elymus* and *Helianthemum nummularium*, as well as plants representing the Asteraceae (pollen of *Ambrosia*, *Aster* t., *Anthemis* t. and Cichorioideae). Abundant *Betula nana*, *Salix herbacea* and taxa of herbaceous plants point to the presence of patches of a shrub tundra. The pollen of trees was most probably transported from a great distance. The occurrence of *Larix*, *Alnus viridis*, *Pinus cembra*, *Juniperus*, *Hippophaë rhamnoides*, *Lonicera nigra*, *Ephedra distachya*, and *E. fragilis* was infrequent. In the top part of the zones, a noticeable increase can be observed in the proportion of *Pinus* and *Juniperus*, what evidences a slight increase in the density of the tree coating, improvement of climatic conditions, and perhaps also of the humidity conditions. The presence of a shallow water basin with *Zannichellia palustris* and *Batrachim* sp., surrounded by a rush belt dominated by *Typha* sp., was recorded in section 4' (Fig. 7).

Environmental conditions typifying the YD were retained in the Holocene. The palynological boundary of the YD/PB was recorded within the Frr and Fb lithofacies of DF sediments (Stachowicz-Rybka, *et al.*, 2009b).

### Holocene (OIS 1)

The boundary is visible in sections 4' and 22, at 2.3 and 1.3 m depths, respectively. The differences in heights, at which the basal parts of the Holocene sediments are located, usually do not exceed 2 m and are difficult to explain. The event of downcutting is contradicted by the recorded type of sediment and pollen zone. The age of the first zone, according to radiocarbon dating, is 10.19 ka BP. The Preboreal period was characterized by local re-development of small basins, some of which were open and periodically drying or disappearing. The basins were inhabited by aquatic snails (*Galba truncatula*, Müll., *Radix peregra peregra*, Müll., and *Anisus leucostomus*, Mill.) and an euryecological bivalve (*Pisidium casertanum*, Poli.). The above-mentioned species were accompanied by land, mainly hygrophile snails: *Vertigo antivertigo* (Drap.) and *Succinea putris* (L.) (Stachowicz-Rybka *et al.*, 2009a).

As a result of proceeding improvement in climatic conditions (Goslar *et al.*, 1995, Ralska-Jasiewiczowa *et al.*, 2003), a relatively intensive development of woody assemblages, dominated by *Pinus* being accompanied by *Picea* and *Larix*, was visible in the closest surroundings of the basins. Trees of higher thermal requirements, like *Ulmus*, *Quercus*, *Corylus*, *Tilia cordata* and even *Abies*, began to appear. Occurrence of the above-listed taxa evidences the initial development of forest floors. Probably, during the Subboreal period, the forest floors of woody assemblages attained a form corresponding to the present-day one. Linden and hornbeam dominated the foothills, the beech-fir forests – the forest floor, and spruce – the upper subalpine forest. Boggy habitats were covered by alder assemblages. Most likely, such habitats were also overgrown by yew, willows and ash. The Subatlantic period was recorded in sections 28 and 4' and dated to 0.625 ka BP by means of radiocarbon analysis. However, the record of the period was probably disturbed. The most noticeable indicators of the

Subatlantic period are taxa associated with human activity, such as *Plantago lanceolata* (growing in areas affected by pasturage), *P. maior*, *P. media*, and *Polygonum aviculare*. An increase is observed in pollen values of herbaceous plants, mainly grasses and *Artemisia*, the presence of which evidences a deforestation. Pollen of cereal plants, including *Triticum*, *Secale* and *Fagopyrum*, also appear.

Both stratigraphy and development of sediments originating from the Eo- and Meso-Holocene are identified only fragmentarily, mainly due to a considerable damage of these sediments in the Ropyshche area. This fact is mostly indicated by positions and datings of sediments sampled from sections 4N, 5N, 6 and 7 (Fig. 5). It even cannot be excluded that section 7 was surrounded by a periodic hollow (formed as a result of subsidence and sinking), which was filled with either a material washed out from nearby mine dumps, or suspensions supplied by the waters of the Velyky Lukavets River during freshets.

Holocene dates (1.27 ka BP and older) can be grouped in time intervals, which are partially conformable with clear phases of cooling and increases in humidity, marked by an increased frequency of extreme events (*i.a.*, Starkel, 1983; Nessje & Johannessen, 1992). The oldest dates: 10.19 ka BP (St II 4'/33), 9.74 ka BP (St II/1/20) and 9.55 ka BP (St II 25/17) were recorded for the turning point of YD/PB. This period was characterized, *i.a.*, by an elevation in the level of lakes in Northern Poland (Ralska-Jasiewiczowa, 1989). The next two dates: 4.5 ka BP (St VL-1/14) and 5.49 ka BP (St II 30/38), recorded for the end of the Atlantic period and the beginning of the Subboreal period, are conformable with the phases of 5.5–4.9 and 4.5–4.1 ka BP. The dates of: 2.91 ka BP (St II/32/05), 3.65 ka BP (St II/4'/24) and probably also 3.91 ka BP (St II/5/06) correspond with the phase of 3.5–2.9 ka BP (Starkel, 2001). Finally, the youngest dates: 1.27 ka BP and 1.5 ka BP, are associated with the Early Middle Ages. During each of these phases, from the Atlantic period onwards, the following events were observed: advance of glaciers in Scandinavia (Karlen, 1991) and in different parts of the Alps, growth of peat-bogs (Żurek & Pazdur, 1999), and development of landslides in the Carpathians (Margielewski, 2006). At Starunia, these dates indicate the stages of deposition of biogenic sediments and muds in swamps and periodic lakes.

The development of the DF fine-grained and biogenic sediments in the most part of this fragment of the Velyky Lukavets River valley indicates that the sediments were formed when the river flow was blocked, and nearby swamps, ponds and shallow lakes functioned nearly without interruption (Sokołowski *et al.*, 2009). Such conditions of deposition were likely to be retained from the Middle Pleniglacial until historical times (Early Middle Ages), what is evidenced by the  $^{14}\text{C}$  age of 1.27 ka BP recorded for the sediments of Frr lithofacies in section VL-3 (Figs 2, 4). After the river channel was unblocked, its level declined by at least 2 m, causing a decline of the level of underground waters in the surrounding terraces. It resulted in the drying of swamps and disappearance of open aquatic basins, at least the larger and deeper ones. These changes are well indicated by the type of malacofauna recorded in the upper part of section 22. The mollusc group was dominated by land spe-

cies typical of open and relatively dry habitats, like *Vallonia pulchella* (Müll.), *Pupilla muscorum* (L.) and *Vertigo pygmaea* (Drap.). There also appeared mesophile species typical of habitats with a medium humidity. Aquatic forms occurred only in accessory quantities. The fauna included mainly species preferring open land habitats, similar to the present-day ones (Stachowicz-Rybka *et al.*, 2009a).

Simultaneously, the deforestation proceeding from that period and causing an increase in the surface flow, resulted in an increase in both quantity and size of the detrital material supplied to the river channels. Consequently, the overbank deposits of the proximal floodplain became sand-muddy or even sandy. The rate of vertical increase must have been relatively high, if the fine-grained sediments, ca. 1.2 m in thickness, overlain a trunk cut after 1298 AD (M. Krapiec, *pers. comm.*, 2009, Alexandrowicz *et al.*, 2005). Also, before the Middle Ages, the greatest part of fine-grained weathering covers was likely to be removed, as among the fine-grained overbank sediments an increase was recorded in the frequency of intercalations bearing coarse-clastic sediments (gravels and sands), linked binding with crevasse splays and/or deltaic cones.

The subsequent stage in the development of the valley is the period of mining exploitation, which affected the river-bed by determining its course and dramatically increasing its supply with material derived from scoured mine dumps.

## CONCLUSIONS

The alluvial sediments filling the Velyky Lukavets River valley in the area of an abandoned ozokerite mine at Starunia were formed between the Eemian Interglacial and the Holocene. Luminescence (OSL) and radiocarbon datings indicate their complexity. Both channel and overbank sediments form three terrace levels. Only the highest one, 8 m in height, is build up exclusively of the Weichselian sediments. The structure of the next level is more complex. The top of the peripheral parts of the valley is marked by the appearance of Holocene sediments. In areas close to the river channel they already compose entire sections.

The basal members of sediments are dominated by gravels. Sandy gravels, located at similar heights, are less frequent. In the three sections the sediments were dated to 120.6 ka, 93.2 ka and 58.9 ka BP, respectively, pointing to the occurrence of intercalations of different age. It is likely that their formation was followed by the development of a distal floodplain with ephemeral swamps, ponds and lakes, during the Glinde Interstadial of the Weichselian Glaciation (48.2 ka BP). The environmental conditions were subject to only slight fluctuations and were sustained until the Subatlantic period of the Holocene (1.27 ka BP). That is why the sections of sediments of this period are clearly dominated by fine-grained sediments with intercalations of biogenic deposits (peat, peat mud and biogenic mud).

The absolute age of the youngest sediments was also determined by means of dendrochronological dating. Their relative age was indicated by examination of anthropogenic material, showing an increase in abundance considerably

associated with mining activity conducted in the area. The earth works resulted in the damage of large amounts of the sediments, particularly ones originating from the Weichselian.

Geological and also stratigraphical fundamentals of further exploration for large mammals in Starunia were described by Sokołowski *et al.* (2009). It appears from this paper that these factors limit the area of further exploration to only two small fragments located in the western part of the Ropyshche area.

### Acknowledgements

Financial support from the grant of the Ministry of Science and Higher Education (No. 139/UKR/2006/01) is kindly acknowledged. Review comments and suggestions by Prof. Elżbieta Mycielska-Dowgiałło and Assoc. Prof. Ewa Smolska of the University of Warsaw were very helpful. John Curtis of the Colorado School of Mines in Golden is kindly acknowledged for the linguistic correction of the text. Ms. Joanna Gawęda-Skrok and Mr. Sebastian Ptak are acknowledged for their help in completing the drawings.

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