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

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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 Interglacial?–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., Butatchium sp., Potamogeton filiformis, Bidens tripartita, Ranunculus sceleratus and Phragmites communis, as well as by halophytic species, like: Zammichellia palustris, Triglochin maritimum, Schoenoplectus tabernemontani, Puccinella 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.

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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.
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 “Cracovian 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 Krukenenice 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 & Lacombat, 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 Polyanitsa beds, dating from the Lower Miocene and bearing more sandstones (Koltun et al., 2005). The Carpathian Foredeep Basin is dominated by the Voro tyschcha 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 Pleistocene. On the culmination of the Pasovyschche (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 (Lanczont & Bogucký, 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 Vorotyschcha 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, Lepeiontium salmonum Ser., which is now known as Spergularia salina J. Presl. et 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 tabernomontani (C.C. Gmel.) Palla, and Phragmites australis (Cav.) Trin. ex Stied. 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 filiformis 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 (Matskevyj, 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', 5N, 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 Sokolowski 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 $^{14}$C dating—at the Poznañ 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 overbank 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 Ropyshche 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 scarp 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; Sokolowski 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 Fr) 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; Sokolowski et al., 2009 – Figs 3, 4) and do not exceed 3.6 m in thickness.
### CHRONOSTRATIGRAPHY AND ENVIRONMENTAL INTERPRETATION

In the paper, the chronostatigraphy (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 chronostatigraphy includes modifications pertaining to the area of Poland (Mamakowa, 2003; Latalowa, 2003a; Mojski, 2005). For the Holocene (1 OIS), we applied the divisions by Starkel (2001) and Latalowa (2003b). Previous correlations between the divisions applied for Poland or Western Europe (Lindner et al., 2004; Lindner & Marks, 2008) and the climatostatigraphic 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 Kolodiv, 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.

### Table 1

<table>
<thead>
<tr>
<th>Subenvironments</th>
<th>Lithology of lithofacies</th>
<th>Deposition</th>
<th>Landforms and geomorphic processes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel (CD)</strong></td>
<td></td>
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<tr>
<td>Gravel (G)</td>
<td>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 (Gr→GSt), planar-cross stratified (Gp→GSp→Sp), sometimes massive (lithofacies Gm) or low-angle cross-stratified, pieces of wood are often common</td>
<td>Deposition of clastic material in: side bars (Gp→GSp→Sp), infill of pools (Gt→GSt) (Gh, GSh→GSh), washing out of bars (Gt→GSt) and channel pavement ? or short-lived high energy flow? (Gm)</td>
<td>River channel, bar sand bedforms</td>
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<tr>
<td>Sandy gravel (GS)</td>
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<tr>
<td>Sand (S)</td>
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<tr>
<td><strong>Overbank</strong></td>
<td></td>
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<tr>
<td>Fine-grained sediments of proximal floodplain (PF)</td>
<td>Brown, grey-brown, muddy sand and sandy mud with ripple-cross laminations (SF, FSr), or horizontal laminations (Fh), rhythmite with horizontal laminations (SFh, FSSh, Fh), in lower members of these deposits wavy (FSw, Fwr) and ripple cross stratification of climbing type (SSF, 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</td>
<td>Infill of young oxbows and/or crevasse channel ?, vertical accretion deposition proximal floodplain</td>
<td>Washouts, oxbows, crevasse channels (?)</td>
</tr>
<tr>
<td>Muddy sand (SF)</td>
<td></td>
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<td></td>
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<tr>
<td>Sandy mud (FS)</td>
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<tr>
<td>Mud, silt (F)</td>
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<tr>
<td>Muddy sand (SF)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy mud (FS)</td>
<td></td>
<td></td>
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<tr>
<td><strong>Biogenic (C)</strong></td>
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<tr>
<td>Brown, dark-brown or almost black organic material (lithofacies Cpa), 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)</td>
<td>Accumulation of plant debris, sometimes with admixture of mud</td>
<td>Lacustrine or wetland areas on distal floodplain or in oxbows</td>
<td></td>
</tr>
<tr>
<td>Yellow, grey-yellow mud, sandy mud (SD)</td>
<td>Washout on slopes, solifluction</td>
<td>Solifluction and/or wash-out covers</td>
<td></td>
</tr>
</tbody>
</table>

**Description of subenvironments: a summary**
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-Wysoczanska & 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; Sokolowski, 1995) and at Czapłakówka 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 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...
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 (Bo-

At Kolodiiv, the soils were formed with the participation of biogenic deposits which were accumulated in an ox-
bow 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 & Boguckyj, 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 (Soko-
lowski 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 Inter-
stadial. 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) tun-
dra: Betula nana L., Alnus viridis, Salix sp. and Cyperaceae (Fig. 6), appeared in the areas of a higher humidity. Such a
Table 2

<table>
<thead>
<tr>
<th>Sections/Depth (m)</th>
<th>Laboratory code</th>
<th>Laboratory number</th>
<th>Radiocarbon (yr BP) or OSL* (ka BP) age</th>
<th>Calibrated age probability 68.2 % (yr BC) or (AD)</th>
<th>Lithology of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>43/5.3</td>
<td>St II/43/07</td>
<td>Poz-27168</td>
<td>40 ± 30</td>
<td>1700 - 1720 AD (10.6%) 1810 - 1840 AD (7.7%) 1880 - 1920 AD (41.3%) 1950 - 1960 AD (8.6%)</td>
<td>Mine dump</td>
</tr>
<tr>
<td>43/8.9</td>
<td>St II/43/08</td>
<td>Poz-27169</td>
<td>&gt; 100 pMC</td>
<td></td>
<td>Mine dump</td>
</tr>
<tr>
<td>VL-3/0.9</td>
<td>St II VL-3/23</td>
<td>Poz-28964</td>
<td>125±30</td>
<td>1680 - 1740 AD (19.8%) 1800 - 1890 AD (39.0%) 1900 - 1930 AD (9.4%)</td>
<td>Clayey mud</td>
</tr>
<tr>
<td>7/5.7</td>
<td>St II 7/32</td>
<td>Poz-28906</td>
<td>210 ± 30</td>
<td>1650 - 1680 AD (24.7%) 1760 - 1800 AD (31.1%) 1930 - 1960 AD (12.3%)</td>
<td>Clayey mud with plant macrofossils</td>
</tr>
<tr>
<td>42/3.9</td>
<td>St II 42/29</td>
<td>Poz-28806</td>
<td>230 ± 30</td>
<td>1640 - 1670 AD (35.8%) 1780 - 1800 AD (26.0%) 1940 - 1960 AD (6.4%)</td>
<td>Clayey mud with black mottles and dispersed organic matter</td>
</tr>
<tr>
<td>15/3.6</td>
<td>St II 15/28</td>
<td>Poz-28799</td>
<td>240 ± 30</td>
<td>1640 - 1670 AD (45.0%) 1780 - 1800 AD (23.2%)</td>
<td>Clayey mud</td>
</tr>
<tr>
<td>28/1.0</td>
<td>St II 28/19</td>
<td>Poz-28801</td>
<td>325 ± 30</td>
<td>1510 - 1600 AD (55.9%) 1610 - 1640 AD (12.3%)</td>
<td>Peat</td>
</tr>
<tr>
<td>VL-4/1.7</td>
<td>Starunia VL-4</td>
<td>GdTl-967</td>
<td>3.67 ± 0.18*</td>
<td></td>
<td>Gravel</td>
</tr>
<tr>
<td>7/10.8</td>
<td>St II/7/12</td>
<td>Poz-27977</td>
<td>390 ± 30</td>
<td>1440 - 1520 AD (56.0%) 1600 - 1620 AD (12.2%)</td>
<td>Clayey mud with black mottles</td>
</tr>
<tr>
<td>4'/1.3</td>
<td>ST II 4'/34</td>
<td>Poz-28905</td>
<td>625 ± 30</td>
<td>1295 - 1320 AD (27.2%) 1345 - 1395 AD (41.0%)</td>
<td>Clayey mud with black mottles</td>
</tr>
<tr>
<td>VL-3/2.1</td>
<td>StII VL-3/18</td>
<td>Poz-28907</td>
<td>1275 ± 30</td>
<td>680 - 725 AD (38.1%) 735 - 770 AD (30.1%)</td>
<td>Peat</td>
</tr>
<tr>
<td>4N/2.2</td>
<td>St II 4N/21</td>
<td>Poz-28808</td>
<td>1505 ± 30</td>
<td>540 - 600 AD</td>
<td>Peat</td>
</tr>
<tr>
<td>32/4.7</td>
<td>St II/32/05</td>
<td>Poz-27167</td>
<td>2915 ± 30</td>
<td>1200 - 1040</td>
<td>Peat mud</td>
</tr>
<tr>
<td>4'/0.9</td>
<td>St II 4'/24</td>
<td>Poz-28804</td>
<td>3655 ± 35</td>
<td>2130 - 2090 2050 - 1960</td>
<td>Clayey mud with black mottles</td>
</tr>
<tr>
<td>5N/5.6</td>
<td>St II/5/06</td>
<td>Poz-27165</td>
<td>3915 ± 35</td>
<td>2470 - 2340</td>
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</tr>
<tr>
<td>VL-1/2.1</td>
<td>St/VL-1/14</td>
<td>Poz-27980</td>
<td>4505 ± 35</td>
<td>3340 - 3310 (11.3%) 3300 - 3260 (7.6%) 3240 - 3100 (49.4%)</td>
<td>Clayey mud with dispersed organic matter</td>
</tr>
<tr>
<td>30/2.5</td>
<td>St II 30/38</td>
<td>Poz-28903</td>
<td>5490 ± 40</td>
<td>4370 - 4320 4290 - 4260</td>
<td>Clayey mud with dispersed organic matter</td>
</tr>
<tr>
<td>15/4.4</td>
<td>St 15/39</td>
<td>Poz-27976</td>
<td>6160±40</td>
<td></td>
<td>Clayey mud</td>
</tr>
<tr>
<td>4'/4.6</td>
<td>St II 4'/22</td>
<td>Poz-28803</td>
<td>8460 ± 50</td>
<td>7580 - 7510</td>
<td>Peat</td>
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<tr>
<td>25/1.7</td>
<td>St II 25/17</td>
<td>Poz-28800</td>
<td>9550 ± 50</td>
<td>9130 - 9000 (36.1%) 8920 - 8800 (32.1%)</td>
<td>Peat mud</td>
</tr>
<tr>
<td>1/1.8</td>
<td>St II 1/20</td>
<td>Poz-28798</td>
<td>9740 ± 50</td>
<td>9280 - 9195</td>
<td>Peat mud with root traces</td>
</tr>
<tr>
<td>4'/2.3</td>
<td>St II 4'/33</td>
<td>Poz-28904</td>
<td>10190 ± 50</td>
<td>10050 - 9810</td>
<td>Clayey mud with plant macrofossils and dispersed organic matter</td>
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<tr>
<td>VL-1/4.7</td>
<td>St/VL-1/13</td>
<td>Poz-27979</td>
<td>11110 ± 60</td>
<td>11130 - 11000</td>
<td>Peat</td>
</tr>
<tr>
<td>VL-1/4.9</td>
<td>St/VL-1/15</td>
<td>Poz-27981</td>
<td>11430 ± 60</td>
<td>11390 - 11270 (68.2%)</td>
<td>Peat</td>
</tr>
<tr>
<td>22/1.7</td>
<td>ST 1/22/04</td>
<td>Poz-27164</td>
<td>12240 ± 60</td>
<td>12230 - 12060</td>
<td>Peat mud with plant macrofossils</td>
</tr>
<tr>
<td>13/2.9</td>
<td>St II 13/35</td>
<td>Poz-28897</td>
<td>13010 ± 60</td>
<td>13570 - 13250</td>
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Table 2 continued

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<tr>
<th>Sections/Depth (m)</th>
<th>Laboratory code</th>
<th>Laboratory number</th>
<th>Radiocarbon (yr BP) or OSL* (ka BP) age</th>
<th>Calibrated age probability 68.2 % (yr BC) or (AD)</th>
<th>Lithology of samples</th>
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<tbody>
<tr>
<td>24/2.1</td>
<td>ST II 24/37</td>
<td>Poz-28901</td>
<td>13690 ± 70</td>
<td>14550 - 14130</td>
<td>Clayey mud</td>
</tr>
<tr>
<td>42/9.5</td>
<td>St 42/40</td>
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<td>16260 ± 80</td>
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<td>Clayey mud</td>
</tr>
<tr>
<td>15/5.8</td>
<td>Starunia 15/5,8</td>
<td>GdTL-969</td>
<td>16.59 ± 0.71*</td>
<td></td>
<td>Sandy mud</td>
</tr>
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<td>2/4.2</td>
<td>ST II 2/26</td>
<td>Poz-28898</td>
<td>21100 ± 100</td>
<td>24002 (1.4%) 23700 - 23350</td>
<td>Peat</td>
</tr>
<tr>
<td>42/9.7-9.8</td>
<td>St II 42/30</td>
<td>Poz-28807</td>
<td>22900 ± 150</td>
<td>21110 - 20800</td>
<td>Clayey mud</td>
</tr>
<tr>
<td>VL1/5.2</td>
<td>VLS 1</td>
<td>GdTL-966</td>
<td>24.7 ± 1.1*</td>
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<td>Gravel</td>
</tr>
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<td>28/2.5</td>
<td>St II 28/36</td>
<td>Poz-28902</td>
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<td>25110 - 24700</td>
<td>Clayey mud with plant macrofossils and dispersed organic matter</td>
</tr>
<tr>
<td>28/6.0</td>
<td>St II/28/16</td>
<td>Poz-28459</td>
<td>33250 ± 300</td>
<td>31650 - 31000</td>
<td>Clayey mud with plant macrofossils and dispersed organic matter</td>
</tr>
<tr>
<td>28/4.0</td>
<td>St II 28/27</td>
<td>Poz-28802</td>
<td>34000 ± 500</td>
<td>32600 - 31500</td>
<td>Clayey mud with plant macrofossils and dispersed organic matter</td>
</tr>
<tr>
<td>22/5.8-5.9</td>
<td>St I/22/01b</td>
<td>Poz-26841</td>
<td>38400 ± 1000</td>
<td>37600 - 35400</td>
<td>Peat</td>
</tr>
<tr>
<td>22/5.8-5.9</td>
<td>St I/22/01a</td>
<td>Poz-26616</td>
<td>40000 ± 700</td>
<td>38800 - 37100</td>
<td>Peat</td>
</tr>
<tr>
<td>22/4.8</td>
<td>ST II 22/31</td>
<td>Poz-28899</td>
<td>43100 ± 1100</td>
<td>42400 - 40100</td>
<td>Peat</td>
</tr>
<tr>
<td>30/6.8</td>
<td>St I/30/02</td>
<td>Poz-26617</td>
<td>48200 ± 1800</td>
<td>48500 - 44500</td>
<td>peat mud</td>
</tr>
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<td>4/4.8</td>
<td>4/4.8</td>
<td>GdTL-968</td>
<td>58.9 ± 2.1*</td>
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<td>Gravel</td>
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<tr>
<td>VL2/2.4</td>
<td>Starunia VL2</td>
<td></td>
<td>93.2 ± 4.1*</td>
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<td>Gravel</td>
</tr>
<tr>
<td>21/5.8</td>
<td>21/5,8</td>
<td>GdTL-970</td>
<td>120.6 ± 5.0*</td>
<td></td>
<td>Gravel</td>
</tr>
</tbody>
</table>

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 Zamichellia palustris and Batracium 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 Brink-kemper et al., 1987), Eleocharis palustris (L.) Roem. and Schult., and Potamogeton filiformis (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; Sokolowski 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 Brzęcnica in the Wisloka River valley (Mamakowa et al., 1997) and between Rzeszów and Łańcut in the Wisłok River valley (Szczepeńek 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 freshts 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 Solotyvynska River valley, was described by Kravchuk (1999). It also corresponds to the height of the terrace level distinguished mostly in the Upper Dniester 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 Kolodiv. The Yezupil site is typified by the presence of loesses, which accumulated slowly during the Middle Pleniglacial (Lanczont & 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 Kolodiv, 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 & Vandenbergh, 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 over lain 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–Allerød 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 Hippophaë rhamnoïdes. 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 Allerød 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 malaco fauna. The macrofossils were typified by the appearance of fruits of Batrachium sp., and the occurrence of remains of Potamogeton filifolium and Zannichellia palustris. The shores were overgrown by a rush with Schoenoplectus tabernaemontani and Eleocharis sp. The malaco fauna, recorded in section 4, at a depth of ca. 4 m, was represented by aquatic snails (Galba truncatula, Müll. and Pitsidium obtuusum laponicum, Clss.), a hygrophilic land snail taxon (Vertigo genus, Gred.,) and small fragments related to the Vertigo or Columella genus, not qualifying for determination (Stachowicz-Rybyka et al., 2009a).

According to the 14C age of 13.69 ka BP (Epe ?/early Oldest Dryas ?), the oldest sediments are represented by the Fin 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-Rybyka 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-Rybyka 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-Rybyka et al., 2009b), located less than 2 m away from section 4’, a corresponding height is typified by the occurrence of the above-mentioned malaco fauna 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
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 distahya, and E. fragilis was frequent. 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 Batrachium 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, Müll.) 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 Ropysłche 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 I/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 (Zurek & 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 (Sokolowska 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 14C 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 malaco fauna recorded in the upper part of section 22. The mollusc group was dominated by land species 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 (gravel 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 gravel. 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 Sokolowski 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.

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