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QUATERNARY ENVIRONMENTAL CHANGES AT STARUNIA PALAEONTOLOGICAL SITE AND VICINITY (CARPATHIAN REGION, UKRAINE) BASED ON PALAEOBOTANICAL STUDIES

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Abstract: The unique nature of the Starunia palaeontological site, where nearly perfectly preserved large mammals were discovered at the beginning of the 20th century, and also the incompletely researched history of the Pleistocene vegetation of the region, provided the necessary stimulus to undertake further complex palaeobotanical investigations. The Pleistocene and Holocene sediments filling the Velyky Lukavets River valley are the object of this type of investigation. Both the succession of vegetation and radiocarbon dating indicate that the formation of biogenic sediments began in the Weichselian Middle Pleniglacial, in the Moershoofd interstadial, and lasted through the Hengelo/Denekamp Interstadial Complex and the Late Glacial and Holocene. Palaeobotanical investigations show the Middle Pleniglacial to have been characterized by an open, forestless landscape. Grassland steppe communities dominated with extremely high proportions of Poaceae, as well as *Artemisia*, Chenopodiaceae, and a number of herbaceous plant taxa. More moist places were occupied by dwarf shrub tundra with *Betula nana*, *Alnus viridis*, and Cyperaceae. Small changes in the character of the vegetation resulting from climatic oscillations made their mark through a slight increase in the proportion of tree-birches, fir and pine. The record of Late Weichselian plant succession in the Velyky Lukavets River valley also documents the dominance of open habitats with a preponderance of steppe and steppe-tundra communities and a dry, continental climate. Only with the beginning of the Holocene did an improvement in climate conditions lead to the rapid expansion of forest communities with a dominance of pine accompanied by fir, larch, and trees, which are more demanding in terms of temperature, *e.g.* elm, oak, lime, hornbeam and hazel.

Key words: pollen analysis, macroremains analysis, palaeoclimate, Pleistocene, Holocene, Starunia, Ukrainian Carpathians.

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INTRODUCTION

The most valuable palaeontological sites for palaeoenvironmental research are those that contain well-preserved, varied, numerous remains of organisms. Such a situation makes it possible to draw varied, mutually complementary conclusions.

A site with precisely these features was discovered in 1907 at Starunia in the Ukraine. During exploitation in an ozokerite mine, some large carcass fragments of two enormous Pleistocene mammals, the woolly rhinoceros and the mammoth, were found in an extremely well-preserved state owing to their saturation with brine and oil.

These were accompanied by numerous plant remains (Raciborski, 1914a, b; Szafer, 1914; Granoszewski, 2002; Alexandrowicz, 2004; Kotarba, 2005; Kotarba & Stachowicz-Rybka, 2008). Unfortunately, as later studies showed, the remains of these large mammals with their associated flora and microfauna were found in a reworked bed in an infilled spent shaft. The uniqueness of this discovery persuaded the Polish Academy of Arts and Sciences to organise a new, comprehensive research project, including a ditch near the shaft containing the above-mentioned remains. More than twenty years later, in 1929, they found the

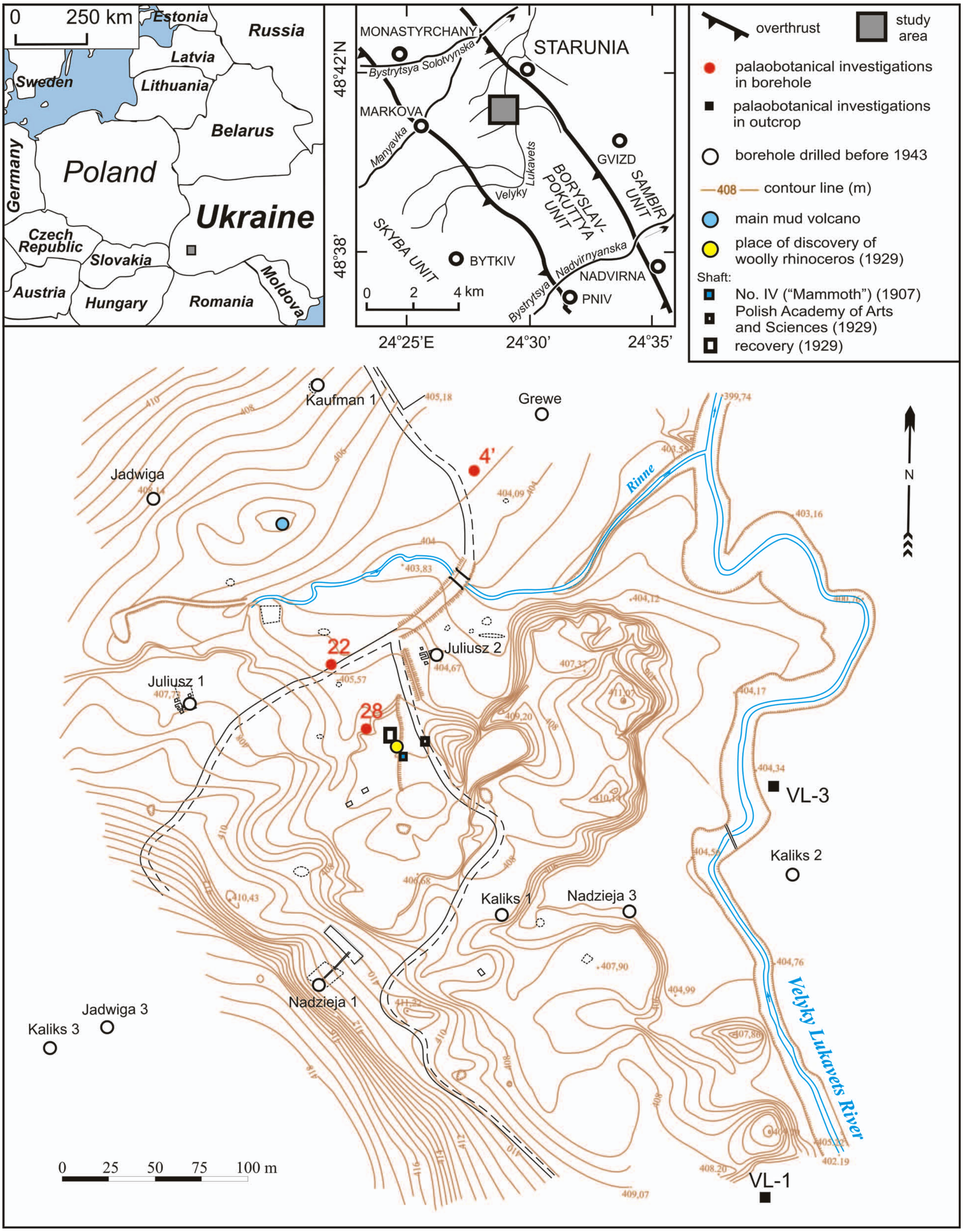

Fig. 1. Sketch map of the Starunia palaeontological site and surrounding area (Carpathian region, Ukraine), with the location of palaeobotanical studies

world's only specimen of the woolly rhinoceros to have been preserved almost intact. This time both the rhinoceros and the accompanying macroscopic flora were found *in situ*. The macroscopic plant remains, both those found in the clays from the immediate surroundings of the rhinoceros and those from inside the animal were initially examined and described by Szafer (1930). The results of this investigation allowed him to say that the examined fossil flora reflects the vegetation of the contemporary arctic tundra. The rich plant material was kept and preserved at the Palaeobotany Museum of the Botany Institute, Polish Academy of Sciences in Kraków. Thanks to this, a number of palaeobotanical investigations were made, among these of mosses (Szafran, 1934; Gams, 1934). The extremely numerous fossil birch leaves were examined by Kucowa (1954), who distinguished over a dozen species of *Salix* on the basis of leaf morphology. However, no palynological investigation was carried out at that time. Only exploratory analyses of grey clayey silts were made, and no arboreal pollen was found among these (Szafer, 1930).

The unique character of the site at Starunia, and absence of modern biostratigraphic research and radiocarbon dating of the sediments – especially considering the divergence in the ages of the rhinoceros tissues found in 1929 – provided the stimulus to undertake a new multidisciplinary investigation, including palaeobotanical research, using modern methods (Kuc *et al.*, 2005). About 10.5 hectares of the area of a disused ozokerite mine were subjected to detailed geological investigation, close to where the large mammal remains had been discovered. The area lies mainly at the bottom of the Velyky Lukavets River valley and its tributary Rinne Stream (Kotarba & Stachowicz-Rybka, 2008). A detailed history of the results of palaeobotanical investigation from both the first and second Starunia finds can be found in the papers by Stachowicz-Rybka *et al.* (2009) and Granoszewski (2002).

LOCATION AND GEOLOGICAL STRUCTURE OF THE STUDY AREA

The investigated site lies within the area of a abandoned ozokerite mine at Starunia, about 130 km SE of Lviv (Fig. 1). The study area belongs to the foreland of the Eastern Carpathians, within the Gorgany Fore-Carpathians, in the Boryslav-Pokuttya Unit (Carpathian Foredeep). It consists of several tectonic slices, thrust one over another. Each of these slices consists of a flysch series covered by molasse. In the top layer of the flysch series there are clayey shales, mudstones and sandstones (the so-called Kliwa Sandstones) of the Menilite beds. The Lower Miocene salt-bearing Vorotyshcha beds, immediately underlying Quaternary sediments filling the Velyky Lukavets River valley, cap flysch strata of the Boryslav-Pokuttya Unit (Mitura, 1944; Korin, 2005; Koltun *et al.*, 2005), and are sometimes replaced by the Sloboda Conglomerates and Dobrotiv beds. The Lower Miocene complex is completed by the Stebnik beds.

The Pleistocene sediments, especially of the clayey facies, in which the large vertebrates were found, were saturated with brine and oil derived from the underlying Vorotyshcha beds. In the area of Starunia (local name – Ropyshche) surface seeps of brine and oil, small lakes, even mud volcanoes occur (Kotarba, 2005).

MATERIAL AND METHODS

The material for palaeobotanical investigations comes from drillings carried out in autumn of 2007 and spring of 2008. In total, over 40 fully-cored boreholes 6–12 cm in diameter were drilled, crossing Quaternary sediments to the top of Miocene strata. Palynological analyses were made for three boreholes Nos 4', 22, and 28, and the VL-1 outcrop (Fig. 1). Samples for macroscopic plant remains were taken in parallel, so that each sample for pollen analysis was taken from the middle of the 10 cm section selected for analysis of macroscopic plant remains, the methods and detailed results of which are presented elsewhere (Stachowicz-Rybka *et al.*, 2009).

Sections for palaeobotanical investigation were selected taking into consideration both the location and depth of the log as well as the quality of the drill core. Only those sections were selected, which were located nearest the place where the rhinoceros was found in 1929 and on the periphery of the study area.

The process of laboratory preparation of sediments for palynological analysis ($1cm^3$) consisted of two stages. First, in order to remove bitumens, the comminuted sample of sediment was immersed in Rokanol DB7 and rinsed in a 10% ethanol solution. Rokanol DB7 is a readily obtainable and non-toxic surfactant reagent used to remove seeps of bitumen into the sediments (Jewulski & Zagrajczuk, 2005). Macerating samples using this compound at the beginning of a standard procedure made the pollen grains less clumped and prevented them from forming aggregates. Initially, cleaned samples of sediment were subjected to the standard method. After adding the indicator (*Lycopodium* spores), the sediment was treated with 10% HCl, and then, in order to remove the humic acids, the sample was boiled in 10% KOH solution. It was subsequently rinsed over a dozen times in water. In case of sediment samples strongly impregnated with bitumens, rinsing with Rokanol DB7 was repeated. Separating the sporomorphs from the mineral components of the sediment was carried out by the flotation method. For this purpose the acidified sediment was treated with $ZnCl_2$ solution with a density of 1.98g/ml (Nakagawa *et al.*, 1998) and centrifuged for 20 minutes at 2000 rev/min. The supernatant was subjected to the Erdtman's acetolysis and after being rinsed in alcohol treated with anhydrous glycerin.

Pollen grains were rather poorly preserved and total pollen sum varied from nearly 100 (two samples) to 600 and more. The basic sum consisted of trees, shrubs and terrestrial plants pollen. The spores and local vegetation pollen were calculated in relation to the basic sum. The pollen diagrams were plotted using the computer program POLPAL for Windows (Nalepka & Walanus, 2003; Walanus & Nalepka, 1999).

Radiocarbon datings were performed by the Poznań Radiocarbon Laboratory; for details of method see Kuc *et al.* (2009), and Sokołowski and Stachowicz-Rybka (2009).

HISTORY OF VEGETATION AND CLIMATE

The sediments of the sections investigated by pollen analysis contain a record of the stages of vegetation development, which took place in the Pleni-Weichselian, the Late Glacial, and the Holocene.

The oldest of these were recorded in logs of boreholes Nos 22 and 28 (Tab. 1, Fig. 2A, B).

Pleni-Weichselian

The radiocarbon datings of the bottom part of the St 22 section point to a Pleni-Weichselian age of the organic sediments from the lower part of the log. The date from the oldest part of the section (at a depth of 5.85 m) is 40,000 ± 700 years BP, while the sample situated higher (4.80 m) was dated at 43,100 ± 700 years BP. The date inversion here does not seem to be of major importance, because of both the margin of error and the fact that these dates lie at the boundary of the applicability of the radiocarbon dating method. The dates obtained allow the lower part of the log to be correlated with the middle of the Pleni-Weichselian (Behre, 1989).

(Stadial phase)

St 22 - 1 Poaceae-NAP L PAZ

The pollen spectra of this level reflect a distinctly forestless, open landscape. The dominance of communities of the grassland type is expressed in very high proportions of Poaceae pollen, as well as *Artemisia*, Chenopodiaceae, and a number of herbaceous plant taxa. More moist places were occupied by dwarf shrub tundra with *Betula nana*, *Alnus viridis* and Cyperaceae. The recorded remains of *Zannichellia palustris* and *Batrachium* sp. document the existence of a shallow, eutrophic body of water. On the edges of the latter, a reed bed was formed with *Typha* sp. and *Juncus* sp., while in damp places or silty temporarily drying parts of the banks communities with *Bidens tripartita* probably occurred.

Moershoofd Interstadial

St 22 - 2 Poaceae-*Pinus*-*Betula nana*

The small, but distinct expansion of pine and birch preceded by the spread of dwarf shrub tundra reflects a change in conditions of climate; initially an increase in moisture occurred, followed by a rise in temperature. An expression of this is the appearance of *Potamogeton filiformis* in the aquatic communities, and the abundant development of vegetation of wet and peat bog sites with *Triglochin maritimum*, *Eleocharis palustris*, *Juncus* sp., and numerous species of *Carex*. It is likely that the period of improved climate did not last long, as suggested by the fairly small increase in the proportion of pine and birch pollen.

(Stadial phase)

St 22 - 3 Poaceae L PAZ

The return to dominance of steppe communities is expressed in the enormous increase in Poaceae and *Juniperus* with a drop in *Pinus* and *Betula* pollen, reflecting the existence of a dry, arctic climate with a strongly continental influence. This is also indicated by the disappearance of aquatic plants and the clear impoverishment of the vegetation of moist sites, both in terms of quantity and species composition.

St 22 - 4 *Betula nana*-Poaceae

This level only spans the beginning of the next climatic change, resembling that which took place at the beginning of the Moershoofd Interstadial. Recession of the steppe communities in favour of tundra is expressed in a distinct increase in the curve of *Betula nana*, Cyperaceae, as well as a greater proportion of tree-birches in the landscape of this time in the Velyky Lukavets River valley. These changes in vegetation are the signal of another moistening of the climate. Unfortunately, the pollen level is incompletely preserved. Perhaps this is the beginning of another interstadial.

Hengelo/Denekamp Interstadial Complex

St 28 - 1 Pinus-Picea-NAP L PAZ

This level is represented by only one sample (Tab. 1, Fig. 2B). It is characterized by the development of forest-steppe communities with *Pinus sylvestris* and *Picea*. Steppe communities, which were undoubtedly dominant in the landscape, made their presence known primarily through the occurrence of various species of grasses and sedges. The presence of Cyperaceae pollen and trace amounts of *Betula nana* pollen would indicate the occurrence of tundra communities in the landscape of this time in the Velyky Lukavets River valley.

St 28 - 2 NAP L PAZ

The composition of the pollen spectra of this level permits the conclusion that accumulation of sediments took place under the conditions of an open climate. Steppe comunities with grass, mugworts, and a number of other herbaceous taxa (such as Chenopodiaceae), formed the primary plant formation. Various other species of *Ephedra* (*E. fragilis* t. and *E. distachya* t.) were also components of these communities. Sites with higher moisture levels were occupied by tundra vegetation, including *Betula nana*, and various representatives of Cyperaceae. Tree vegetation was most probably represented by infrequent patches of tree-birches.

In the sub-zone *Pinus*-NAP there is a slight, but distinct increase in the proportion of pine (*Pinus sylvestris*) in the Velyky Lukavets River valley, with coeval recession of tundra communities. It cannot be ruled out that this change in the vegetation was the result of a climatic oscillation. The direction of changes in vegetation would suggest not a significant warming of the climate as it became drier. Considering the radiocarbon datings, this oscillation can be correlated with the Denekamp Interstadial (Behre, 1989).

Late Weichselian

Alleröd Interstadial

St 4'-1 – St 4'-5 L PAZ (NAP-*Pinus*, *Betula nana*-*Artemisia-Poaceae*, NAP-*Pinus*, *Artemisia-Betula nana*-Poaceae, NAP-Pinus)

The record of the Late Glacial vegetation succession in the Velyky Lukavets River valley began with a dominance of open habitats, with prevalence of steppe and steppe-tundra communities. The occurrence of grass (Poaceae) and mugworts (*Artemisia*) was characteristic of these communities, as was that of representatives of the Asteraceae family

Table 1

Description of Local Pollen Assemblage Zones L PAZ

L PAZ	Name of L PAZ	Depth (m)	Description of pollen spectra
Borehole 4'			
4'-1	NAP-*Pinus*	5.05-4.75	AP from 21% to 30%. Poaceae pollen max. - 47%. *Artemisia* 13%, *Betula nana* increases from 1% to 4.3%, Cyperaceae - 25%, Chenopodiaceae - 2.5%. Among trees *Pinus* 20.5%, *Betula* - 7%. Pollen of *Juniperus* and *Ephedra fragilis* t. are present. In upper part of the zone, Filicales monolete rise to 62%. Sporomorphs degraded-10.5%, Dinoflagellata - 3%. Upper limit - decline of value of *Pinus* and rise of *Betula nana*
4'-2	*Betula nana*-*Artemisia*-Poaceae	4.70-4.55	AP 8.5% to 32%. *Betula nana* pollen rises to 8%, *Artemisia* - to 11%, Poaceae - to 59% (average about 34%). Cyperaceae decline from 32.5% to 9.5%. Value of *Pinus* diminishes to 4%, *Betula* increases from 1% to 13% in central part of the zone. Pollen of *Larix*, *Salix glauca* t., *Juniperus*, *Ephedra fragilis* t., *Ephedra strobilacea* t. appears. The destroyed sporomorphs amount to 5%. Upper limit - decrease of value of *Betula nana* and rise of *Pinus*
4'-3	NAP-*Pinus*	4.45-4.05	AP from 21.5% to 33.4%. Poaceae about 31%. Value of *Artemisia* declines from 13% to 5.5%, *Betula nana* - about 2%, Chenopodiaceae - 2%, *Ambrosia* - 2.3%, Cichorioideae - 1.2%. Value of *Pinus* increases from 14% to 29%, *Betula* about 5.5%. Pollen of *Larix*, *Slaix glauca* t., *Juniperus*, *Ephedra fragilis* t., *Ephedra distachya* t. appears. The destroyed sporomorphs - 3.5%. Upper limit - decline of value of *Pinus*, rise of *Artemisia*, *Betula nana* and Poaceae
4'-4	*Artemisia*-*Betula nana*-Poaceae	4.00-3.90	AP changes from 10.4% to 24.3%. *Artemisia* reaches at maximum 16.5%, *Betula nana* - 4.8%, Poaceae diminishes from 52% to 23.5%, Cyperaceae increase from 17% to 43.5%. *Pinus* rises from 4.2% to 18%, *Betula* about 3.6%. Pollen of *Salix glauca* t. (1.2%), *Juniperus*, *Ephedra fragilis* t. occurs. Destroyed sporomorphs rise to 9%. Upper limit - increase of value of *Pinus*
4'-5	NAP-*Pinus*	3.85-2.75	AP changes from 26% to 46.5%. Poaceae about 37% (max. 48%), Cyperaceae diminishes from 24% to about 10%, *Betula nana* - from 3.4% to about 1.2%. From among trees, *Pinus* changes from 15% to 35.5%, *Betula* - from 1.7% to 9.5%. Pollen of *Larix*, *Pinus cembra*, *Alnus viridis* and *Salix gluaca* t., *Juniperus*, *Ephedra fragilis* t., *Ephedra strobilaceae* t. appear. The pollen of other trees comes from redeposition. Value of Chenopodiaceae rises to 2.4%. Considerable values reach Asteraceae (*Aster* t. - 2.2%, *Ambrosia* - 0.9%, Anthemis t., Cichorioideae) and *Filipendul*a - 6.5%. Destroyed sporomorphs attain 6% and cysts of Diniflagellata occur. Upper limit - decline of value of pollen pine, increase of NAP
4'-6	Poaceae-*Artemisia Betula nana*	2.70-2.35	AP is from 10% to 32%. Pollen of Poaceae is dominant - max. 55.5%, *Artemisia* from 4% to 13.5%, *Betula nana* - 3%, Cyperaceae - 32% and Chenopodiaceae - 3.2%. *Pinus* reaches minimum 5% and increases to 20%, *Betula* rises from 3.2% to 7%. *Salix glauca* increases to 1.3%. The pollen of others trees strongly destroyed. Corroded sporomorphs attain 6.5%; continually present cysts of Dinoflagellata. Upper limit - increase of value of *Pinus*, decline of NAP
4'-7	*Pinus*-NAP	2.25-1.75	AP from 45% to 58%. *Pinus* reaches maximum value - 47%. Trees' pollen in upper part of the zone reach considerable values: *Picea* - 7%, *Corylus* - 3.4%, *Tilia* - 3.9%, *Alnus* - 4%. *Abies* and *Carpinus* begins continuous curve. Pollen of *Betula nana* almost completely disappears. Considerable values have Poaceae - initially 38%, then decline to 30%, Cyperaceae - about 10.5%, *Artemisia* - about 3.3%. Upper limit - decrease of value of *Pinus*, *Picea*, *Corylus* and *Tilia* pollen and decrease of value NAP
4'-8	*Corylus*-*Tilia*-*Picea*	1.65-1.45	AP from 62% to 77%. Value of *Pinus* declines to 8.5%. A high proportion reach *Corylus* (17%), *Tilia* (13%), *Picea* (11%) and *Alnus* (10%). *Fagus* begins continuous curve (about 2.7%). *Ulmus* - 1.5%, *Carpinus* - 6%, *Abies* - 3%. Values of the herbaceous plant pollen reduced. Poaceae change from 25% to 11%, Cyperaceae - from 3.7% to 8%, *Artemisia* about 3%. Upper limit - breakdown of curves of most trees, rise of NAP pollen
4'-9	*Fagus*-*Picea*-*Carpinus*-*Abies*	1.15-0.75	AP maximally reaches 94%. The highest value attain pollen of Picea (from 10.5% it rises to 21.5%) and Fagus (18.5%, and it declines in the upper part of the zone to 4%). Values of Corylus and Tilia gradually increase from 9% to 17.5%, and from 5% to 16.5%, resp. Quercus reaches 2.1%, Carpinus 14% and Abies 9%. Value of Alnus is stable - about 12.5%. Value of NAP considerably declines. Amount of Poaceae reduced to 1.4%, Cyperaceae and Artemisia to 1%. This zone has not upper limit and finishes succession in section St-4
Borehole 22			
22-1	Poaceae-NAP	5.85-5.35	AP from 9.4% to 13.1%. Poaceae reaches the highest values - 70.5% (average about 61%). *Artemisia* - 5.5%, *Betula nana* - 1.6%, Cyperaceae - 18%. From trees, *Pinus* reaches about 7%, *Betula* about 2%. *Alnus viridis*, *Juniperus*, *Salix glauca* t. appears. Destroyed sporomorphs reach 5.5% and cysts of Dinoflagellata appear. Upper limit - rise of value of *Pinus*.
22-2	Poaceae-*Pinus*-*Betula nana*	5.20-4.60	AP from 16.4% to 27.3%. The Poaceae reaches maximally 65%, *Betula nana* in central part of the zone - 17.5% (average about 4%), *Artemisia* - 9.5% (average about 4.7%), Cyperaceae about 10%, Chenopodiaceae - 1.2%. Value of *Pinus* changes from 9% to 14%, *Betula* - from 2.2% to 16%. Pollen of *Juniperus*, *Salix glauca* t., *Salix herbacea* t., *Lonicera nigra* appear. The destroyed sporomorphs attain 6.5%, cysts of Dinoflagellata - 0.8%. Upper limit - decline of value of *Pinus*
22-3	Poaceae	4.40-4.10	AP from 6.9% to 10.1%. Pollen of Poaceae is dominant - 71%. *Artemisia* - 4%, *Betula nana* - about 2%. Cyperaceae - 33.5%. Pollen of *Elymus* reaches 1.4%. *Pinus* about 4%, *Betula* - about 2%. Pollen of *Alnus viridis*, *Larix*, *Pinus cembra*, *Juniperus*, *Salix glauca*, *Salix herbacea*, *Ephedra fragilis* t. appear. Upper limit - increase of value of *Betula nana* pollen, decline of value of Poaceae

Table 1 continued

L PAZ	Name of L PAZ	Depth (m)	Description of pollen spectra
22-5	*Artemisia-Betula nana*-Poaceae	3.40-1.50	AP from 9% to 39.3%. Pollen of *Artemisia* is dominant - even 30% (average over 10%). *Betula nan*a rises to maximally 13.5% and it in the upper part of the zone decreases to only 1.5%. Poaceae reach 37%. High values attain *Anthemis* t. - 1.3%, *Aster* t. - 1.3%, *Helianthemum nummularium* t. - 2.1%, *Ambrosia* - 1%, Chenopodiaceae - 2.4%. Value of *Pinus* - initially 5%, then it rises to 24.5%. *Betula* - 5% (max. 9.5%). In the upper part of the zone value of Salix glauca increases to 5%, *Salix herbacea* - to 2.2%. Values of destroyed sporomorphs rise to 19%, cysts of Dinoflagellata appear. Upper limit - rise of value of *Pinus* pollen, decline of NAP
22-6	*Pinus*-NAP	1.30-0.50	AP from 30% to 50%. Pollen of *Pinus* is dominant - maximally 40.5%. Continuous curves begin *Picea*, which reaches 6%, *Ulmus* - 2.5%, *Tilia* - 1%, *Abies* - 1.8%, *Quercus* - 1.1%. Continuous curve initially sustain *Salix glauca*, and - rarely - *Ephedra fragilis* t. High value sustained for NAP. Poaceae rise from 21.5% to 34%, Cyperaceae decrease from 25.5% to 13.5% and increas to 33% again, *Artemisia* declines from 5.5% to 2%. Value of Filicales monolete spores reaches 27.5%. The level has not upper limit and finishes succession in section St-22
Borehole 28			
28 - 3	Carpinus-Abies-Picea (Fagus)	1.2-0.6	Max. AP 95%; *Carpinus* 24%, *Tilia cordata* t. 21%, *Picea* 18.5%, *Abies* 16.7%, *Fagus* 10.4%, *Alnus glutinosa* t. 10.5%, *Corylus* 10.9%. *Cerealia* t. 10.6%, Pollen of Secale and *Triticum* t. are present
28 -2	NAP	5.90-1.90	NAP up to 95%; *Poaceae* (45.5-26.2%), Cyperaceae (42.6-12%), *Artemisia* (45.5-5.6%). *Betula alba* t. pollen from 10.6% to 0.9%), Quite high proportions of Chenopodiaceae pollen up to 4.2%. *Pinus sylvestris* t. 6.9% - 0.8%). Pollen of *Picea abies*, *P. cembra*, *Ephedra fragilis* t., *E. distachya* t., and *Juniperus* present. High amount of degraded pollen. In this L PAZ, a sub-zone St28 2a, Pinus-NAP is distinguished (depth 3.7-3.3 m). It is characterized by an increase in *Pinus sylvestris* t. pollen up to 14.2%. and small decrease in NAP
28-1	*Pinus-Picea*-NAP	6.40	AP 43%. *Pinus sylvestris* t. pollen 32.4%, *Picea abies* 6%. Among NAP dominates pollen of Poaceae (31%), Cyperaceae (14.7%), and *Artemisia* (9.6%)
Outcrop VL-1			
VL-1-4	Tilia-Carpinus-Abies-Picea (Fagus)	0.40-0.25	Only two samples belong to this zone. AP exceeds 90%. *Tilia cordata* t. pollen close to 40%. *Carpinus* and *Abies* pollen above 10%, slightly higher *Picea abies* pollen. Pollen of cereals is present
VL-1-3	Tilia-Corylus-Carpinus-Abies	1.25-0.40	This zone is bipartite. The bottom part is dominated by NAP, Poaceae and Cyperaceae pollen above 20%, *Artemisia* ca. 10%. *Filipendula* pollen 23%. Among AP, pollen of *Quercus* 70%, *Ulmus* ca. 4%. *Pinus* above 10%, and *Betula alba* t. 3% are present. Pre-Quaternary pollen about 40% The upper part of the zone dominated by AP, mainly *Tilia cordata* t. 38%. *Carpinus* ca. 20%, *Abies alba* ca. 10%, *Alnus glutinosa* t. 18%. *Fagus* ca 2%. Pollen of Cerealia t. 6%, *Secale* and *Triticum* are present. No pre-Quaternary sporomorphs present in this part
VL-1-2	Pinus-NAP	1.84-1.25	In the lower part of the zone *Pinus sylvestris* t. pollen exceeds 60%, *Betula alba* t. ca. 3%. Cyperaceae max 45%. In the upper part of the zone, *Pinus sylvestris* above 20% and *Betula alba* t. exceeds 10%. *Picea abies* 5%. *Ulmus* and *Alnus glutinosa* pollen above 1-2%. Cyperaceae max 15%, Poaceae exceeds 30% and *Artemisia* 15%. Continuous curve of *Filipendula* pollen (max ca. 20%)
VL-1-1	Artemisia-Poaceae	2.52-1.84	AP at the bottom part nearly 90%; Poaceae 55%, Cyperaceae max. 56%, *Artemisia* max. 25%. Chenopodiaceae 8%. Among tree pollen, *Pinus sylvestris* t., max 26.6%, dominates. Nearly 20% of pre-Quaternary pollen; Dinoflagellata cysts are present

and *Helianthemum nummularium*, which also underlines the presence of a dry, continental climate. The considerable openness of the landscape is moreover attested by the presence of *Juniperus*, *Ephedra fragilis*, *E. distachya*, *E. strobilacea*, and *Hippophaë rhamnoides*. The presence of *Betula nana* and Cyperaceae, together with the occurrence of *Selaginella selaginoides* and *S.* cf. *helvetica*, points to the presence of communities of a tundra type. Pine and birch most probably formed loose communities of boreal forests, in which larch and spruce were also present. The proportion of the latter increased significantly in the Velyky Lukavets River valley in the younger part of the interstadial. The numerous degraded and redeposited sporomorphs in the sediment as well as Dinoflagellate cysts are evidence of unstabilised soils and increased surface runoff (Tab. 1, Fig. 3A).

The presence of *Batrachium* sp. fruits unequivocally confirms the aquatic origin of the sediment. This is, moreover, the only level in which this plant has been recorded, and this fact should be associated with improved moisure conditions. *Potamogeton filiformis* and *Zannichellia palustris* grew in the body of water. On its bank there was a reed community with *Schoenoplectus tabernaemontani* and *Eleocharis* sp. The appearance of aquatic and reed plants may reflect a warmer phase or a change in water trophy (Stachowicz-Rybka *et al.*, 2009).

It cannot be excluded that the noticeable fluctuation towards cool climatic conditions, observed in zone St 4'-4 and indidated by a decline in the AP/NAP curve, is likely to be associated with the Oldest Dryas Stadial. In section 4 (Stachowicz-Rybka *et al.*, 2009; Sokołowski & Stachowicz-

Rybka, 2009), located less than 2 m away from section 4', sediments of corresponding height are marked by the occurrence of the above-mentioned malacofauna group, being an indicator of cold climate and boggy habitats, typical of the Younger Dryas Stadial. However, the variability observed in the pollen diagram as well as the radiocarbon date (12.23 ka – Bölling Interstadial) recorded at a depth of 3.5 m, also in section 4, suggest an older age of the stadial. The credibilty of the date can be confirmed by the readible existence of a contemporary aquatic basin with aquatic and rushy flora (Stachowicz-Rybka *et al.*, 2009).

Younger Dryas

St 4' - 6 Poaceae-*Artemisia-Betula nana* L PAZ
St 22 - 5 *Artemisia-Betula nana*-Poaceae L PAZ
St VL-1 - 1 *Artemisia*-Poaceae L PAZ

A cooling of the climate led to the spread of steppe and steppe-tundra communities with a dominance of Poaceae, Cyperaceae, *Artemisia* and Chenopodiaceae. The steppe character of the landscape of this time in the vicinity of Starunia is demonstrated by *Elymus*, *Helianthemum nummularium*, and representatives of Asteraceae (pollen of *Ambrosia* t., *Aster* t., *Anthemis* t., Cichorioideae). The commonly occurring *Betula nana*, *Salix herbacea* and taxa of herbaceous plants indicate the presence of patches of dwarf shrub tundra. The arboreal pollen probably comes from long-distance transport. *Larix* (larch), *Alnus viridis* (green alder), *Pinus cembra* (stone pine) and *Juniperus* (juniper) may have occurred sporadically, as well as *Hippophaë rhamnoides*, *Lonicera nigra*, *Ephedra distachya*, and *E. fragilis*. In the upper part of the levels, the proportion of *Pinus* and *Juniperus* clearly increased, which indicates a slight increase in the continuity of tree cover and an improvement in the climate and possibly also in moisture. A shallow body of water remained, with *Zannichellia palustris* and *Batrachium* sp, and the reed belt was dominated by *Typha* sp. Damaged, pre-Quaternary sporomorphs were still common in the sediment (VL-1 – 1 LPAZ), as were Dinoflagellate cysts (Tab. 1, Figs 2A, 3A, 3B).

Holocene

Preboreal

St 4' - 7 *Pinus*-NAP L PAZ
St 22 - 6 *Pinus*-NAP L PAZ
VL-1 - 2 *Pinus*-NAP L PAZ

The improvement in climate resulted in a rapid expansion of forest communities with a dominance of pine (*Pinus sylvestris* t.) accompanied by spruce (*Picea*) and larch (*Larix*). More thermally demanding trees began to appear, as *Ulmus*, *Quercus*, *Tilia cordata*, *Alnus glutinosa* and *Corylus*. Low frequencies of *Abies alba* pollen most probably are of long distance transport origin. The presence of the latter taxa indicates the beginning of forest zones. Communities of open vegetation with grasses, mugworts and goosefoot (Chenopodiaceae) were still common, but they were accompanied occasionally by other plants, what points to impoverishment of these habitats and their recession. The appearance of greater quantities of *Filipendula* and pteridophytes (Filicales monolete) and accompanying sedges (Cyperaceae) may reflect an increase in the proportion of moist communities. The soils were still affected by increased solifluction, as evidenced by the presence of degraded sporomorphs and Dinoflagellate cysts.

Boreal and Atlantic

St 4' - 8 *Corylus-Tilia-Picea* L PAZ
St VL-1 - 3 *Tilia-Corylus-Carpinus-Abies* L PAZ

The dominance of forest communities with *Corylus* and *Tilia cordata* points to an improvement in climate and a further stabilisation of vegetation zones. The considerable proportion of lime (*Tilia*) in the tree stands of the submontane zone is particularly noteworthy. These were accompanied by admixtures of *Ulmus* (elm), *Quercus* (oak) and *Carpinus* (hornbeam) – these were probably fairly sparse, multi-species mixed deciduous forests. The stream valleys were occupied by communites of *Alnus glutinosa* with *Filipendula*, Cyperaceae and Filicales in the understorey. The lower forest zone was formed by *Fagus* (beech) and *Abies* (fir); while spruce (*Picea*) formed the upper mountain forest zone occurring above it. The open vegetation communities were in retreat, but still present. Poaceae and *Artemisia* were their main components. Pollen of cereal crops (Cerealia t.), including *Triticum* t.(wheat) and *Secale* (rye) was recorded. A significant proportion of the arboreal pollen in this pollen zone was damaged, which may indicate disturbance of the sediment. A similar phenomenon associated with the drying and aeration of the sediments of the Atlantic age was also recorded in the Western Carpathians (Rybnickova *et al.*, 1989).

Subboreal

St 4' - 10 *Fagus-Picea-Carpinus-Abies* L PAZ
St VL-1 - 4 *Tilia-Carpinus-Abies*-(*Fagus*) L PAZ

It seems likely that the formation of montane forest zones resembling the modern ones took place during this period. Lime and hornbeam dominated in the submontane zone. They were accompanied by hazel (*Corylus*), maples (*Acer*), ash (*Fraxinus*), and broadleaved lime (*T. platyphyllos* t.). The understorey was formed by *Sambucus nigra* and *Frangula*. Wetter sites were occupied by communities of alder carr (*Alnus*). Yews (*Taxus*), willows (*Salix*) and ash most likely grew in these habitats. Beech-fir forests formed the lower montane zone, the upper montane zone being the province of the spruce. Some traces of cereal crop farming are present.

Subatlantic

St 28 - 2 *Carpinus-Abies-Picea-Fagus* L PAZ

The Subatlantic period was only recorded in fragments in section St 28. It is characterized by a greater openness of the landscape, expressed in an increase in herbaceous pollen values, mainly grasses, *Artemisia*, and cereal crops, including *Triticum*, *Secale*, and *Fagopyrum* (buckweat). A number of taxa associated with human activity were also recorded, such as *Plantago lanceolata* (grazing), as well as *P. maior*, *P. media* or *Polygonum aviculare*.

St 4' - 9 L PAZ

Local level St 4' - 9 in section St 4' probably belongs to the Subatlantic period. It is unmistakeably disturbed and unsuitable for the purposes of interpretation. This zone is also characterised by a high proportion of *Pinus sylvestris* t. and *Tilia cordata* t. pollen in its bottom part, and a considerable increase in herbaceous plant pollen in the top layer. The sporomorphs of this zone showed a high degree of corrosion. At the same time, the level was radiocarbon-dated at 625 ± 50 years BP, *i.e.* the Subatlantic period. The above facts point to disturbance in this part of the St 4' section. The most likely interpretation seems to be contamination by descending particles from the youngest, strongly aerated sediments. The high proportions of lime and pine pollen with an absence of the pollen of other trees may be explained by a much greater resistance of the exine of these two taxa to corrosion.

DISCUSSION

In south-eastern Poland, Weichselian sites of palynologically examined organic sediments are infrequent. The situation is similar with respect to the sites of Holocene age. There are still fewer such sections from the Ukraine, from where the Starunia sections were taken.

In the Dnister River Basin Halyč Region (Western Ukraine) there are several sites of loesses and palaeosoils, whose age spans the interval from the Early Weichselian to historic times (Komar, 2002; Boguckyj & Łanczont, 2002). The upper layers of the Yezupol section record changes in vegetation, indicating a Weichselian Interpleniglacial succession in the form of interstadial brown soil. The results of palynological studies show that after a period of the dominance of herbaceous plants, including xerophytes and halophytes, the development of sparse pine forest with a small component of deciduous trees began in this region. This level corresponds with the Dubno soil horizon, as distinguished by Boguckyj and Łanczont (2002). Geomorphological analysis of the Kolodiiv section (Boguckyj & Łanczont, 2002) has made possible a detailed stratigraphy of the interpleniglacial. Two levels of subarctic brown soils, Dubno 2 – the older one, and Dubno 1 – the younger one, have been distinguished in this section, which arose in interstadial conditions, and a layer of loess separating them, which developed under stadial conditions. Individual layers correspond to the middle part of the Weichselian Pleniglacial in the Dnister River Basin Halyč Region.

The section from Rzochów near Mielec (Środoń, 1976), where the mammoth skeleton was found (*Mammuthus trogontherii*) (bones dated at 50,000 – 56,000 years BP), presents a picture of forest steppe during the Brörup Interstadial (Early Weichselian). Sparse pine forests dominated the landscape, with juniper and communities of the grassy steppe type with sedges, mugworts and numerous light-loving plants. In the river valley alder woods grew with *Alnus*, *Pinus*, *Picea*, *Betula*, and *Humulus lupulus*.

Brzeźnica on the Wisłoka River, lying some 15 km south of Rzochów (Mamakowa & Starkel, 1974), whose sediments were dated at 35,965±1000 yeara BP – Hengelo Interstadial (Brzeźnica B) and 27,990±1,415 yeras BP – Denekamp Interstadial (Brzeźnica A), also presents a forest-steppe landscape. *Pinus cembra*, *Larix* and *Juniperus* dominated here, and *Ephedra fragilis* and *E. distachya* were also found to occur. Communities of dwarf shrub tundra with *Betula nana* and *Salix polaris* played a significant role, as well as those with Poaceae and *Artemisia*. As at Starunia, also in Brzeźnica sediments of the young Holocene lie above those of the Pleni-Weichselian. A hornbeam trunk (*Carpinus*) was dated to the Subboreal Period (3,380±65 years BP). Hornbeam forests with oak and beech dominated during this time, and in the river valley also alder woods with lime and tree-birches occurred.

The bottom of the sediments from Łążek near Zaklików on the Sanna River (Mamakowa, 1968) was dated at 25,580 (+3 270 –2 420) years BP, *i.e.* also to the upper Pleni-Weichselian. In this case, the results of pollen analysis also point to the presence of vegetation of the park tundra type at that time, with patches of poorly differentiated pine-larch forest. Steppe communities with a large amount of grass and light-loving plants also developed (*Artemisia*, Chenopodiaceae, *Helianthemum oelandicum*, *Linum austriacum* and *Ephedra distachya*).

The age of the bottom of the peat sediments from Jasło-Bryły (Mamakowa & Wójcik, 1987) was determined at over 45,000 years BP – Hengelo Interstadial, the top of the upper layer – 34,000±1,000 years BP, and its bottom – 35,300±1,500 years BP. Initially, park tundra dominated in the Pleni-Weichselian in the region of Jasło, with *Larix*, *Pinus cembra* and *Juniperus*; *Alnus viridis* also occurred at this time. It developed into a more open landscape with dominant grasses and sedges and frequently present light-loving herbaceous plants, *Pleurospermum austriacum* and *Helianthemum nummularium* among others. These were accompanied by *Betula nana* on the wetter sites. Tree thickets were formed of Pinus *cembra* and *Larix*.

The most complete palynological records related in terms of their vegetation development to those at Starunia lie in the Bieszczady Mts. (Ralska-Jasiewiczowa, 1980). The Tarnawa Wyżna I and II sites present a plant succession from the Older Dryas (Late Weichselian) to the Subatlantic Period. In the Alleröd, fairly sparse pine forests dominated by *Pinus cembra*, *Larix*, and *Juniperus*. *Picea* also appeared. Cooling in the Younger Dryas brought with it the dominance of open vegetation with a dominance of grasses and mugworts, with frequently occurring Asteraceae and infrequent trees of *Pinus sylvestris*, *Pinus cembra*, *Larix* and *Juniperus*. The Preboreal Period was characterized by an increase in the proportion of pine and a distinct reduction in the proportion of herbal vegetation. In the Boreal Period forests with *Ulmus*, *Betula* and *Alnus* dominated. In the Atlantic Period, *Corylus* did spread, with *Quercus* and *Tilia cordata*. *Fagus* began to dominate from the Subboreal Period to the Subatlantic Period, together with *Carpinus* and *Abies*. Other sites in the Bieszczady Mts. (Ralska-Jasiewiczowa, 1980) describe plant succession from the Atlantic Period – Smerek and Zakole, Subboreal Period – Smolnik and Wołosate, to the Subatlantic Period.

In pollen sections from Starunia (Tab. 1, Figs 2A, 3A), in sediments ascribed to the Boreal Period, *Abies* pollen is present. Its low percentages (<1%) most probably suggest a long distance transport, but scarce stands of this tree in this part of the Carpathians can not be ruled out. However, this occurrence requires more detailed studies of organic sediments of this age from the territory of the Ukraine.

CONCLUSIONS

The ecological record of Quaternary organic sediments from the Velyky Lukavets River valley shows some correspondence with data from the Polish Carpathians. Insignificant differences, first of all the dominance of the open grassland communities, are due to the geographical location and influences of more continental climate conditions for the vegetation of the studied site.

The development of Pleni-Weichselian plant communities, both in colder (stadials) and warmer periods (interstadials) clearly show communities by the name of mammoth steppe developing and dominating at that time in the Velyky Lukavets River valley, and no doubt also on the scale of the whole area of the Ukrainian Carpathians. This plant formation is characteristic of sites, at which large Pleistocene mammals were found to be present both on the Eurasian and North American continent (Guthrie, 1982, 1990).

The Holocene vegetation history in the territory of the Ukraine, owing to the short distances to the Carpathian and Balkan glacial refuges, was much more dynamic compared to that of Poland. Expansion of *Tilia*, *Abies*, and *Fagus* was very quick and took place nearly at the same time, while these trees encroached the Polish territory considerably later and within a much longer time interval.

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