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Paleofloristic and paleofaunistic analysis of Dudváh River oxbow and implication for Late Holocene paleoenvironmental development of the Žitný ostrov Island (SW Slovakia)

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Abstract: Žitný ostrov, the largest island of the Danube River (SW Slovakia) gained its present shape in the Neoholocene period. As a result of increased flood and geomorphological Danube river activity dated to 1378–1528 AD, the Lower Dudváh River was abandoned and its alluvium became a part of the Žitný ostrov. Study of a Dudváh terrestrialized paleomeander by means of pollen and macrofossil analysis provides new information about the paleoenvironments of the Danubian Plain. The meander under study was cut-off during the Sub-Boreal period when the land was mostly covered by oak-dominated mixed forest with a notable high frequency of *Fagus* and *Abies*. In low-lying depressions, *Alnus glutinosa* formed typical alder carrs. The largest decline of the mixed forest occurred during the Sub-Atlantic period. Until the mid-19th century the region was strongly influenced by shallow groundwater and periodical floods, as reflected by pollen of aquatics and marsh species. Amongst non-arboreal taxa, pollen of Cyperaceae, Brassicaceae/*Cuscuta*, Poaceae and Apiaceae prevailed. Local successional changes started with i) stage of abandoned oxbow still with influx of moving water, poor in both macrophytes and molluscs, ii) shallow eutrophic oxbow lake with slowly flowing or stagnant water overgrown with aquatics (*Ranunculus* subgen. *Batrachium*, *Potamogeton* sp., *Ceratophyllum demersum* etc.) and abundant molluscs, iii) an open marsh dominated by Cyperaceae (mainly *Carex riparia*) with *Atriplex prostrata*, supporting diverse molluscan and Ostracod fauna. Present-day habitat is a result of landscape changes, which have been associated with draining, intensified agriculture, ruderalisation and spread of invasive species.

Key words: Holocene, SE Slovakia, paleoecology, palynology, paleomeander, Mollusca, Ostracoda, Dudváh River.

Introduction

River paleochannels are often filled with organogenous deposits, suited to paleoecological analyses. Such layers represent valuable natural archives (Břízová 2007).

Žitný ostrov, the largest intracontinental Danube island (1600 km^2), is a result of complicated sedimentary evolution and river pattern development. Its territory covers a substantial part of a large alluvial fan of the Danube River extending downstream from the Devín Gate gorge into a subsiding Danube Basin infilled with marine and limnic Tertiary deposits and overlaid by Quaternary fluvial deposits on the top. The present river subdivision into the Danube main-channel, Lesser (Malý/Little) Danube and Moson Danube (Fig. 1) is a result of nature conditions in the postglacial period and their stabilization under anthropogenic influence. The general geomorphological features, geological structure and lithology of Žitný ostrov are known (e.g. Lukniš & Mazúr 1959; Vaškovská et al. 1978; Tkáčová et al. 1996), in contrast to the particulars of its geomorphologic development and paleoecological conditions in the Holocene, especially in comparison with the situation on other large European rivers and the Upper Danube alone (cf. Schellmann 1990; Buch & Heine 1995).

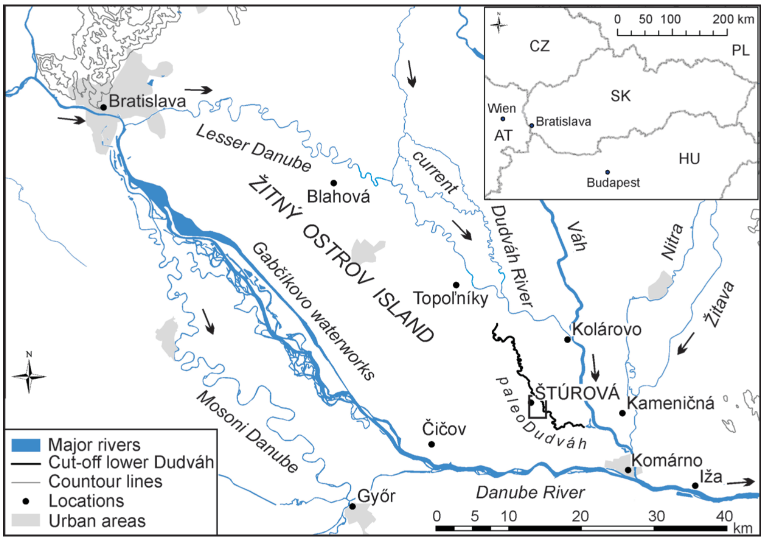

Fig. 1. Location of the study site — wider regional context. The small frame refers to the territory, depicted on the Fig. 2.

The terrain of the Žitný ostrov is shaped by numerous paleochannels of several generations. These geomorphological features are the key to knowledge of its past development. Although many earlier paleochannels are blurred by ploughing and barely discernable in the field, they may be easy to recognize using old maps and aerial photography. These forms are characterized by shallow groundwater, distinctive soil types (Fulajtár et al. 1998) and vegetation. Most patches of native and semi-natural floral communities are bound to these old river landforms.

The most notable fen complex bound to former channels (351 ha, with maximum peat thickness up to 5 m) was located in the central part of Žitný ostrov (Raučina 1968 in Válková & Stanová 2000). A major part of these fens fell victim to peat harvesting in the 1960–1980s. Organic layers have been tentatively dated from Late Pleistocene to Mesoholocene (Lukniš & Mazúr 1959; Krippel 1963; Krippelová 1967).

Our present knowledge of Holocene paleoenvironments of this region is mainly based on the palynological studies of E. Krippel (1963, 1986). Local paleoenvironmental data were obtained by earlier study of molluscan taxocenes (Ložek 1955) and by studies of woodland, meadow- and marshy vegetation (Jurko 1958; Zahradníková-Rošetzká 1965; Krippelová, l.c.). They managed to document the remnants of original flora persisting on Žitný ostrov Island until the largest human interventions of recent decades, which have included peat extraction, intensive agriculture and construction of the Gabčíkovo hydroelectric plant.

Žitný ostrov Island as the geographical unit known today has been formed relatively recently, as late as in the High Middle Ages (Püspöki-Nagy 1985; Pišút 2006). Until this period its lower part formed a separated geographical unit historically referred to as *Vágköz* with Dudváh as its dominant stream. Sometime between 1378–1528 AD serious channel changes resulted in cutting-off the Lower Dudváh due to formation of a new 16 km long avulsion channel of the Lesser Danube between Topoľníky and Kolárovo, so that the whole district of *Vágköz* was incorporated into the Žitný ostrov, together with the town of Komárno (Fig. 1).

Recently, this knowledge stimulated an investigation focused on the former Dudváh floodplain. The research comprised detailed study of present-day vegetation and molluscan fauna, associated with several Dudváh paleomeanders (Kubalová 2006; Pišút et al. 2007). Attention was also paid to paleoecological analysis of a terrestrialized oxbow next to the village of Štúrová (Břízová et al. 2007; Pišút et al., l.c.). In this paper we present the summary results of our study. Its major objectives are i) reconstruction of the regional paleoenvironments mainly based on pollen record, ii) reconstruction of local successional series of the abandoned oxbow *in situ* (based on local and extralocal pollen record, plant macrofossil assemblages, Mollusca and Ostracoda), iii) provide evidence of the human impact on the regional vegetation and iv) provide evidence for assumed essential changes of the river network, which occurred on Žitný ostrov in the past, by dating of the paleochannel. Reconstruction of the paleoenvironments is also based on the study of recent habitats associated with paleochannel landforms, such as vegetation survey, study of subfossil and recent molluscs.

Study area

The study area is located in a depressed part of lower Žitný ostrov, that has fine-grained deposits and impeded drainage due to its subtle slope. Prior to cultivation and draining, this Early Holocene depression was badly drained even by low water and covered by almost continuous swamps, with fens and wetland soils. The study area is located on the 3.5 km wide and 20 km long lowland plain, slightly (1 m) elevated above the depression bottom. This belt with the only medieval village (Čalovec) has been already previously identified as the natural levee of the former Dudváh (Lukniš & Mazúr 1959). Dudváh is a 97 km long lowland river of SW Slovakia entering the Lesser Danube (catchment area of 1507 km^2). The abandoned lowermost reach of the former Dudváh is represented by more or less continuous river bed at least 24 km long (Fig. 1), but also by remnant paleochannels.

The oxbow under study is part of a cluster of six such paleomeanders located between the villages of Štúrová and Čalovec in heavily managed, almost completely deforested agricultural landscape (Fig. 2). The region is warm and very dry with mild winters. Average annual air temperatures in the period 1931–1990 was 9.6 °C (data from the Hurbanovo meteorological station). The mean July temperature was 19.8 °C, mean precipitation total 553 mm (1961–1990 period; Majerčáková et al. 2006).

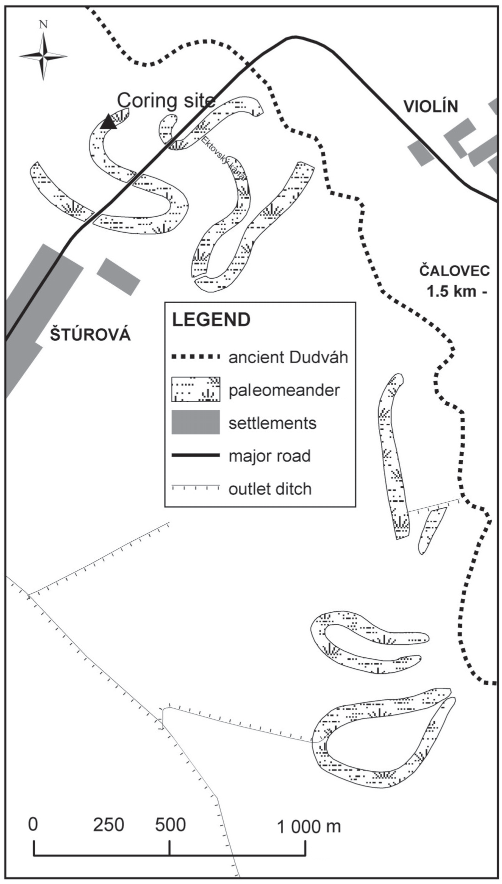

Fig. 2. Paleomeanders of the Dudváh River with location of the coring site.

The study paleomeander ("Štúrová" site) is 37–50 m wide. Bottom of terrestrialized S-shaped oxbow is lowered some 1.3–2 m when compared to the adjacent floodplain (108–109 m a.s.l.). A gently elevated part of the paleochannel upper reach is currently planted with monoculture of Canadian Poplar. There is also a minor patch of remnant semi-natural willow stand with former pollard trees. Closed-canopy reed beds cover the lower half of the former channel (Pišút et al. 2007). Roughly 8 % (0.5 ha) of the bed is overgrown by large sedge communities (*Magnocaricion elatae*). Communities with *Bolboschoenus maritimus* agg. and *Glyceria aquatica* also occur with patchy distribution (Kubalová 2006). Coring site is placed in the lower portion of the channel, within a tall-sedge habitat dominated by *Carex riparia*, 6 m from the edge of the former eroded channel bank (47°50′20.99″ N, 17°56′49.17″ E) with supposed maximum depth of the paleochannel about 2.8 m (Fig. 2).

In the past, completion of protective embankments along with partial draining of the territory led to slight lowering of the regional groundwater. Since the mid-19th century the territory had only been inundated during extreme floods that resulted in levee breaches (Füry et al. 1986). In the period between 1962 and 1992 mean groundwater was gradually decreasing by an additional 20–50 cm, but it rose again after the Gabčíkovo hydroelectric plant have been put into operation in 1992 (Hlavatý & Banský 2006). Despite continuing warming of the entire region since the 1870s and prevailing moisture deficit conditions (Fulajtár et al. 1998; Majerčáková et al. 2006) the groundwater level in the paleomeanders fluctuates between 0.5–1.5 m. In the spring, ground-water may spill above the ground surface of paleomeanders by up to 20–40 cm. Present-day conditions also favour the probability of soil salinization.

Material and methods

In the first phase of sediment sampling (on October 24, 2006) a pit was opened by hand at the study site. Herb layer was represented by *Carex riparia*, *Atriplex prostrata*, *Symphytum officinale*, *Calystegia sepium* and *Cuscuta australis*. Fully grown shells of the largest molluscs (*Lymnaea*, *Viviparus*, *Planorbarius corneus*, *Unio tumidus*) were hand-picked during the course of excavation. Samples of sediment were taken directly from the face of a cleaned vertical section from the depths 0 to 60 cm. Subsamples for pollen analysis were taken at 5 cm interval, those for macrofossils at 10 cm intervals. Due to shallow groundwater additional subsamples to 80 cm were taken with steel flighted auger (∅ 15 cm) and samples from 80–100 cm with a split tube sampler (∅ 5 cm).

Due to extremely warm and dry weather in 2007 the regional groundwater level exceptionally dropped. This allowed us to describe the lithostratigraphy of the sedimentary infill in more detail and also additional sampling for pollen and macroremains analyses up to the depth of 130 cm (on July 27, 2007). Description of the soil profile followed the Guidelines for soil description (2006), soil colour was determined by Munsell Charts (2000). In total, 20 samples of sediment (from the depth of 0–130 cm) were retrieved for pollen analysis and 10 subsamples for macrofossil analysis. Soil samples were analysed in the Institute of Soil Science and Protection, Bratislava for granulometry (pipette methods), pH in both H_2O and KCl, carbonates, humus content, content and quality of humic acids (colour index), respectively.

The sediments were rich in molluscan shells, but comparatively poor in palynomorphs. The samples also contained plant macroremains, ostracods, leathery cocoons possibly of Annelida/Turbellaria, insect fragments, numerous charcoals (not determined yet), several bone fragments (cf. micromammalia) and a fish scale. Pollen and macrofossil analyses were performed, two levels of sediment sequence were radiocarbon-dated.

Microscope slides of pollen subsamples were prepared using hydrofluoric acid HF and modified Erdtman acetolysis (the standard procedure is described in detail in Břízová (1999b, 2007). Two slides of each sample were observed under the microscope according to the concentration of sporomorphs in one sample. At least 300 arboreal pollen grains (AP) were counted for each sample if available (for sum of pollen counts see Fig. 3). Palynomorphs were determined with the help of reference recent pollen and photographic documentation, as well.

For calculations of the pollen data and plotting of the pollen diagrams — and for molluscan and plant macroremains diagrams as well — the programme POLPAL (Walanus & Nalepka 1999) was used. The pollen sum of woody plants (AP, arboreal pollen) and non-arboreal pollen (NAP) was considered to be 100 % (AP + NAP = 100 %). Identifiable plants were grouped according to the life-form system into trees, shrubs, dwarf-shrubs, herbs and graminids, local plants (the latter including aquatics, telmatophytes and amphiphytes). Pollen of some strictly wetland species was considered as a part of local component, even if it was not recorded as macrofossil, but is recorded by present-day floral survey at the study site or in its close vicinity. *Pteridophytes*, *Bryohytes*, *Fungi* etc. were excluded from the pollen sum but also plotted on the graph. On this basis the percentages of individual determined pollen types were calculated. Relative dating of the pollen spectra was done on the basis of its composition. Reconstruction of the vegetation development is based on modified classification for Central Europe (Firbas 1949, 1952; Dreslerová et al. 2004). On the basis of the results and with the help of principal component analysis (= module of the POLPAL programme), the profile has been dated stratigraphically and pollen diagrams divided into local pollen assemblage zones (LPAZ). Symbols in the lithology column follow the Troels-Smith system (Aaby & Berglund 1986). Pollen record was also compared to the results of macrofossil analyses and study of present-day vegetation.

For separation of plant and animal macroremains, bulk samples of sediment (the amount ranging from 300–550 g) were soaked for at least 24 hours (up to 3 days) in 10% solution of hydroxene peroxide in deionized water. Floating shells, ostracods, cocoons of *Annelida* (*Turbellaria*), insect remains and charcoals were picked and remnant macrofossils were separated by wet sieving through the 0.25 mm mesh. The most resistant crumbs of carbonaceous clay were also treated with Calgon. Identification of seeds, fruits and molluscan shells was done upon drying with a low-power bino-

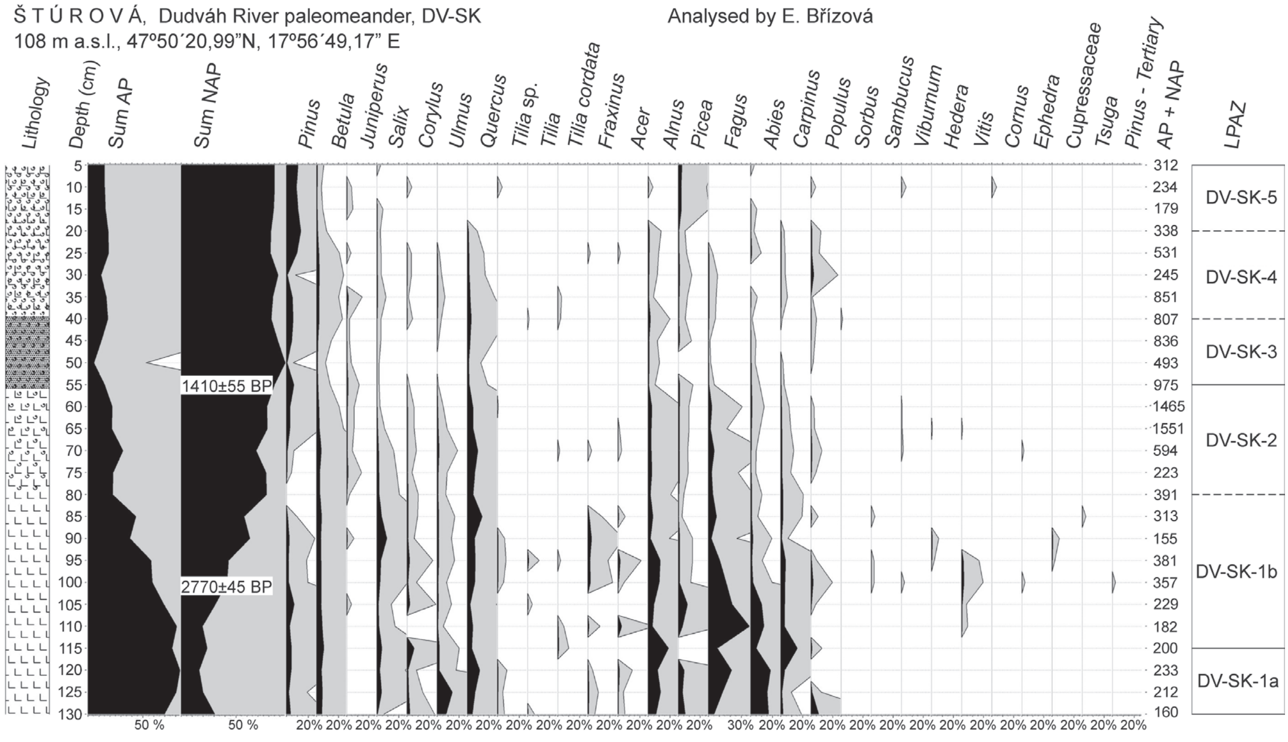

Fig. 3. Pollen diagram for the Štúrová-Dudváh paleomeander, arboreal pollen.

cular microscope. For determination of plant macroremains primarily the authors' own reference collection of recent flora was used, but also atlases of seeds (e.g. Cappers et al. 2006). Nevertheless, only determinable (at least to the family) taxa were included in the plant macrofossil diagram. Identification of molluscan death assemblages (taxocenes) was done visually using POLPAL diagram, but also verified with the help of statistical cluster analysis (Ward's method, Euclidean distance), performed with PAST software (Hammer 2009).

Correlation of pollen data is also supplemented by two radiocarbon dates of mollusc shells from 55 and 102 cm. Their age was determined by the conventional decay-counting method using carbon isotope ^{14}C. Radiocarbon dating was performed at the Radiocarbon Laboratory of the Institute of Physics, Silesian University of Technology in Gliwice, Poland.

Interpretation of fossil finds was also done based on the survey of present-day vegetation of the adjacent portion of abandoned Dudváh River (Kubalová 2006; Pišút et al. 2007). Vascular plant nomenclature follows Marhold & Hindák (1998). Names of phytosociological vegetation units (syntaxa) follow Jurko (1958), Mucina & Maglocký (1985), Oťahelová (1995a,b) and Oťahelová et al. (2001).

Results

Lithology of paleomeander infill sediments — soil characteristics

At the time of detailed profile description (on 27 July, 2007) the groundwater was at a level of 130 cm. In the topsoil up to 5 mm wide vertical cracks occurred, spaced up to 20 cm from each other, starting 11 cm below the surface and reaching to the depth of 85 cm. The lithology of the studied profile is shown in Table 1.

According to textural parameters of 5 selected diagnostic horizons, sediments were classed as silty clay and silty clay loam with % clay (<0.2 μm) ranging from 28.3 to 56.10 % (Guidelines for soil description 2006). The admixture of coarser material most apparent in 39–56 (74) cm was mainly represented by very fine sand and coarse silt. The humus content of the studied soil is very high (above 5 %), similarly to other hydromorphic and texturally heavy soils of the region (cf. Fulajtár et al. 1998). The C_{HA}/C_{FA} ratio (<1) indicates humus of lower quality with a relatively low degree of humification and humus stability ($Q_6^4 > 4.0$). Slightly alcalic reaction of the soil is associated with the strongly to extremely calcareous soil matrix ($CaCO_3$ from 14 to 49 %), also correlating with the high pH of the soil (Table 2). The presence of secondary carbonate nodules along with increased concentration of calcium carbonate content in the subsoil layer of 40–52 cm is related to shallow groundwater and the water regime of the area. Currently the pedon is classified as Gleyic, Calcic Fluvisol (Calcaric, Clayic; IUSS Working Group WRB, 2006). Prior to draining the soil was probably a typical waterlogged Gleysol with reducing conditions within 50 cm of the mineral soil surface.

Radiocarbon dating

Calibrated radiocarbon dates of two freshwater molluscan taxa are shown in Table 3 and indicated on the pollen diagram (Fig. 3). They covered a period of 1600 years between

Table 1: Lithology of paleomeander sediment infill (soil horisons).

Horizon (cm)	Signature	Colour (Munsell, when moist)	Morphological properties
0–20	A	10YR 2.5/2	dark brown-grey humus horizon, dry silty clay; granular to blocky subangular structure (aggregates < 10 mm), consistence slightly hard; abundant mollusc shells and their fragments; strongly calcareous material, gradual boundary with:
20–39	Cl1	10YR 3.5/1	strongly calcareous, dark brown-grey silty clay with apparent sand admixture; consistence friable to firm; massive (coherent) structure; abundant fragments and whole shells of molluscs; broken horizon transition into
39–56	Cl2	10YR 4.5/3	brown silty sand, consistence friable to firm; abundant fragments and whole shells of molluscs; in the depth of 55–62 cm layer with abundant shells of *Planorbarius corneus*. Clear transition into
56–74	Cl3	10YR 3.5/2	dark grey-brown silty clay with apparent admixture of coarser particles; massive coherent structure, loose; slightly plastic; from 67 cm below diffuse rusty mottles; few fine- to medium-size, weekly cemented carbonate concretions; mollusc shells and their fragments; gradual boundary to
74–141	Cr4	10YR 3.5/1.5 (5Y 4.5/1.5 when dry)	silty clay with prevailing reductimorphic brown-grey colour. Plastic, slightly sticky material, massive coherent structure. Common, faintly contrast, medium-sized rusty mottles, also around voids. Few fine- to medium-size, weekly cemented carbonate concretions
141–260	Cr		(by drilling) grey silty carbonaceous clay, very sticky and plastic, structureless, massive, extremely hard upon drying.

the levels 102 cm and 50–60 cm of the profile. Although the real ages of molluscan shells could have been significantly influenced by the freshwater reservoir effect ("hardwater" error), the radiocarbon data obtained seem to be in accordance with the paleoecological data and relative dating and thus can be considered reliable.

Pollen record

On the basis of pollen composition and also with help of the principal component analysis and numerical analysis pollen stratigraphy has been subdivided into five local palynological zones and two subzones, which are used as a framework for the discussion of results and can be dated stratigraphically. For better graphic representation the total diagram has been divided into the partial ones (Figs. 3, 4, 5). Selected palynomorphs are also shown in the Fig. 6.

Subzone DV-SK-1a-VIII: depth 130–115 cm
Abies–Fagus–Ulmus–Alnus–Quercus–Carpinus–Populus

In the lowermost layers of the analysed sequence pollen grains of the native tree species were important, as in the following zone. Several forest formations can be deduced from pollen data: i) bottomland floodplain forest, ii) lowland woodlands, iii) (sub) mountainous Carpathian forest, iv) alder carrs. The zone is characterized by high AP values reaching up to 70–80 %, suggesting a mainly forested landscape. Floodplain woodlands were characterized by relatively greatest proportions of *Ulmus* (elm, 15 %) and *Populus* (poplar, 8 %) of the entire profile, although oak (10 %) was an important constituent of these woodlands. The proportion of *Abies* (silver fir) pollen reached up to 19 % along with increasing share of *Fagus* (beech, 20 %) in this zone and at the start of the next subzone DV-SK-1b. The percentage of *Alnus*

Table 2: Selected chemical soil parameters.

Horizon (cm)	Designation	$CaCO_3$ (g/100 g)	Cox (g/100 g)	Humus content	HA/FA	Q_6^4 (HA)	CEC (cmol+/kg)	pH/H_2O	pH/KCl
5–15	A	29	5.29	9.12	0.51	4.68	37.70	8.21	7.66
25–35	Cl1	29	3.21	5.53	0.55	4.31	35.03	8.47	7.82
40–52	Cl2	49	5.91	10.19	–		–	8.34	7.76
55–70	Cl3	14	8.57	14.78	–		–	8.16	7.60
90–100	Cl4	13.6	1.95	3.36	–		–	8.01	7.59

Table 3:

Sample ID	Lab. No.	Material/ Species	Age ^{14}C (BP)	Calibrated age range 68 %	Calibrated age range 95 %
Dudváh 50–60 cm	Gd-12990	*Planorbarius corneus*	**1410 ± 55**	**590 AD–665 AD (68 %)**	**535 AD–695 AD (93.4 %)** 700 AD–710 AD (0.4 %) 745 AD–765 AD (1.6 %)
Dudváh 102 cm	Gd-11901	*Unio tumidus*	**2770 ± 45**	975 BC–950 BC (12.1 %) **945 BC–840 BC (56.1 %)**	**1020 BC–815 BC (95.4 %)**

Gd — Radiocarbon Laboratory Institute of Physics, Silesian University of Technology, Krzywoustego 2, 44-100 Gliwice, Poland

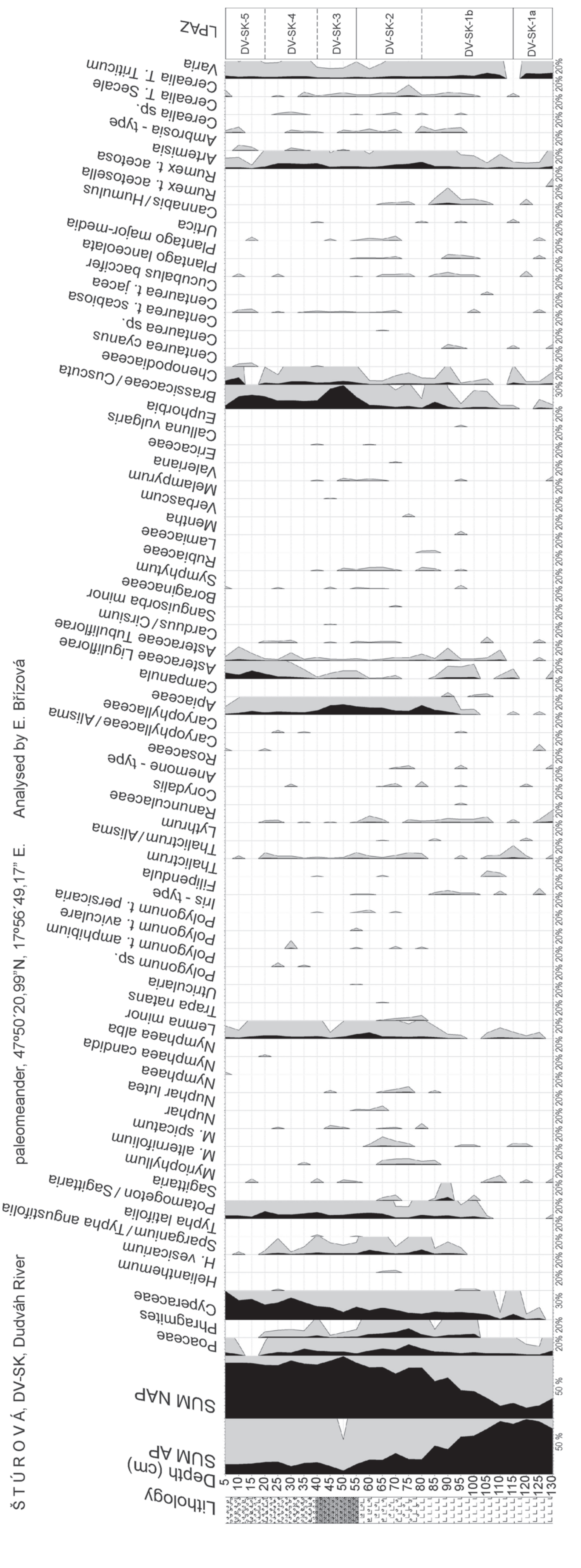

Fig. 4. Pollen diagram for non-arboreal pollen, plant taxa.

pollen (up to 15 %) along with *Thelypteris palustris* indicates presence of alder woods in the area. At the start of this zone the pollen of Polypodiaceae also culminated (over 10 %).

As early as in this subzone, indicators of open country and human impact are represented by pollen of Chenopodiaceae, *Artemisia*, *Carduus/Cirsium*, *Centaurea*, *Plantago major-media*, *P. lanceolata* and *Rumex* t. *acetosa* and *R.* t. *acetosella*.

Aquatics, some littoral and marsh species are represented by sporadic pollen of *Potamogeton/Sagittaria*-type, some *Myriophyllum* (including *M. spicatum*), *Lemna minor*, *Thalictrum/Alisma*-type and of *Cladocera*. A rare find is that of *Salvinia natans* (floating fern). Stratigraphically the sediment is classed into the Sub-Boreal period (VIII 5 100/4 500–2 300 BP, Firbas 1949, 1952; Dreslerová et al. 2004).

Subzone DV-SK-1b-IX: depth 115–85 cm
Abies–Fagus–Picea–Alnus–Salix–Quercus–Cyperaceae

Although at the start of this subzone the AP : NAP ratio was high in favour of trees (80 : 20), later the situation changed completely. Therefore, this subzone is characterized by the most pronounced decrease in pollen of trees indicating gradual forest clearance. At the beginning pollen frequencies of *Alnus* (alder, 15 %), *Carpinus* (hornbeam, 12 %) and *Corylus* (3 %) culminated. The most prominent was the peaking percentage of *Fagus* (beech) which occurred shortly after the beginning of the zone, reaching almost 40 %, although after that it was steadily decreasing to reach very low values at the end, similarly to *Abies*. In the course of the subzone *Alnus* pollen gradually decreased to about 1–2 %. Compared to the species of *Quercetum mixtum*, there was a slight increase in pollen percentages of *Fraxinus* and *Acer*. A maximum proportion of *Salix* (willow, up to 10 %) in the latter half of this zone may indirectly indicate increase in erosional activity of rivers, since willows and poplars need bare surfaces of freshly deposited channel bars for their generative reproduction. This may also be associated with pollen grains of "exotic trees" of genus *Pinus* (of Tertiary age), Cupressaceae (*Tsuga*), along with *Dinoflagellata*, redeposited from the older layers, which appeared solely in this zone.

Forest clearance and opening of the forest cover is also indicated by the appearance of several shrubs (*Sambucus nigra*, *Viburnum*, *Hedera*, *Ephedra*), including *Juniperus* as the characteristic indicator of grazing.

Apophytes and antropophytes were a common part of plant ecosystems in this period (Fig. 4).

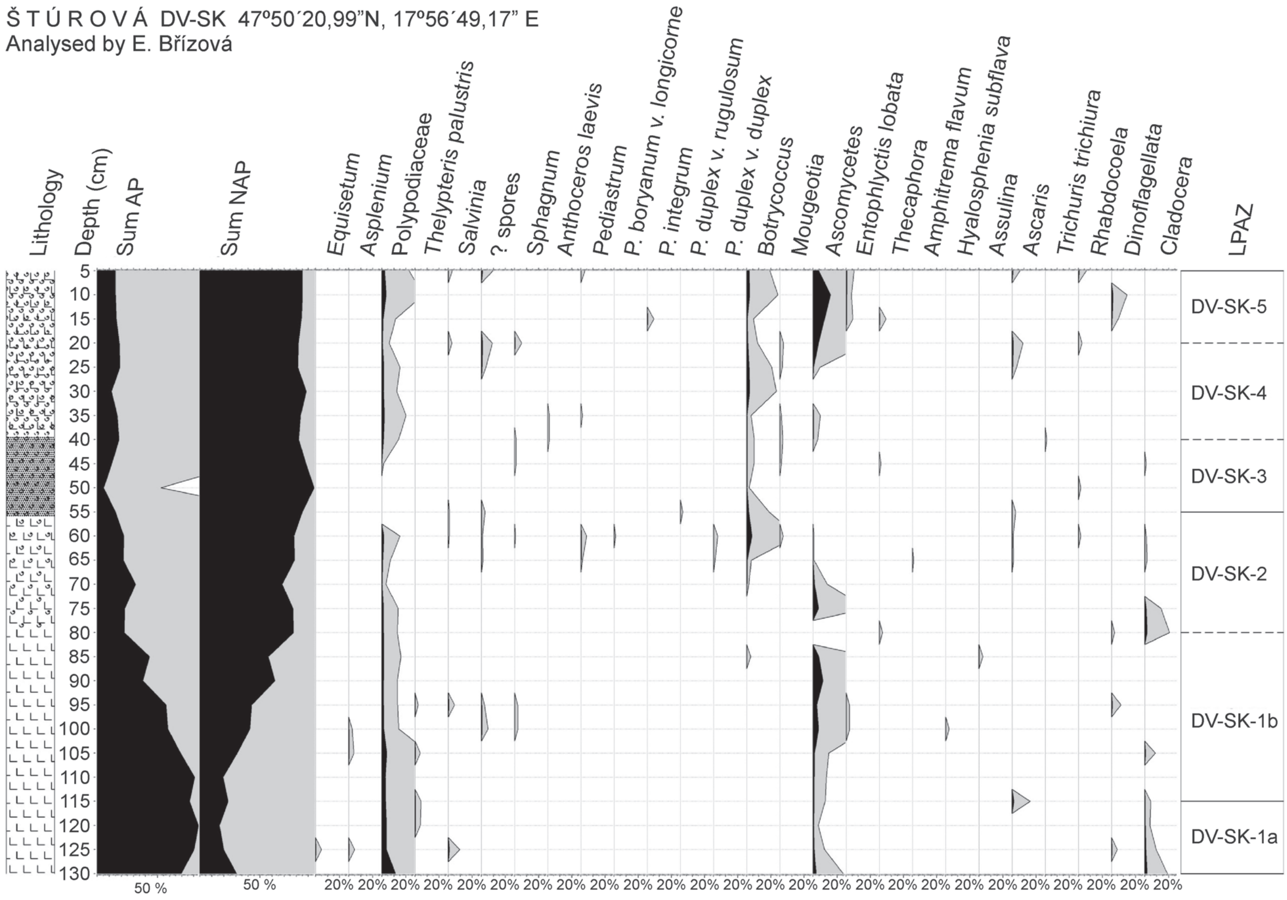

Fig. 5. Diagram of sporomorphs, excluded from the pollen sum.

From the start of this zone, cereal palynomorphs appear in the record, reflecting prehistoric agriculture: first *Cerealia* of *Triticum* type, later on also *C.* type *Secale*. From the younger part of the subzone the presence of cereals is almost constant.

Pollen of predominantly local and extra local aquatics and marsh species indicate a presence of marshy, littoral and open water habitats, the latter with running-water but also slowly flowing or stagnant lacustrine environment. In this zone pollen of *Sparganium/Typha angustifolia* first appeared, indicating marshy and littoral habitats along with *Sagittaria*-type. The increasing percentage of Cyperaceae, representing the most frequent types amongst herbs (>over 10 %), is also ascribed to local marshy plants. At the end of the zone Brassicaceae/*Cuscuta* reached over 10 % and so did Apiaceae, reaching its first maximum within the profile.

When compared to the vegetation development of an abandoned Labe oxbow near Stará Boleslav, this zone is palynologically correlated with the older Sub-Atlantic period (IX, 2 800/2 300 BP–500/650/700 AD, Firbas 1949, 1952). In terms of archaeological chronology it probably coresponds to the Iron Age (La Tène culture) and the Roman period (Břízová 1999a,b; Dreslerová et al. 2004). Stratigraphical classification is also supported by calibrated radiocarbon age 2770±45 years BP of *Unio tumidus* shell in 102 cm, even if the real age is significantly younger, due to the hardwater effect (for calibration see Table 3).

Zone DV-SK-2-Xa: depth 85–60 (80–60) cm
Cyperaceae–Poaceae–aquatics–*Quercus*

In this zone, the forest cover continued to decline, although at a markedly slower pace than previously. Of trees *Quercus* (oak) prevailed with 6–7 %, *Fagus*, *Alnus* and *Betula* were represented with subtle percentages (2–3 %). Continuous presence of *Juniperus* in this and the next zones indicates grazing in the territory.

Besides steadily increasing and prevailing pollen of Cyperaceae (almost 20 %), Poaceae and Apiaceae also reached a higher proportion in this zone. Part of the Brassicaceae/*Cuscuta* pollen is attributable to local swamp species of the genus *Rorippa* as reflected by finds of *Rorippa* cf. *sylvestris* seed in 70–80 cm. *Cuscuta* (dodder) has been reliably determined by seed finds only in the youngest zone DV-SK-5-Xc.

Amongst indicators of cultivation, cereals and their weeds appeared again. At the DV-SK-2 and DV-SK-3 transition, *Artemisia* reached its first maximum in the profile. *Urtica*, *Carduus/Cirsium*, *Centaurea* types *jacea* and *scabiosa* were also more represented, while *Plantago major-media*, *Polygonum* t. *aviculare* and *Helianthemum vesicarium* appeared. Green al-

Fig. 6. Microphotographs of selected sporomorphs. Štúrová–Dudváh — AP: **1** — *Pinus*, sample DV-SK 60/2, depth 0.60 m; **2** — *Juniperus*, sample DV-SK 90/2, depth 0.90 m; **3** — *Carpinus*, sample DV-SK 65/1, depth 0.65 m; **4** — *Salix*, sample DV-SK 75/2, depth 0.75 m; **5** — *Populus*-type, sample DV-SK 95/2, depth 0.95 m; **6** — *Fraxinus*, sample DV-SK 70/2, depth 0.70 m; **7** — *Vitis*, sample DV-SK 95/2, depth 0.95 m; **8** — *Ephedra* cf. *fragilis*, sample DV-SK 100/2, depth 1.00 m; NAP: **9** — *Nymphaea alba* type, sample DV-SK 20/2, depth 0.20 m; **10** — *Nuphar lutea* type, sample DV-SK 55/2, depth 0.55 m; **11** — *Utricularia*, sample DV-SK 65/1, depth 0.65 m; **12** — *Lemna minor* type, sample DV-SK 95/2, depth 0.95 m; **13** — *Potamogeton*, sample DV-SK 75/2, depth 0.75 m; **14** — *Myriophyllum*, sample DV-SK 35/1, depth 0.35 m; **15** — *Alisma*, sample DV-SK 50/2, depth 0.50 m; **16** — *Trapa natans*, sample DV-SK 80/2, depth 0.80 m; **17** — *Sparganium*/*Typha angustifolia*, sample DV-SK 65/1, depth 0.65 m; **18** — *Phragmites*, sample DV-SK 75/2, depth 0.75 m; **19** — Brassicaceae/*Cuscuta* type, sample DV-SK 55/2, depth 0.55 m; **20** — *Sagittaria*-type, sample DV-SK 60/2, depth 0.60 m; **21** — *Anemone*-type, sample DV-SK 95/2, depth 0.95 m; **22** — *Plantago lanceolata*, sample DV-SK 100/2, depth 1.00 m; **23–24** — *Artemisia*, sample DV-SK 55/2, 75/2, depth 0.55 m, 0.75 m; **25** — *Mentha*-type, sample DV-SK 95/2, depth 0.95 m; **26** — Cerealia T. *Triticum*, sample DV-SK 75/2, depth 0.75 m; **27** — Apiaceae, sample DV-SK 65/1, depth 0.65 m; **28** — Chenopodiaceae, sample DV-SK 80/2, depth 0.80 m; Spores: **29** — *Salvinia*, sample DV-SK 20/2, depth 0.20 m; **30** — *Thelypteris palustris*, sample DV-SK 115/2, depth 1.15 m; **31** — Algae: *Botryococcus*, sample DV-SK 30/2, depth 0.30 m. Photo E. Břízová.

gae were represented by *Botryococcus* and sporadically by types of genus *Pediastrum*, which were hard to determine due to their bad preservation.

This zone is characterized by a relatively high proportion of taxa, indicating open water communities of predominantly slowly flowing or stagnant water. This pollen originated mainly from local to extra local pollen deposition (*Nuphar*, *Nymphaea*, *Myriophyllum*, *Trapa natans*, *Potamogeton/Sagittaria* type, later on *Lemna minor*, *Utricularia*). An important part of this pollen was derived from submerged and floating-leaf water plants, growing *in situ*, as indicated also by numerous macrofossil finds (e.g. of genus *Potamogeton*). The presence of littoral communities and reed beds existing in the surroundings is indicated by culminating *Phragmites* pollen in this zone (almost 15 %) with *Iris*, *Sparganium/Typha angustifolia*, *Thalictrum/Alisma* type and *Sagittaria*.

In this and preceding zone microremains of *Vermes-Trichuris trichiura* (human whipworm) together with *Ascaris* (cf. *lumbricoides*, roundworm) were recorded. Remnants of eggs of these parasites of humans and swine are also often found elswhere in medieval objects in sediments deposited during this period (Břízová 1998, 1999a,b; Břízová & Bartošková 1994).

Stratigraphically, this zone most probably belongs to the transition zone of the older Sub-Atlantic period (IX) and older phase of younger Sub-Atlantic (Xa, 500/650/700 AD–1200 AD, Firbas 1949, 1952). From the archaeological viewpoints, this zone could be correlated with the Migration Period and Early Middle Ages (Břízová 1999a,b; Dreslerová et al. 2004).

Zone DV-SK-3-Xa: depth 60–45 (55–45) cm
Brassicaceae/*Cuscuta*–Cyperaceae–Apiaceae

This zone is particularly characterized by the lowest percentage of arboreal pollen (maximum NAP sum over 95 %) within the whole analysed sequence. This probably indicates intensified forest clearance of virtually all types of woodlands. At the transition to DV-SK-4, sporadic pollen of *Sorbus* appeared. Worthy of note is also the broken curve of Polypodiaceae. Pollen of Sub-Atlantic *Calluna vulgaris* (heather) also recorded in the preceding zone indicating grazing is almost certainly of extra regional deposition. The arboreal component was replaced by an increasing proportion of herbaceous taxa (Fig. 4). The highest frequencies in this zone are reached by pollen types of family Brassicaceae/*Cuscuta* (over 35 %) and Cyperaceae (steadily increasing). Apiaceae reach their second maximum (almost 15 %) in the profile.

In this zone a total number of aquatic species decreased to *Myriophyllum*, *Nuphar*, *Nymphaea* and *Lemna minor*, indicating gradual loss of open-water habitats. At the coring site, this zone represents a transitional stage from shallow lake with macrophytes into the marsh community. Terrestrialization of the lake was probably accelerated by influx of coarser mineral material as shown by admixture of sand and coarse silt particles between 39–56 (74) cm. Apart from several Cyperaceae, littoral and marsh communities are indicated by pollen of *Potamogeton/Sagittaria* type, *Sparganium/Typha angustifolia*, *Typha latifolia* and *Thalictrum/Alisma* type.

This zone stratigraphically belongs to the older phase of the Younger Sub-Atlantic period (Xa, 500/650/700 AD–1200 AD, Firbas 1949, 1952), and it corresponds to the archaeological chronology of the Early Middle Ages (Břízová 1999a,b, Dreslerová et al. 2004). The dating is also supported by calibrated radiocarbon age 1410±55 BP of *Planorbarius corneus* shells from 50–60 cm.

Zone DV-SK-4-Xb: depth 45–20 (40–25) cm
Cyperaceae

In comparison with the preceding zone, arboreal pollen appear to subtly increase again in this zone to 10–20 % (Fig. 3). *Ulmus*, *Corylus*, *Carpinus*, *Tilia cordata*, *Acer* and *Fraxinus* reappeared, perhaps indicating recovery of some forests or their understorey trees. This may also be related to the disrupted pollen curve of *Juniperus*. At the transition to DV-SK-5 *Pinus* reached its Late Holocene maximum in the profile (over 10 %).

Prevalence of Cyperaceae (20–30 %) is associated with local floral succession reflected by macrofossil finds. Brassicaceae/*Cuscuta* reached around 15 % and Apiaceae receded in comparison with the previous zone (to 5 %). Littoral and marshy plants are represented by pollen of *Potamogeton/Sagittaria* type (almost 10 %), *Phragmites* and *Sparganium/Typha angustifolia* type. A good indicator of medieval cornfields, *Centaurea cyanus* (cornflower) first appeared. *Artemisia* reached its second maximum in this zone, around 10 %.

This zone stratigraphically belongs to the younger phase of the younger Sub-Atlantic period (Xb, from 1200 AD until now; Firbas 1949, 1952), into the High Middle Ages (Břízová 1999a,b; Dreslerová et al. 2004).

Zone DV-SK-5-Xc: depth 20–0 cm
Cyperaceae–Brassicaceae/*Cuscuta*–*Pinus*–antropophytes

The uppermost pollen zone is associated with the most recent human-induced changes of landscape and vegetation cover. The sum of Non-Arboreal Pollen (NAP) reaches 85–90 %. Pollen of *Quercus*, *Ulmus*, *Fraxinus*, *Acer*, *Carpinus*, *Fagus*, *Alnus* is completely absent from the major part of this zone. On the other side, *Pinus* pollen remains at a value close to 10 % and percentage of *Picea* slightly increased for the first time since the Roman period. Of shrubs, *Viburnum* and *Cornus* appeared.

Almost 50 % of total pollen is represented by Cyperaceae pollen, reaching its maximum values in the whole studied sediment sequence. As in the case of the Danube paleochannel at the site "Bláhová dedina" (Krippel 1963), a continuously increasing percentage of Cyperaceae towards the top of the profile is related to the dominant proportion of local palynomorphs. The latest stage of the paleochannel terrestrialization resulted in establishment of current community dominated by *Carex riparia*. Other taxa of the Cyperaceae family have also been present at the study site until today (mainly *Scirpus lacustris* and *Bolboschoneus maritimus* agg.), as shown by macrofossil record and present-day vegetation survey (Kubalová 2006). Aquatics and littoral/marsh species are rare (Fig. 4).

Amongst anthropophytes, Asteraceae Liguliflorae reach their maximum in this zone with 10 %. Second peak of Brassicaceae/*Cuscuta* pollen (20 %) is at least partially related to local pollen deposition of neophytic parasithic species *Cuscuta australis*, shown by several seeds only in this zone. Similarly, a peaking percentage of Chenopodiaceae (10 %) is associated with the local presence of *Atriplex prostrata*. The recent age of this zone is also indicated by pollen of neophytic *Ambrosia* (whereas its occurrence in previous zones DV-SK-3 and DV-SK-4 is possibly the result of bioturbation).

This zone is stratigraphically classified into the younger phase of the younger Sub-Atlantic period (Xc, 1700 AD from end of the Middle Ages to the present; cf. Firbas 1949, 1952). Archaeology also shows that this zone corresponds to the time period from post-medieval times to the present (cf. Břízová 1999a,b; Dreslerová et al. 2004).

Plant macroremains

The plant macrofossil record is essential for reconstruction of local successional series in abandoned paleomeanders since it allows us to identify the local component of pollen spectra. Plant macroremains in the macrofossil diagram have been aligned stratigraphically (Fig. 7).

1. Initial–lowermost–assemblage of plant macroremains (80–130 cm) corresponds to pollen LPAZ DV-SK-1a and DV-SK-1b. It is represented by seed finds of *Alnus glutinosa*, *Aegopodium podagraria*, *Lycopus* cf. *europaeus*, *Ranunculus* subgen. *Batrachium*, *Solanum dulcamara*, *Eriophorum* sp., *Fragaria* cf. *vesca*, *Linaria vulgaris*, *Persicaria lapathifolia*, *Urtica dioica* (also present in the assemblage 2), *Lythrum salicaria*, Poaceae and Caryophyllaceae seeds.

Solanum dulcamara commonly occurs in softwood floodplain woodlands, marshes and river banks. *Persicaria lapathifolia* is a marshy plant growing on at least seasonally damp habitats, including ruderal places and fields around rivers. *Urtica dioica* (seeds found in 60–70, 120–130 cm and pollen record) is strongly associated with high levels of nitrogen and phosphorus. It is a native component of inundated floodplain woodlands (abundant and dominant in *Salici-Populetum*), but it also grows along with *Aegopodium podagraria* in hardwood floodplain forests (Jurko 1958). On the other side, stinging nettle is a typical indicator of disturbed lands and eutrophic habitats, associated with human habitation and long abandoned buildings.

2. Sediment layers from 50–80 cm contained numerous well-preserved seeds belonging to *Ranunculus* subgen. *Batrachium*, at least two different (not closely determined) species of genus *Potamogeton* and seeds of *Ceratophyllum demersum*. They indicate the next important stage in the local succession, suggesting that permanent open water habitat — an oxbow lake with only slowly flowing or stagnant water was present at the site under study. The first plant to colonize the lake was most probably *Ranunculus* subgen. *Batrachium*, which already appeared in the assemblage 1. Seeds of *Phellandrium aquaticum* indicate, that parts of the studied paleomeander could have been temporarily exposed. This species, together with record of Brassicaceae cf. *Rorippa sylvestris* al-

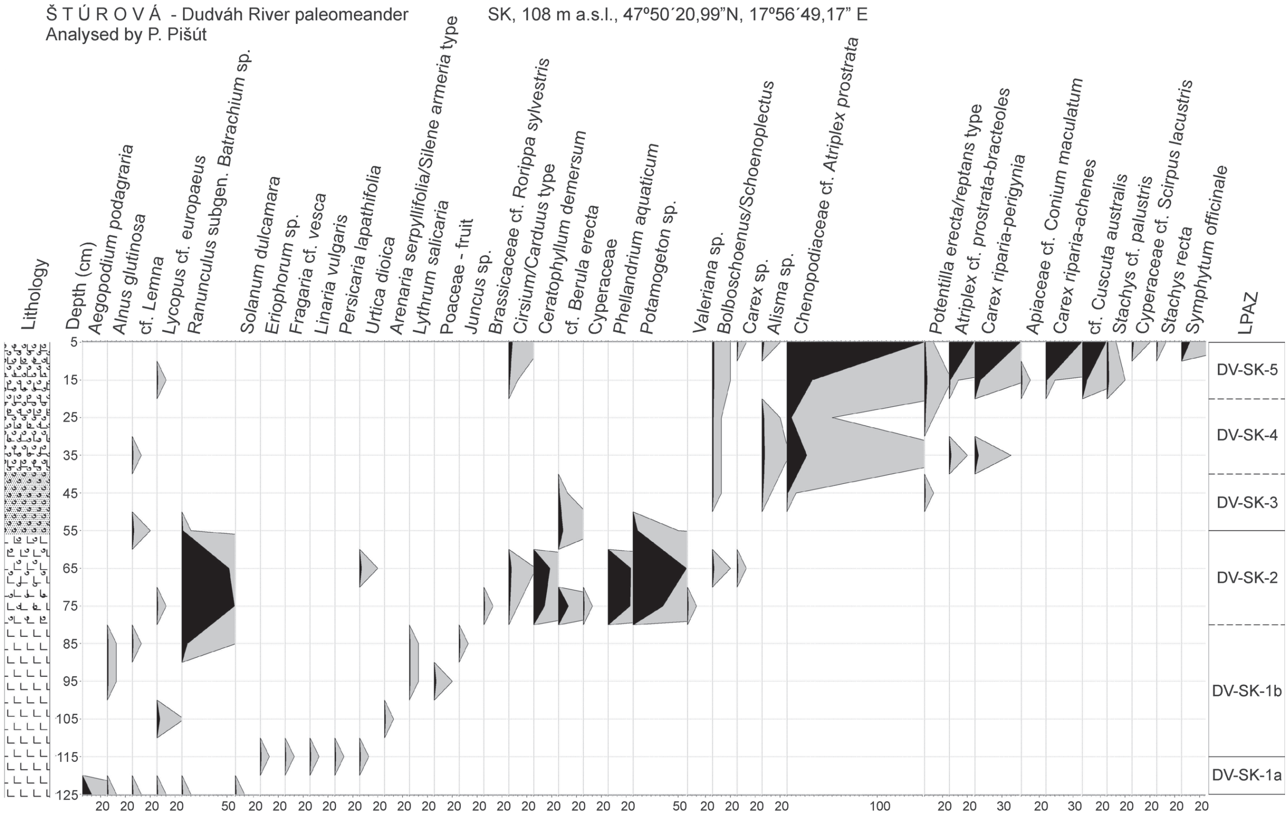

Fig. 7. Plant macrofossil diagram.

low us to suggest the presence of littoral communities of temporary waters of *Oenanthetalia aquaticae* (Oťahelová et al. 2001). Marsh and littoral species are also represented by seeds of *Carex* sp., *Bolboschoenus/Schoenoplectus*, *Lycopus* cf. *europaeus*, *Valeriana* sp., *Juncus* sp. and cf. *Berula erecta*. Among additional finds, *Urtica dioica* and seed of *Cirsium/Carduus* type were also present, the latter also indicated by pollen in this zone. This stage of succession roughly corresponds to pollen zone LPAZ DV-SK-2.

3. The topmost assemblage of plant macroremains from 0–50 cm, corresponding to LPAZ DV-SK-3 to DV-SK-5 is characterized by numerous macroremains of marsh plants along with some anthropophytes present, whereas the water plants (except cf. *Lemna*) entirely disappeared. This assemblage is associated with the gradual conversion of the overgrown lake into an open marsh during LPAZ DV-SK-3. Besides seeds of *Alisma* sp., *Bolboschoenus/Schoenoplectus*, *Lycopus* cf. *europaes*, cf. *Lemna* and *Potentilla erecta/reptans* type the assemblage is represented first of all by numerous seeds and bracteoles of *Atriplex* cf. *prostrata* (Chenopodiaceae) and by both perigynia and achenes of *Carex riparia*. These species are related to the present-day late successional plant community existing at the coring site. Only in the topmost layer 0–20 cm, corresponding to LPAZ DV-SK-5, seeds of neophytic twinner *Cuscuta australis* (Convolvulaceae), *Symphytum officinale*, *Stachys* cf. *palustris* and *Stachys recta* were found. Common marshy species *Stachys palustris* and *Symphytum officinale* grow on the site until today. *Potentilla reptans* has been commonly recorded during survey of the current flora (Kubalová 2006). Seeds of *Cirsium/Carduus* type, *Stachys recta* and *Apiaceae* cf. *Conium maculatum* indicate characteristic and frequent weeds, that are commonly found in the fields surrounding the study paleomeander.

Molluscan assemblages

In total, 2183 specimens representing 33 freshwater species (including 6 bi-

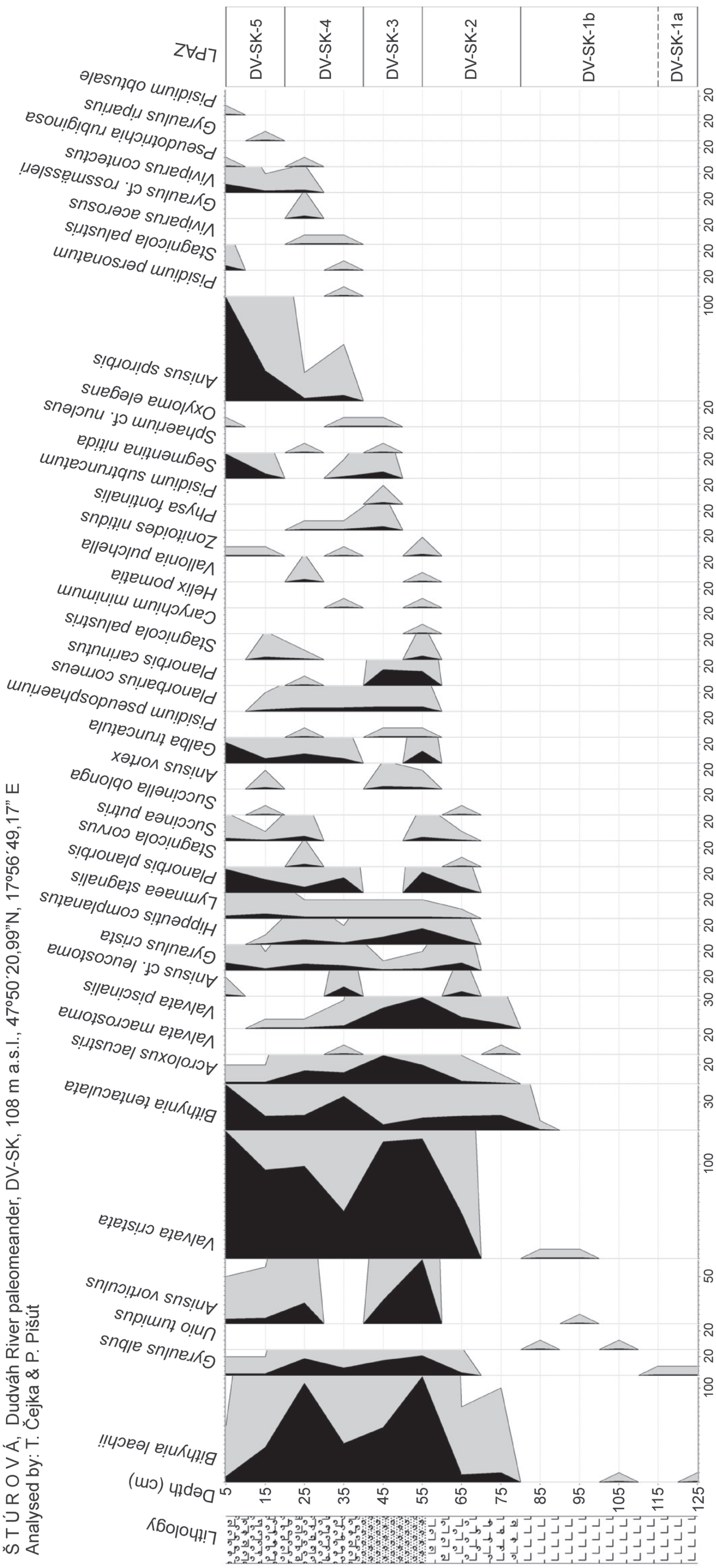

Fig. 8. Molluscan assemblages diagram.

valves) and 8 terrestrial taxa were recovered from the sediment samples. The most frequent species (>60 % of all samples) in the whole profile were *Valvata cristata*, *Bithynia leachii*, *B. tentaculata*, *Gyraulus albus*, and *Acroloxus lacustris*. The samples also contained opercula of *Bithynia tentaculata* and *B. leachii* (not included in the diagram, in order to avoid duplicate records). Molluscan data have been expressed in absolute numbers and aligned stratigraphically (Fig. 8). Four distinct molluscan death assemblages (taxocenes) have been identified that are characterized as follows:

Taxocene A (80–130 cm): ***Unio tumidus***

Almost the entire lower half of the profile was very poor in molluscs. In total, it contained only 41 pieces of shells belonging to 5 species. However, in contrast to the dominating minor shells, two excellently preserved large conchs of *Unio tumidus* were excavated during sampling (in 83 and 102 cm). Low diversity and total number of shells are most probably related to a permanently moving water environment with no or only scarce water plants. In such conditions, limnophilous species that reproduce on submerged vegetation are missing, or occur only sporadically (brought by flow), and are able to survive only for a short time (*Anisus vorticulus*, *Valvata cristata*, *Bithynia leachii* and *Gyraulus albus*; see Fig. 8). Only a few species are adapted to such conditions, that usually do not create dense populations. This is the case of the *Unio tumidus*, which occurs in moderately or slowly flowing portions of large rivers or their major channels. The assemblage concerned roughly corresponds to LPAZ DV-SK-1a and DV-SK-1b.

Taxocene B (60–80 cm): ***Valvata cristata–Bithynia leachii–B. tentaculata–Valvata piscinalis***

The molluscan taxocene from 60–80 cm is indicative of a paleoenvironmental change, probably towards a quieter environment, since the total number of species increased to 15. Besides eurytopic species *Bithynia tentaculata* (13 %), which was probably the first to colonize the new habitat, also *Bithynia leachii* and *Valvata piscinalis* (10 %) appeared, indicative of channels with moving-water. In the latter half of the zone *Valvata cristata*, typical for terrestrialized channels, became the dominant species of the assemblage (42 %). This taxocene corresponds to the lower part of LPAZ DV-SK-2.

Taxocene C (20–60 cm): ***Valvata cristata–Bithynia leachii***

Samples from 20–60 cm contained the largest number of shells and the most diverse molluscan fauna (37 taxa). The assemblage is characterized by dominance of *Valvata cristata* (30 %) and *Bithynia leachii* (24 %), the latter able to live in slow flowing waters. In the lower part of the zone, roughly corresponding to LPAZ DV-SK-3 (40–60 cm), several additional species peaked (*Anisus vorticulus*, *Acroloxus lacustris*, *Valvata piscinalis*, *Planorbis carinatus*, *Hippeutis complanatus*, *Gyraulus albus*). The layer between 55–62 cm contained abundant conchs of full-grown *Planorbarius corneus*. This species is indicative of stagnant waters, overgrown with aquatics, such as cut-off channels and may also occur in seasonal depressions. It is only exceptionally found in channels with moving water. This taxocene corresponds to LPAZ DV-SK-3 and DV-SK-4.

Taxocene D (0–20 cm): ***Valvata cristata–Anisus spirorbis–(Bithynia leachii)***

In total, 27 species were recorded in the uppermost part of the sequence studied. Besides the absolutely prevailing *Valvata cristata* (35 %), this assemblage is also characterized by declining *Bithynia leachii* and increasing abundance of *Anisus spirorbis* (22 %). The abundance of *Segmentina nitida* and *Galba truncatula* also increased both indicative of strongly terrestrialized channels or minor waterbodies, which may be seasonally dry. Amphibious *Galba truncatula* is also able to survive in a semi-terrestrial environment.

Ostracoda

Six extant freshwater taxa were determined in the samples (Table 4); three are left in open nomenclature of which *Candona* sp. 1 juv. and *Pseudocandona* sp. 2 juv. are of early ontogenetical stages (?A-3, ?A-4) and can represent only juveniles of *Candona weltneri* and *Pseudocandona compressa* (Fig. 9). Elongated valves of *Candona weltneri* are attributed to forma *weltneri* (Meisch 2000). The Candonidae are

Table 4: Distribution and abundance of the ostracods in the samples. **C** — carapace, **V** — valve, **juv.** — juvenile.

Depth (cm)	0–10	10–20	20–30	30–40	50–60	60–70	80–90	110–120
Candonidae								
Candoninae								
Candona weltneri Hartwig, 1899			1C		3C, 5V			
Candona sp. 1 juv.		2V	2C, 1V		1C, 1V			1V
Candona sp. 2 juv.			1V	5C, 1V				
Fabaeformiscandona balatonica (Daday, 1894)					1V			
Pseudocandona compressa (Koch, 1838)			2C		2C	1C		
Pseudocandona sp. 1 aff. *P. hartwigi* (G.W. Müller, 1900)					2C			
Pseudocandona sp. 2 juv.			3C	6C, 1V			1C	
Cyclocypridinae								
Cyclocypris laevis (O.F. Müller, 1776)				1C	1C		1C, 1V	
Cyclocypris ovum (Jurine, 1820)	1C		3V	1C	1C			
Cyprididae								
Eucypridinae								
Prionocypris zenkeri juv. (Chyzer & Toth, 1858)		1V						

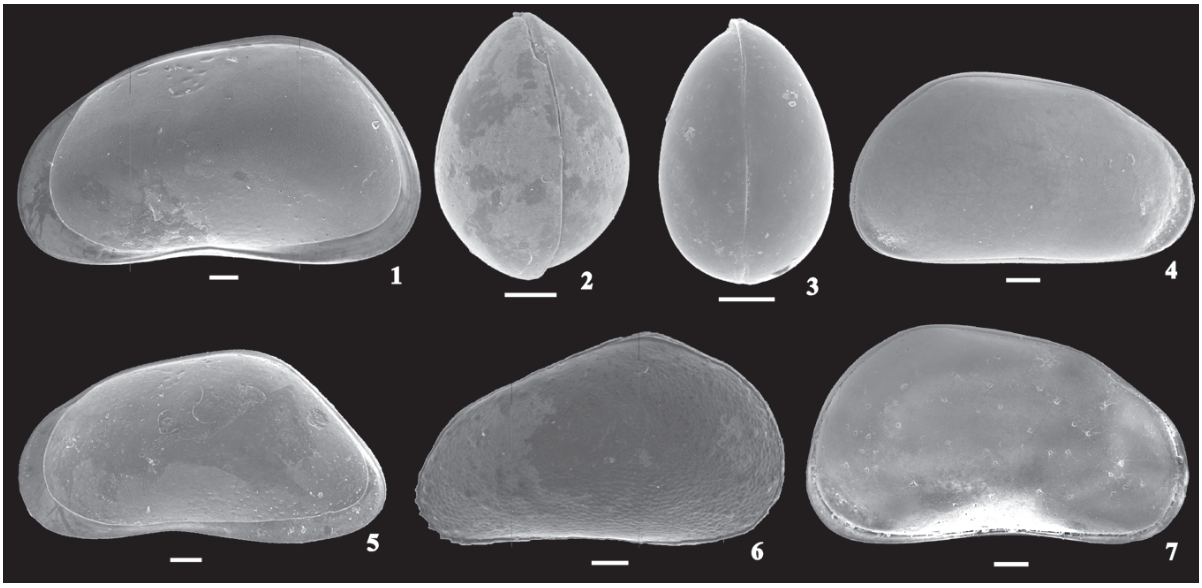

Fig. 9. Freshwater ostracods of Dudváh paleomeander. **1** — *Candona weltneri* Hartwig, 1899, RV♀, internal lateral view; **2** — *Cyclocypris laevis* (O.F. Müller, 1776), C, dorsal view; **3** — *Cyclocypris ovum* (Jurine, 1820) C, dorsal view; 4 — *Pseudocandona* sp. 1 aff. *P. hartwigi* (G.W. Müller, 1900), RV♀ , external lateral view; **5** — *Fabaeformiscandona balatonica* (Daday, 1894), RV♀, internal lateral view; **6** — *Prionocypris zenkeri* (Chyzer & Toth, 1858); RV, juvenil, external lateral view; **7** — *Pseudocandona compressa* (Koch, 1838), RV♀, external lateral view. **RV** — right valve, **C** — carapace, ♀— female. Scale bar 0.1 mm.

the most abundant family and they occurred in all samples. The Cyprididae have been observed in one sample. The amount of preserved carapaces in taphocoenosis is two times higher, exactly 35 : 18, than open valves which signalizes a rapid burial of the dead individuals (Oertli 1971).

Where the biogeography and ecology of the ostracods are concerned all the determined species are extant freshwater taxa widely distributed in the Holarctic (*Cyclocypris ovum, C. laevis*), Palearctic (*Candona weltneri*, *Pseudocandona compressa* (possibly Holarctic), *Fabaeformiscandona balatonica* (possibly Holarctic) regions and in Europe and Asia Minor (*Prionocypris zenkeri*). *Candona weltneri* settles in lakes, ponds, swamps and ditches. *Prionocypris zenkeri* prefers slow flowing streams with rich aquatic vegetation. It occurs also in dead arms, nor far from the river inflow (Meisch 2000). *Pseudocandona compressa* lives in permanent and temporary water bodies. It prefers shallow areas of lakes, but it is known also from bog and ditches.

Both the recognized *Cyclocypris* tolerate a wide range of environmental factors. *Cyclocypris laevis* settles permanent and temporary ponds with or without vegetation, springs, streams and the littoral zone of lakes. *Cyclocypris ovum* is known in almost every type of aquatic habitats, including springs and swamps.

Fabaeformiscandona balatonica prefers the swampy, shallow zone of lakes that dries up in the summer; but is also known from small canals with vegetation and streams.

Paleoenvironmental reconstruction and discussion

The studied paleomeander of the Dudváh River was most probably abandoned in the ***Sub-Boreal period*** (5100/4500–2800/2300 BP), which correlates with the archaeological chronology of the Bronze Age (1900–700 BC), Iron Age (700–0 BC) or earlier. In this period the study area was a part of the alluvium of the active Dudváh River. For this reason high contents of $CaCO_3$ in the soil matrix are also the result of the suggested admixture of moved loessic material, originally transported by the Dudváh River from the Trnavská pahorkatina Hill Land.

According to the pollen record supported by radiocarbon data, the deposition of sediment layers between 70–130 cm may have lasted over several centuries. During this period, the abandoned paleomeander most probably remained connected with the Dudváh River and had permanent influx of moving water for most of the year. As reflected by the macrofossil record, the littoral zone and the bottom of this side channel were possibly still mostly free of aquatics. This oligotrophic environment did not provide favourable conditions for molluscan and ostracod fauna, apart from the large bivalve *Unio tumidus* (Swollen river mussel). Most of the molluscan shells were recovered from the upper 80 cm of the sediment, whereas the lower part of the study profile (80–130 cm) was almost shell free. This distribution pattern is comparable to that from the typical fining-upward sequence of fluvial deposits from Bratislava, where samples of 90–165 cm only contained few shells of moving-water *Lithoglyphus naticoides* and some marshy/littoral species *Oxyloma elegans* and *Galba truncatula* (Pišút & Čejka 2002). At Štúrová, a sample from 110–120 cm also contained a well-preserved scale of *Perca fluviatilis* (European perch). This common fish lives in slow-flowing freshwater rivers, ponds, lakes, often close to underwater obstacles.

According to our results, the riverine landscape along the lower Váh and Dudváh was still mainly forested in the Sub-

Boreal period (pollen zone DV-SK-1). Floodplain and bottomland woodlands, which were growing along rivers or/and on adjacent hilly lands are clearly indicated by pollen of several tree species of *Quercetum mixtum*.

The pollen record along with some macrofossil finds (e.g. *Aegopodium podagraria*, *Fragaria vesca*) indicate the presence of a Pannonian hardwood floodplain forest of *Fraxino pannonicae-Ulmetum*, particularly of its subtypes *Ulmo-Fraxinetum aegopodietosum*, *U.-F. hederetosum* and *Ulmo-Quercetum convallarietosum*. Such woodlands with oak (*Quercus* sp.), elm (*Ulmus laevis* or *U. carpinifolia*), ash (*Fraxinus* sp.), hazel (*Corylus avellana*) in the shrub layer and with other tree species were probably growing on the slightly elevated Dudváh levee not far away from the coring site. Excellently preserved seeds of *Aegopodium podagraria* (Ground elder) are most probably related to the patches of mesophilous floodplain forest, which may have occupied relatively elevated terrain in the immediate vicinity of the meander or along the adjacent reach of Dudváh River. Ground-elder is a nitrophilous plant which grows in shady places and readily spreads vegetatively by underground rhizomes. Along the Danube in Slovakia, it is a characteristic species of the hardwood elm-ash forest and particularly of its typical subassociation *Ulmo-Fraxinetum aegopodietosum*. This habitat is less frequently to seldom inundated. The notable finds are those of *Fragaria vesca* and *Linaria vulgaris*. Woodland strawberry naturally grows along trails and roadsides, embankments, hillsides, stone and gravel laid paths and roads, meadows, young woodlands, sparse forest, woodland edges and clearings. From the floodplain woodlands it has been only sporadically cited from the relatively dry woodland habitat of *Ulmo-Quercetum convallarietosum*. The seed could also originate from a cultivated plant. In Slovakia, strawberries are documented by archaeobotanical finds from habitation areas already from the Roman and Migration periods (Hajnalová 1989). A find of the common-toadflax (*Linaria vulgaris*) may also reflect the presence of humans in the landscape. Although it may grow naturally on the dunes, it is widespread on ruderal spots, along roads, on disturbed and cultivated land.

It is suggested that in the Sub-Atlantic period rarely flooded *Ulmo-Quercetum* woodland community was one of the most extensive on the Žitný ostrov (Krippelová 1967). The presence of oakwood from the turn of Sub-Boreal and Sub-Atlantic is also shown by wood remnants from a Hallstatt burial mound in Dolné Janíky. The main tree species represented were oak (*Quercus*, 52 samples), some *Ulmus* (5 samples), 1 *Alnus* and 1 *Populus* (Hajnalová & Mihályiová 1998).

Concerning the substantial percentages of *Fagus* pollen in DV-SK-1 (up to 20 %, and even 30 % in the DV-SK-1b) and the peaking proportion of *Abies* (silver fir, up to 19 %), it must be said, that pollen of these trees could have come both from local and extra regional pollen deposition, corresponding to their present-day and post-medieval distribution. Beech is abundant in upper basin of Dudváh (Malé Karpaty Mts) and one of the nearest places where it grows is Gerecse Mts in Hungary, 40 km from the coring site. Some archaeobotanical finds (Krippelová 1967) do not exclude the existence of an additional type (no longer existing) of not inundated woodlands with European Beech during the Sub-Atlantic period directly on the alluvial plain or on levees and lower terraces close to Váh, Dudváh and other rivers. Stands with at least admixture of beech and silver fir could have created minor patches intermingled within habitats of mesophilous floodplain forest (Krippelová 1967). Similarly quite high pollen frequencies — with respect to the lowland area — of both species were found in the contemporary fen peat of Kameničná (Váh River oxbow; Fig. 1), where peat deposition started in the Atlantic and ceased in the Sub-Atlantic period (Krippel 1963). On the other side, *Pinus* pollen with 26–55 % was much more represented at Kameničná where the total AP : NAP ratio reached 2 : 1 to 1 : 2 in the same period. At Blahová site, the *Pinus* pollen even reached 46–94 % (Krippel 1963), probably indicating local dominance of pine. The country in general seems to have been already much more open there, with AP : NAP reaching from 1 : 1 to 1 : 5. In the case of Štúrová, *Pinus* pollen frequencies did not exceed 6 % until the zone DV-SK-4, indicating that pine forests grew at a quite appreciable distance from the studied site.

The striking culmination of *Fagus* (up to 40 %), *Alnus* and *Carpinus* in the samples from 110–115 cm could be associated with abrupt climate change to more oceanic at the Sub-Boreal-Sub-Atlantic transition (between 850 and 760 calendar yr BC) as a consequence of climatic deterioration (for details see van Geel et al. 1996).

Close to the banks of the cut-off meander or not far away upstream woodlands with alder existed. Alder could not be the only component of *Salicion albae* floodplain forest, which has been assumed to have covered large low-lying areas with high groundwater of this region in the past (Michalko et al. 1987). In accordance with Krippelová (1967), both pollen and macrofossil record allows us to suggest that at least part of this territory which originally had fen soils (the present-day histic and/or gleyic subtypes of mollisols due to draining; cf. Fulajtár et al. 1998), may have been occupied by characteristic alder carrs of the alliance *Alnion glutinosae* during the Sub-Boreal and Sub-Atlantic periods. These are not only indicated by palynomorphs and seeds of *Alnus glutinosa* (from 90–130 cm), but also by pollen of *Thelypteris palustris* and *Filipendula*, the latter almost exclusively restricted to the LPAZ zones DV-SK-1a and DV-SK-2. *Thelypteris palustris* (marsh fern) is one of the dominant plants in the field layer of regional alder carrs (Jurko 1958; Krippel 1965, 1967). *Filipendula ulmaria* is also a regular constituent of these forests, although it may also grow on moist meadows (it declined in DV-SK-3). The last minor isolated fragments of alder carrs (*Carici elongatae-Alnetum*) still existed on Žitný ostrov Island in the 1950s (Jurko 1958). At present, there are no alder trees — neither *Alnus glutinosa*, nor *A. incana* — in the wider surroundings of the study site. Among trees, poplar and willow prevail completely (Pišút et al. 2007). The pollen record of alder in this period corresponds to comparable 5–18 % pollen percentage of *Alnus* reported by Krippel (1963) from peat of the Váh oxbow at Kameničná from the Sub-Boreal period.

In the course of the ***older Sub-Atlantic period and in the earlier phase of the younger Sub-Atlantic*** (samples from 110–55 cm), the most pronounced changes of vegetation cover occurred in the region. These are first reflected by the DV-SK-1b pollen zone, in SW Slovakia corresponding to Celtic habitations (La Tène period, 420–0 BC), later on to the presence of Germanic settlements and Roman garisons. The second stage is correlated with the Migration Period (0–600 AD) and Early Middle Ages (600–1000 AD), with nomadic Huns, early Slavs and eventually Avars (DV-SK-2).

In the course of this period the arboreal pollen sum within the region of SW Slovakia continuously decreased until it reached roughly the present-day level, indicating the most pronounced decline of woodlands. The decrease in AP coincides with occurrence of shrub pollen, among which some species were represented in the pollen diagram only during this period (*Hedera*, *Vitis*, *Ephedra*), but also with start of continuous presence of *Juniperus* pollen in the LPAZ zones DV-SK-2 to DV-SK-4. Presence of *Hedera* pollen (which has poor dispersal) may be associated with clearance and disturbance of the original woodlands of *Ulmo-Fraxinetum hederetosum*, where the common ivy (*Hedera helix*) used to grow as a ground cover and dominant species of the herb layer. This mesophilous hardwood floodplain forest community with elm, oak and ash used to be much more widespread along the Dudváh and Váh (Jurko 1958). The presence of *Vitis* (Vine) pollen in the DV-SK-1b zone, is also notable. It could belong to wildly growing *Vitis* or to its cultivated form (Maděra 2002). The latter possibility is supported by archaeobotanical finds of *Vitis vinifera* in objects from the Roman period and from the start of Migration period in Bratislava and in Iža (Leányvár) — Roman *castellum* (Fig. 1), the latter located only 21 km from Štúrová study site (Hajnalová 1989).

Over this period the total forest area already steadily decreased in the wider surroundings of the study site. Woodlands were used for fodder production, either thinned out and becoming more open due to deliberate burning, cutting and girdling (rind-barking). Arboreal pollen recorded at the Dudváh site also correspond to trees and shrubs, represented by charcoals found in the remains of Roman marching camp in Iža from the same period. The species could have grown in mixed oak forest with shrubs in understory affected by man, more or less open, which existed in the hinterland of the camp on the bank of the Danube or on its higher and further situated terraces (Čejka & Hajnalová 2000).

Eventually, woodlands were completely transformed into pasturelands, later on into hay-meadows. Grazing and pannage of livestock first occurred on relatively drier places, slightly elevated levees and on sand dunes in the surroundings of the settlement sites next to the Danube, Dudváh and Váh rivers. On particular sites animal husbandry could have contributed to reestablishment of forest steppe and steppe habitats. These may be related to the presence of *Ephedra* pollen in samples from 70 and 100 cm. The only local representative of this genus is *Ephedra distachya*, a lower shrub. In Slovakia it is currently extremely rare and only growing along the Danube on the northernmost edge of its native range. In the nature reserves next to Čenkov *E. distachya* grows on sand dunes along with *Populus alba* and *Juniperus communis*. Such conditions may have existed, for example, on Haplic and Gleyic-Haplic Chernozems near Veľké Kosihy or Kameničná, only few kilometers away from the study site.

The character of secondary grasslands and meadows in the region varied accordingly to soil type, groundwater level and exposure to floods. These communities were described in detail by Krippelová (1967). Common alder carrs (*Alnion glutinosae*) on Histosols and Gleyic soils were gradually transformed into the wet meadows of alliance *Molinion coerulae*. Soft floodplain forest of *Salicion albae* (on Fluvisols and Gleysols) was replaced by secondary communities of *Rorippo-Agrostidetum stoloniferae*. Pasturelands of association *Trifolio-Lolietum* originated on relatively dry places after the mesophilous and subxerophilous hardwood floodplain *Ulmenion* forest had been cleared. The community *Potentillo-Festucetum pseudoovinae* originated by grazing of original fragments of steppe habitats on Gleyic-Haplic Chernozems. In low-lying areas a community of association *Artemisio-Festucetum pseudoovinae* developed on saline soils (Krippelová 1967). The possible presence of above cited secondary communities is indicated by pollen of several species of herbaceous vegetation (Fig. 4).

From the younger part of the zone DV-SK-1b the presence of cereals is almost constant. These data are in accordance with the recent archaeobotanical data, according to which *Triticum spelta* (spelt) had the decisive proportion in the finds from the La Tène period (420–0 AD). Grains of *Secale cereale* (rye) also occur. It probably originally appeared as a weed in the fields of *Triticum aestivum* (common wheat), which was cultivated from the middle La Tène. During the Roman and Migration periods *T. aestivum* takes a decisive role and wide distribution on fields, along with the types *Triticum aestivo-compactum* (Hajnalová 1989).

A seed of Caryophyllaceae from 100–110 cm belonging either to *Arenaria serpyllifolia* or *Silene armeria* type is also associated with plants of arable fields or ruderals. Caryophyllaceae are also indicated by pollen from the same LPAZ DV-SK-1a and from DV-SK-4, as well. Seed of *A. serpyllifolia* was also found in the samples from a filled trench of the Roman camp1. at Iža–Leányvár (Čejka & Hajnalová 2000).

During the ***Migration period (0–600 AD)*** and in the ***Early Middle Ages (600–1000 AD)*** the Lower Dudváh still existed as a river but pollen of several water plants of pioneer communities of the classes *Lemnetea* and *Potametea* with *Potamogeton*, *Myriophyllum*, *Nuphar* (including *N. lutea*), *Nymphaea*, *Trapa natans* also indicate the presence of shallow, stagnant or only temporarily flow-through waterbodies in close vicinity of the study site. These plants grew in previously abandoned oxbow lakes and remnant Dudváh meanders. Higher flows gradually filled them with carbonaceous mud, so that became shallower and progressively more overgrown with aquatics. Also at the coring site numerous macrofossil finds from the depth of 40–80 cm indicate a significant change in paleoecological conditions. When an influx of running water into the abandoned oxbow gradually ceased, the shallowing lake started to be largely overgrown by macrophytes. First *Ranunculus* subgen. *Batrachium* appeared, shortly followed by different species of the genus *Potamogeton* and *Ceratophyllum demersum*.

The prevailing paleoecological conditions of these oxbow lakes can be reconstructed based on knowledge of the present-day distribution and ecology of typical water plant communities in Slovakia (Oťahelová 1995a,b). According to them, the overgrowing waterbody at the coring site had slowly flowing or stagnant water for most of the year. The oxbow lake reached a mean depth from 0.3 to 1.2 m. So, for instance the currently common community *Potamo perfoliati–Ranunculetum circinati* with dominant *Batrachium circinnatum* typically grows in stagnant and slow waters of oxbows and side channels, where its cover area may reach up to 100 %. It is tolerant of moderate salt content, the mean water depth is 0.8 m (0.35–1.3 m). *Myriophyllum verticillatum* and *M. spicatum* form submerged stands, frequently with *Ceratophyllum demersum*, *Potamogeton lucens* and *Utricularia vulgaris*. The community with dominant *C. demersum* grows in stagnant and slow running waters, as in dead arms. It indicates warm, eutrophic reservoirs with rich influx of nutrients. The mean water depth is 0.3–1.2 m, pH range from neutral to slightly alkalic. *Nymphaea alba* and *Nuphar lutea* (= vulnerable plant taxa of Slovakia) are characteristic of the community *Nymphaeetum albo-luteae* (with mean water depth 0.8–1.2 m). *Trapa natans* is a relict and endangered species of Slovakia, forming a monodominant community *Trapetum natantis* (Oťahelová 1995a,b).

Furthermore, the water level in the abandoned oxbow fluctuated over the year and parts of the river bed became seasonally exposed. This is reflected for instance by *Utricularia vulgaris*, indicated by pollen from 65 cm. Carnivorous bladderwort is an indicator of infilled and overgrown meso- to eutrophic waters with a mean water depth of 0.3 m. It is a characteristic species of the hydro-littoral ecophase of dead arms and depressions and of the community *Lemno-Utracularietum vulgaris*. On the seasonally exposed bed we also suggest the presence of the community *Oeanantho aquaticae–Rorippetum amphibiae*. Its typical species *Phellandrium aquaticum* is indicated by the seed record from 60–80 cm and also a part of the pollen grains of the Apiaceae family is ascribed to this species. This small-scale community optimally grows in seasonally drying marsh habitats in the medium stage of their terrestrial conversion or in the littoral zone of slowly flowing lowland rivers, with a depth of water level up to 30 cm (Oťahelová et al. 2001). Local occurrence of natural plant communities of the alliance *Oenanthion aquaticae* characteristic of dead arms and shallow, slowly flowing waters with fluctuating water regime is also indicated by a record of the additional species *Bolboschoenus* and *Sagittaria*.

Water plant communities of the studied oxbow and neighbouring shallowing paleomeanders bordered on or made mosaic with communities of reed beds, large sedges and marshy plants of the class *Phragmito–Magnocaricetea* (Oťahelová et al. 2001). Several characteristic species of this class are indicated by pollen or macrofossils, such as *Alisma* (cf. *lanceolatum*), *Lycopus* cf. *europaeus*, *Schoenoplectus/Bolboschoenus*, *Lythrum salicaria* (seed). The presence of *Iris*-type pollen in the zones DV-SK-2 and DV-SK-3 is also in good accord with the demands of the common marshy plant *Iris pseudacorus*, which could grow on the banks and bottom of the paleochannel. The plant grows best in very wet conditions, both in open and wet forest habitats, where it tolerates submersion, low and anoxic soils.

In the same period (LPAZ DV-SK-2) the pollen of *Phragmites* also reached its maximum values. *Phragmites australis* (common reed) in its characteristic community *Phragmitetum vulgaris* may have occupied shallower parts of the paleochannel or could have formed line belts along its banks. It could also form extensive reed beds in depressed areas elsewhere in the surroundings. Local toponyms referring to historical occurrence of reed beds were common on Žitný ostrov Island (Unti 2002).

At the end of the zone DV-SK-2 the proportion of *Lemna minor* pollen also significantly increased. *L. minor* is a typical representative of the class *Lemnetea*. Structurally simple plant communities of unrooted pleustophytes occupy meso- and eutrophic, stagnant and slowly-flowing waters. They mainly occur in the hydro-littoral ecophase, but also tolerate fluctuations of the water table. They are found both ephemerally and in mosaic with communities of the classes *Potametea* or *Phragmiti-Magnocaricetea*. This explains the almost constant presence of *Lemna minor* pollen in the whole profile until the present. The community with dominant *Salvinia natans* (Oťahelová 1995a), indicated by the pollen record throughout the profile, also belongs to the *Lemnion minoris* alliance.

Altered water regime in the abandoned channel and gradual transformation of the shallowing overgrown lake into open marsh in LPAZ DV-SK-3 and DV-SK-4 was associated with the optimum development of molluscan and ostracod fauna. Freshwater molluscs seemed to have reached their maximum abundance and diversity during the LPAZ DV-SK-3 (taxocene C). Besides *Valvata cristata* and *Bithynia leachii* which dominated the molluscan assemblage, *Anisus vorticulus*, *Valvata piscinalis*, *Acroloxus lacustris*, *Hippeutis complanatus*, *Gyraulus albus*, *Planorbis planorbis*, *P. carinatus* and *Planorbarius corneus* were also more abundant. Ostracods particularly thrived in the sampled interval from 60 cm to 20 cm. According to their ecological demands, they lived in a shallow, slow flowing cold water environment (Table 5) covered with aquatic vegetation and fed by river and springs. The calcium content of the water was 18–72 mg Ca/l, occasionally above this level; salinity could occasionally reach oligohaline range (0.5–5 ‰).

Table 5: Ecological characteristics of the ostracod species. Explanation of used terms: mesotitanophylic — occurring at 18–72 mg Ca/l; polytitanophylic — occurring at > 72 mg Ca/l; titanoeuryplastic — occurring indifferently on Ca content (according Meisch 2000).

	Temperature	Water velocity	Ca content	salinity	pH
Candona weltneri, form *weltneri*	cold stenothermal	oligorheophilic	titanoeuryplastic	oligohalophilic	–
Fabaeformiscandona balatonica	?mesothermophilic	–	–	–	–
Pseudocandona compressa	mesothermophilic	oligorheophilic	meso-polytitanophilic	oligo-mesohalophilic	euryplastic
Cyclocypris laevis	thermoeuryplastic	mesorheophilic	meso-polytitanophilic	mesohalophilic	euryplastic
Cyclocypris ovum	thermoeuryplastic	rheoeuryplastic	titanoeuryplastic	mesohalophilic	euryplastic
Prionocypris zenkeri	oligothermophilic	mesorheophilic	polytitanophilic	–	–

Table 6: List of reconstructed or suggested phytosociological syntaxa, based on paleobotanical data or mentioned in the text.

Class	Order	Alliance	Association/Community
Querco–Fagetea Br.-Bl. et Vlieger in Vlieger 1937	*Fagetalia* Pawlowski in Pawlowski et al. 1928	*Ulmenion* Oberd. 1953	*Fraxino–pannonicae Ulmetum* Soó in Aszód 1936 corr. Soó 1963 *Ulmo-Fraxinetum aegopodietosum* Jurko 1958 *Ulmo-Fraxinetum hederetosum* Jurko 1958 *Ulmo-Quercetum convallarietosum* Jurko 1958
	Quercetalia pubescentis Br-Bl. 1931	*Aceri tatarici – Quercion* Jakucs et Fekete 1957	*Junipero-Populetum albae* Zólyomi 1950
Salicetea purpurae Moor 1958	*Salicetalia purpurae* Moor 1958	*Salicion albae* (Oberd. 1933) Th. Müller et Görs 1958	*Salici-Populetum* (R. Tx. 1931) Meijer Drees 1936
Alnetea glutinosae Br.-Bl. et R.Tx. 1943	*Alnetalia glutinosae* R. Tx. 1937	*Alnion glutinosae* Malcuit 1929	*Carici elongatae–Alnetum* Koch 1926
Molinio–Arrhenatheretea R. Tx. 1937	*Molinietalia* Koch 1926	*Molinion coerulae* Koch 1926	
	Agrostietalia stoloniferae Oberd. in Oberd. et al. 1967	*Ranunculo repentis – Rumicenion crispi* Hejný et Kopecký 1979	*Trifoli repentis– Lolietum* Krippelová 1967
		Lolio–Potentillion R. Tx. 1947	*Rorippo-Agrostidetum stoloniferae* (Moor 1958) Oberd. et Th. Müller 1961
Festuco–Puccinellietea Soó 1968	*Artemisio – Festucetalia pseudovinae* Soó 1968	*Festucion pseudovinae* Soó in Máthé 1933	*Artemisio-Festucetum pseudoovinae* Soó (1933) 1945
Festuco–Brometeta Br.-Bl. et R. Tx. 1943	*Festucetalia valesiacae* Br.-Bl. et R. Tx. 1943	*Festucion valesiacae* Klika 1931	*Potentillo-Festucetum pseudoovinae* Soó 1933
Lemnetea de Bolós et Masclans 1955	*Lemnetalia minoris* de Bolós et Masclans 1955	*Lemnion minoris* de Bolós et Masclans 1955	*Salvinio-Spirodeletum polyrhizae* Slavnić 1956
	Lemno-Utricularietalia Passarge 1978	*Utricularion vulgaris* Passarge 1978	*Lemno-Utracularietum vulgaris* Soó 1947
	Hydrocharitetalia Rübel 1933	*Hydrocharition* Rübel 1933	*Ceratophylletum demersi* Hild 1956
Potametea R.Tx et Preising 1942	*Potametalia* Koch 1926	*Nymphaeion albae* Oberd. 1957	*Nymphaeetum albo-luteae* Nowiński 1928
			Trapetum natantis V. Kárpáti 1963
			Potametum natantis von Soó 1927
	Callitricho–Batrachietalia Passarge 1978	*Ranunculion aquatilis* Passarge 1964	*Potamo perfoliati–Ranunculetum circinati* Sauer 1937
Phragmito – Magnocaricetea Klika in Klika et Novák 1941	*Phragmitetalia* Koch 1926	*Phragmition communis* Koch 1926	*Phragmitetum vulgaris* von Soó 1927
		Magnocaricion elatae Koch 1926	
	Oenanthetalia aquaticae Hejný in Kopecký et Hejný 1965	*Oenanthion aquaticae* Hejný ex Neühäusl 1959	*Oeanantho aquaticae–Rorippetum amphibiae* Lohmeyer 1950

Deforestation of the region seems to have culminated in the pollen zone DV-SK-3 probably correlated with the historical ***early medieval period*** (600–1000 AD). Between the 7 th–9th and 10 th–13th century a number of new settlements were established in SW Slovakia and population density markedly increased (Čaplovič 1998). Probably in this period the last major remnant patches of until then relatively untouched floodplain forest (due to impeded drainage and periodical flooding) around the Lower Dudváh and Váh River started to be methodically cleared and grazed. Until then — until the start of the zone LPAZ DV-SK-3 — pollen of *Quercus* (oak) was constantly present with over 5 %. Also *Ulmus* (elm) and *Corylus* (hazel) were part of the forest. From the depth of 55 cm up-section in relation to the forest clearance the presence of pollen of additional tree species also decreased (*Fagus*, *Abies*, *Carpinus*, *Picea*). The pollen count of *Alnus* diminished as well, although its curve remained continuous. It can be assumed that although closed woodlands with dominant *Alnus glutinosa* probably disappeared from the wider surroundings, alder remained a component of the Dudváh riparian belts, even though it did no longer grew on the study site.

During the period concerned the eutrophic oxbow lake gradually developed into a marsh habitat. Local aquatics were eventually replaced by a tall-sedge community with dominant *Carex riparia* (indicated by numerous achenes and perigynia), which have persisted on the site until the present. This community is also indicated by pollen frequencies of Cyperaceae, steadily increasing from the bottom of the profile with maximum at the topsoil. Molluscan assemblage indicates open marsh conditions, although trees may have grown along the banks of a paleochannel. From the establishment of this swamp community *Atriplex prostrata* also became its important component. This obligatory halophyte species indicates periodical slight salinization of the topsoil which may occur in dry seasons. Other characteristic plants growing in this marsh were *Bolboschoenus* and/or *Schoenoplectus lacustris* (Cyperaceae), *Alisma* sp., *Lycopus* and *Potentilla reptans* (or *P. erecta*).

The entire molluscan taphocoenosis at Štúrová was dominated by freshwater species. Moreover, among land snails, woodland and/or shade-demanding species were completely missing, providing no evidence of closed woodland either at the study site or nearby. Even at present, when the banklines of the paleomeander are vegetated with poplars and willows, only *Cepaea hortensis* is present here from the eurytopic woodland species.

During the ***High Middle Ages*** (1000–1300 AD) paleoecological evidence is already supplemented by written records about the character of the historical landscape. Despite a large degree of deforestation the whole countryside was still strongly affected by surface water and shallow regional groundwater. The entire territory around the Lower Dudváh River was seasonally inundated and characterized by excessive water. There were extensive open wetlands, many marshes, numerous lakes, reed beds and places covered by large sedges. According to a record from 1268 the village of Čalovec on the Dudváh was "located among reed beds". There is also written evidence of tall-sedge habitats, oak, elm, alder, willow, poplar and other tree species (Fejér 1829; Marsina 1987). Some tree species are also recorded by archaeologists. In the 13th century, *Alnus*, *Betula* and *Salix* were used for the construction of a garden fence, unearthed in Šamorín (Urminský 2005).

A number of lakes mentioned in the 13th century charters along the Dudváh indicates that the terrestrial conversion of its former paleochannels had not been completed yet. Lakes were used as fish ponds or as profitable fishing places. Several lakes were shallowing and developing into inundated swamps in this period (Fejér 1829).

In the ***Late Middle Ages*** (1300–1526 AD) the Lower Dudváh became subjected to serious geomorphological changes that probably occurred in response to a new phase of intensified Danube activity. Sometime between 1378 and 1528 AD a new avulsion course of the Lesser Danube was formed between the villages of Topoľníky and Kolárovo (Fig. 1). This resulted into the abandonment of at least a 24 km long lower stretch of the Dudváh River. Significantly increased erosion activity of the Danube River also seems to be reflected from the southern Danube branches (Pišút 2006). This activity coincides with the period of increased soil erosion and transport of sediments in the northern part of the Bavarian stretch of the Danube (Buch & Heine 1995). The largest Danube flood of the past millenium also occurred in this period in August 1501 AD with an estimated peak flow in Vienna of 15,000 $m^3 \cdot s^{-1}$ (Rohr 2005).

After these channel changes, gradual siltation began in the cut-off Lower Dudváh. Nevertheless, the river still kept on carrying some running water at least seasonally even in the 18th century (Alapy 1933).

In the youngest phase — ***post medieval period until the present*** (since 1526 AD) — the cultural landscape in the surroundings of the study site was almost completely open, similar to the present day situation. Most of the trees were growing in riverine belts along paleochannels or in only small patches and clusters of floodplain woodlands. Waterlogged and seasonally flooded meadows and pasturelands dominated the countryside, so that ploughland was still underrepresented. This structure of cultural landscape is already well documented also by map sheets of the 1782–1785 military mapping (Arcanum 2004). During this period several farmsteads with minor areas of isolated fields were established on the levee of the former Dudváh. In the pollen record a slight increase in *Pinus* and *Picea* (spruce) can be distinguished, coming from extra regional pollen deposition. Increased pine pollen is thought to be associated with intentional large-scale plantings of *Pinus sylvestris* (Scotts pine) on blown sands of the Záhorská nížina Lowland, which were most intensive between 1650–1740 AD (Krippel 1965; Budke 1981). A slight increase in spruce pollen is related to introduction of its monocultures mainly in the 19th and 20th centuries.

The complete absence of *Quercus, Ulmus* and *Carpinus* pollen is essentially in accord with the current negligible representation of these species in surroundings of the study site. Nevertheless, apart from this most recent period, the pollen curve of oak was continuous within the whole profile. These data are also in agreement with the charcoal record from the total of 45 archaeological sites located in the Trnavská pahorkatina Hill Land and the Váh alluvial valley, according to which oak has prevailed from the Atlantic period until the present with mixed oak forest being the main woodland type in this territory (Hajnalová 1990).

The late successional stage of the abandoned oxbow at Štúrová was largely dominated by the molluscan assemblage of freshwater *Valvata cristata* and *Bithynia leachii*. Several modern analogues of this community have been recorded from SW Slovakia by Čejka (personal data) from side channels, streams and dead arms with much aquatic vegetation, as in the Čičov oxbow (47°46′33″ N, 17°43′52″ E), the Čierna voda Stream at Turňa (48°11′42.86″ N, 17°24′4.66″ E) and the Šrek backwater of the Morava River near Stupava (48°16′35.39″ N, 16°56′32.5″ E). The molluscan assemblage consisted of several species, which are currently rare, endangered or extinct. The most notable are *Anisus vorticulus* (abundant in taxocene B), *Gyraulus riparius* (a single shell in taxocene A), *Gyraulus rossmässleri* (three shells in taxocene B), *Planorbis carinatus* (taxocene B), *Valvata macrostoma* (one shell in taxocene B and D), *Pisidium pseudosphaerium* (3 shells in taxocene B). Most of these species are now scarce not only in the study area, but in the whole Danubian Lowland; some are probably already extinct here (*Gyraulus rossmässleri*, *Valvata macrostoma*).

The ***current habitat*** at the coring site is a result of the most recent landscape changes during the 19th and 20th century, which have been associated with drainage, intensified agriculture, ruderalization and spread of invasive species. After the completion and strengthening of the embankments along the Danube in the 17th and 18th centuries, problems due to waterlogging and deteriorated outlet of floodwaters exacerbated. The study site was first affected by drainage in 1822 (Gyulai 1896). Nevertheless, even in 1876 large territories of lower Žitný ostrov Island were predominantly used for pastures and wet meadows, with only small patches of arable lands (Bálint map, reproduced by Krippelová 1967).

The establishment, refinement and completion of the drainage network from the late 19th century to the 1960s caused lowering of the mean regional groundwater table by about 60–100 cm. Thus, parts of the original open swamps in paleomeanders came to be occupied by secondary softwood floodplain woodlands (*Salici–Populetum*). Several willow-dominated woodland patches have been planted intentionally, being used mainly as pollard trees. The last remnant of shallow open waterbodies rapidly disappeared and organic soil layers have been partially mineralized. As a result, originally waterlogged soils have developed into the current prevailing Calcaric Mollic Fluvisols and Mollic Gleysols (Fulajtár et al. 1998). Consequently, this drying has resulted in retreat of original swamp habitats and enabled the large-scale transformation of pastures and meadows into arable lands. This process was completed by the establishment of a new agricultural colony — the current village of Štúrová — near former Dudváh in 1950s.

Conclusions

The Late-Holocene biostratigraphy at the Štúrová site has been subdivided into different local pollen assemblage zones that are correlated with the general Holocene climatostratigraphic subdivision for Central Europe. Five zones and two subzones were identified as follows: DV-SK-1a-VIII: depth 130–115 cm, *Abies–Fagus–Ulmus–Alnus–Quercus–Carpinus–opulus*; DV-SK-1b-IX: depth 115–85 cm, *Abies–Fagus–Picea–Alnus–Salix–Quercus*–Cyperaceae; DV-SK-2-Xa: depth 85–60 cm, Cyperaceae–Poaceae–aquatics–*Quercus*; DV-SK-3-Xa: depth 60–45 cm, Brassicaceae/*Cuscuta*–Cyperaceae–Apiaceae; DV-SK-4-Xb: depth 45–20 cm Cyperaceae; DV-SK-5-Xc: depth 20–0 cm, Cyperaceae–Brassicaceae/*Cuscuta–Pinus*–anthropophytes. Paleoecological analysis provides new information about the paleoenvironments of the Danubian Plain from the Sub-Boreal to the younger Sub-Atlantic period. Apart from the two lowermost subzones DV-SK-1a-VIII and DV-SK-1b-IX, non-arboreal pollen prevailed in samples including several indicators of cultivation, reflecting an open cultural riverside landscape.

The paleomeander of the Dudváh River at Štúrová site was cut-off during the Sub-Boreal period when the land was still mostly covered by oak-dominated mixed forest, although with a notable high frequency of *Fagus* and *Abies* with respect to the lowland basin. Floodplain woodlands with *Quercus*, *Ulmus*, *Tilia*, *Fraxinus*, *Populus* and *Salix* were the most important part of the regional forest vegetation. In low-lying depressions, *Alnus glutinosa* formed typical alder carrs. The largest human-induced decline of the regional forest occurred during the Sub-Atlantic with peaking forest clearance in the early medieval period. The results confirm earlier palynological (Krippel 1963, 1986) and archaeobotanical data, and provide new data on the composition of vegetation in this part of Žitný ostrov. Until the mid-19th century the region was strongly influenced by shallow groundwater and periodical floods, as reflected by abundant pollen of aquatics and marsh species. Amongst non-arboreal taxa, pollen of Cyperaceae, Brassicaceae/*Cuscuta*, Poaceae and Apiaceae prevailed. Paleobotanical, macrofossil and ostracod records allowed the local species to be recognized in the paleorecord and individual stages of terrestrial conversion of paleomeander to be identified. Local successional changes started with i) stage of abandoned oxbow still with influx of moving water, poor in both macrophytes and molluscs, went on through ii) a shallow eutrophic oxbow lake with slowly flowing or stagnant water overgrowing with aquatics (*Ranunculus* subgen. *Batrachium*, *Potamogeton* sp., *Ceratophyllum demersum* etc.) and with abundant invertebrates that finally developed into iii) an open marsh dominated by Cyperaceae (mainly *Carex riparia*) with *Atriplex prostrata*, supporting diverse molluscan and ostracod fauna. The molluscan assemblages were almost completely dominated by freshwater taxa, typical of a still aquatic habitat and shallow open marsh. The current habitat with Cyperaceae and subdominant *Atriplex prostrata* established itself on the site already in medieval times.

The results contribute to the historical biogeography of several plant and molluscan taxa of conservation concern. These taxa no longer exist at the studied site at all, and are scarce nowadays in Slovakia, and in the whole Danubian Lowland, many being vulnerable, endangered and protected (water plants *Nymphaea*, *Nuphar*, *Trapa natans* agg., *Utricularia*, *Salvinia* etc., molluscs *Anisus vorticulus*, *Gyraulus riparius*, *G. rossmässleri*, *Planorbis carinatus*, *Valvata macrostoma*, *Pisidium pseudosphaerium*). Some species are probably already extinct in this region (e.g. molluscs *Gyraulus rossmässleri*, *Valvata macrostoma*).

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