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Šúr, a former late-glacial and Holocene lake at the westernmost margin of the Carpathians

Šúr – zaniklé pozdně glaciální a holocenní jezero na nejzápadnějším okraji Karpat

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Dedicated to Kamil Rybníček and Eliška Rybníčková on the occasion of their 80th birthdays

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There is a unique palaeolimnological record of the late-glacial and Holocene periods in the former lake Šúr near Bratislava in western Slovakia. The aim of this study was to reconstruct the development of the environment in the locality of the lake, including the gradual infilling of the lake. We reconstructed the development of the lake environment by combining results of a geochemical analysis with analyses of diatoms and plant macrofossils. We also carried out a pollen analysis to assess the changes in the surrounding terrestrial vegetation. The results reveal how the character of the lake has changed over time. At the peak of the glacial period, water flowed through the lake and deposited sand there. Later on the flow of water through the lake ceased and a vast oligotrophic lake developed. During the Holocene, the lake gradually became eutrophic. The pollen record contains evidence of the occurrence of woody species of broad-leaved forest in the late-glacial period in the Carpathians and of the expansion of mixed forests of *Fagus* and *Carpinus* in the Holocene around 4500 BP. The development of the vegetation in the locality of lake Šúr is more similar to that at localities in Hungary than those situated north and west of the Western Carpathians.

Keywords: geochemistry, geomorphology, multi-proxy reconstruction, Pannonia, palaeobotany, palaeolimnology

Introduction

There are specific geological, geomorphological and climatic conditions, and a high diversity of vegetation in the contact zone between the Carpathian and Pannonian phytogeographic regions (Meusel et al. 1992). The western margin of this region is important in terms of the florogenesis of central Europe, in particular as a migratory route and the presence there of glacial refugia for plants (Taberlet et al. 1998, Hewitt 1999). The key period for the development of the current vegetation in the Western Carpathians is the late-glacial period and the early Holocene, when forest trees migrated from glacial refugia and, conversely, species of open habitats barely survived (Ložek 1973, Lang 1994). The human influence on the distribution and species composition of vegetation gradually increased towards the end of the Holocene (Lang 1994). One way to reconstruct vegetation development in that period is to carry out a palaeoecological analysis of natural archives. These archives are mostly represented by peat bogs, fens and lake sediments. A lake environment may remain stable with continuous sedimentation (Cohen 2003) if the lake is deep and there is no through-flow of water. In addition, sediments in such lakes provide large quantities of palaeoecological proxy data, which facilitates the cross-verification of results (e.g. the multi-proxy approach). Lake sediments, therefore, provide a unique palaeoecological record not only of the lake environment but also of its surroundings. Research on lake sediments requires the use of a combination of approaches ranging from palaeobotany, sedimentology, geomorphology, geophysics to geochemistry (Bristow & Jol 2003, Hubbard & Glasser 2005). Only in this way is it possible to reconstruct the changes in the lake environment in detail and correlate them with climate changes, vegetation and the effect of human activity on the landscape.

Holocene lakes in Europe occur mainly in regions affected by the last glaciation, be it continental or local mountain glaciation (Ehlers et al. 2011). This is why lakes are relatively rare in the unglaciated part of central Europe. In the Western Carpathians and Pannonian Lowland, lake sediments collected in the Tisicum region (Magyari et al. 2008, Sümegi et al. 2011), around Lake Balaton (Medzihradszky 2005) and north of the Carpathians in Poland (Obidowicz 1996) have been analysed. In Slovakia, very few lake sediments have been studied (Buczkó et al. 2009), with the exception of the High Tatras (Rybníčková & Rybníček 2006). In southern Moravia, the former lakes Vracov (Rybníčková & Rybníček 1972, Svobodová 1997) and Čejč (Břízová 2009) have been studied.

Palynological localities in the Western Carpathians occur mainly in the northern part, in the region of Orava and the Podtatranská kotlina basin (Buczkó et al. 2009). The current fragmentary palynological evidence presumes a continuous existence of a coniferous taiga in the area of the Spišská kotlina basin, which is documented from the full glacial (site Šafárka; Jankovská et al. 2002, Jankovská & Pokorný 2008) to the late-glacial period and the Holocene (site Sivárňa; Jankovská 1988a, 2008). There are comparable records from malacozoological localities in the same region (Farkašovo site; Ložek 2005), which show a combination of species typical of forest communities in a glacial environment. From the western edge of the Carpathians there are records from several areas around springs of Holocene age (Rybníček & Rybníčková 2008). Records of the development of vegetation in the Holocene from the western-Pannonian lowlands (Slovakia) are mostly of older age. Kripell (1963, 1986) analysed two pollen profiles from the Záhorská nížina lowlands (Cerové – Lieskové, Zelienka), which contain a record of the entire Holocene. For the south-eastern edge of the Danubian lowlands the profiles collected at Pusté Úľjany (Krippel 1965, 1986) and Šúr (Kinzler 1936), were analysed by the author. These profiles have not been radiocarbon dated, but indicate a predominance of conifers in the glacial period, of broad-leaved woody species in the early Holocene and the effect of human activity in the late Holocene. Lastly, there are studies of palaeomeanders of the rivers Danube and Váh on Žitný ostrov island (Pišút et al. 2010), which are dated to the late Holocene. It is Šúr, which thanks to its area and environment appears to be a suitable locality for studying the palaeoenvironment, the results of which potentially could complete the palaeoecological record for this area.

The aim of the present study is a revision of the previous results for Šúr, where Kinzler (1936) studied a profile named "Pállfi major". The specific objectives were to: (i) ascertain the changes in vegetation that occurred in the late Pleistocene and beginning of the Holocene, (ii) determine the development of the environment in the lake basin, (iii) compare the results with those from localities situated further south in the Danube and Tisza river basins and north of the Carpathian arc, and (iv) revise previous findings and date the most important environmental changes.

Study area and present day environment

The present day nature reserve Šúr is located in the Danubian Lowland below the south-eastern slope of the Malé Karpaty Mts, approximately 6 km north-east of Bratislava, Slovakia (Fig. 1). In the north, the basin is delimited by the channeled watercourse of the river Čierná voda, in the south and west by the Šúrský canal and in the east by an Upper-Pleistocene fluvial accumulation terrace (Geological map of Slovakia 1:50,000, 44-22). The fen covering the basin is a north-western sloping plain between 128 and 130 m a.s.l. The dimensions of the basin are approximately 4.3 and 2.8 km, from north-to-south and east-to-west, respectively. In this area are Pleistocene and Holocene sediments (gravels and sands of accumulation terraces and organic humolites) overlying neogenous (Pannonian and Sarmatian) deposits (Maheľ 1986). In the north-west, the basin is permeated by

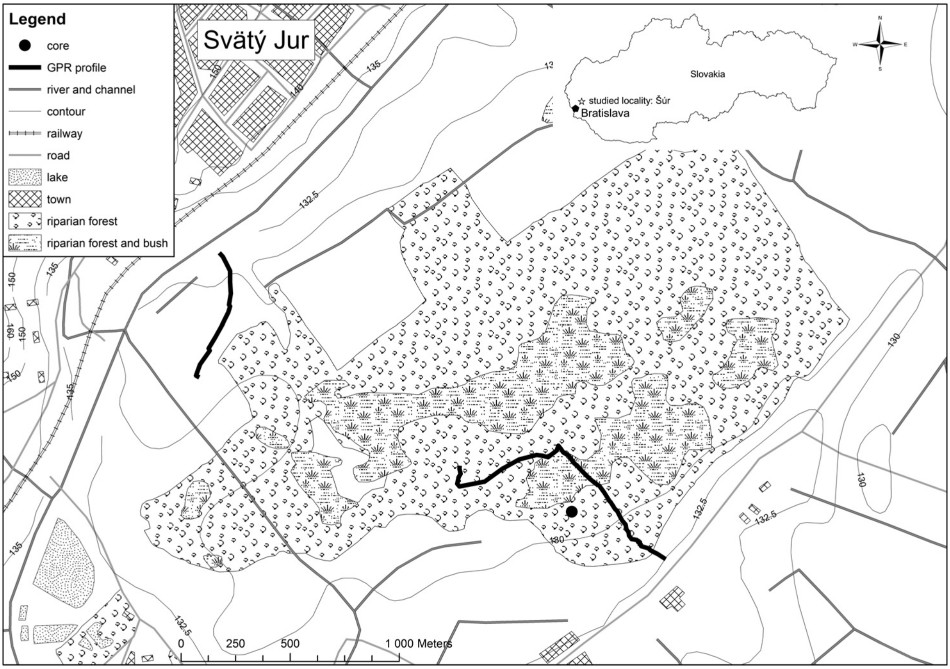

Fig. 1. – Map of the Šúr National Nature Reserve showing the locations of the profiles obtained using ground penetrating radar and coring, and a description of present-day vegetation cover.

alluvial fans of proluvial sediments extending outwards from the valleys of the Malé Karpaty Mts (Urbánek 1966, Lukniš 1977). This area was drained in the 20th century (Puchmajerová 1948), which resulted in an unbalanced water regime. The entire basin has a high groundwater table, which is indicated by the extensive pools that cover most of the basin during spring snow melt. The mean annual temperature is 10.3 °C, and mean annual precipitation 657 mm (Dohnal 1965).

The vegetation at Šúr lake is highly diverse (Majzlan & Vidlička 2010), ranging from aquatic communities to xerothermic woodland (Füry 2010). Dominant in the Šúr reserve is tall-trunk alder carr (association *Carici elongatae*-*Alnetum glutinosae*). As the water is stagnant for part of the year the *Alnus glutinosa* trees growing there have prop roots. Meadow and reed vegetation surrounds the carr. Waterlogged meadows occur at the north-western edge of this locality. The communities of the alliance *Magnocaricion elatae* there are associated with the formation of organic sediments and creation of characteristic hummocks. Communities belonging to the alliance *Phragmition* occur in the areas that are regularly flooded and have replaced the original alder woodland. Current aquatic vegetation is limited to an artificial water reservoir (Šúrsky rybník) at the south-western edge of this locality, and isolated pools. The so-called Pannonian wood in the vicinity of the village of Černá voda is a sunny oak-hornbeam forest with a xerothermic to halophilous character. Intensive grazing in this woodland in the past has had a marked effect on its character. Markedly halophilous vegetation with species such as *Tripolium pannonicum*, *Eryngium planum*, *Artemisia santonicum* subsp. *patens*, *Bupleurum tenuissimum* or *Plantago maritima* is present in part of the Pannonian wood.

Methods

Coring and description of the sediment

In order to ascertain the extent and spatial deposition of the different types of sediment, ground penetrating radar profiles (total length of 2100 m) of the basin were produced (Fig. 1). To do this we used ground penetrating radar (GPR), RAMAC, with a shielded Malå 250 MHz antenna. Profile lines were calibrated using regular hand-punched probes at intervals of approximately 120 m. The material from each probe was always described on the spot in terms of its spatial deposition, colour and granularity. The profile for the palaeoecological analysis was collected (based on results of GPR profiling examining the thickness and spatial deposition of sediments and considering the accessibility of the locality) at the south-eastern edge of the basin (48°13.893' N, 17°14.156' E, 129 m a.s.l.). The main aim was to sample the limnic sediment in that part of the lake basin furthest from the influx of sediments from the surrounding landscape. The profile was sampled using an Eijkelkamp peat sampler (uncompressed cores, 5 cm in diameter and 50 cm long) from two parallel boreholes in order to collect sufficient material for both a pollen and macrofossil analyses. For the profile studied, basic characteristics were determined, which describe the amount of organic and mineral components in the sediment and its chemical composition.

The percentage in terms of weight of organic matter in each core was determined by means of loss-on-ignition (LOI). The LOI analysis (550 °C) was carried out according to Heiri et al. (2001) and Holliday (2004). The temperature used for drying was 105 °C for

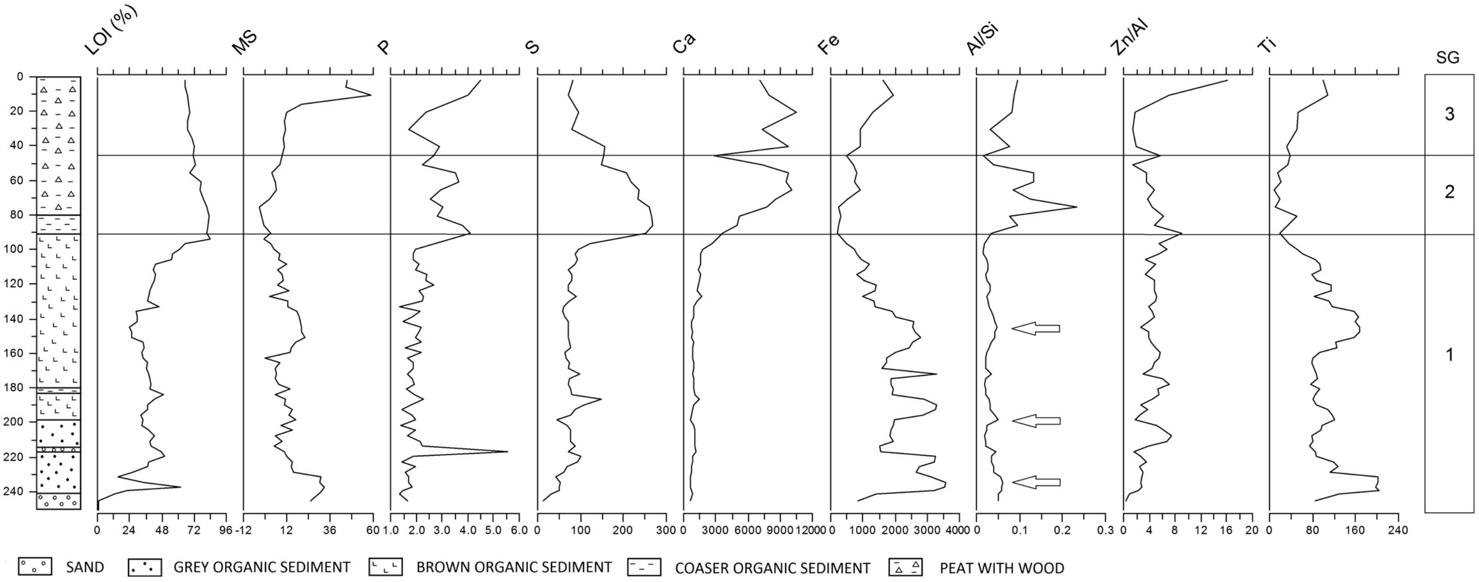

Fig. 2. – Graph of lithological and geochemical properties, which are indicated by loss-on-ignition (%), magnetic susceptibility (·10-6 SI) and chemical elements (mg/kg), of the profile for the Šúr site.

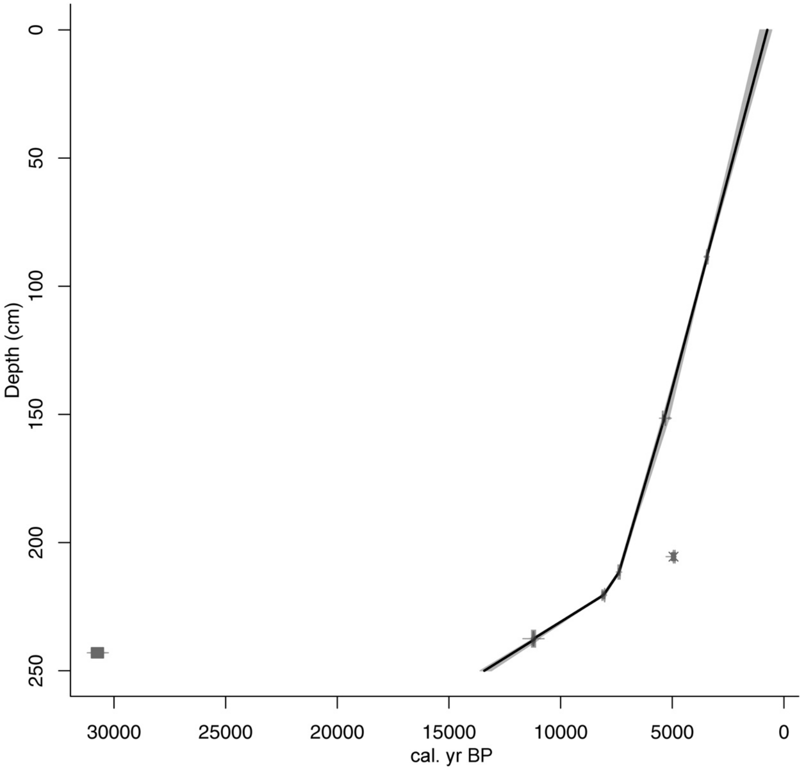

Fig. 3. – Depth-age model of the Šúr profile based on linear interpolation between dated levels based on estimated sedimentation rates. Cross indicates assumed outlying dates (UG-5590, UG-5392 and UG-5393).

Table 1. – Radiocarbon dating used in the study.

Sample (depth)	Laboratory code	Material	C14 age	δ^{13}C ‰	Calibration (BP)
87–90 cm	UG-5391	seeds	3220±25	–27.9	3480–3380
150–153 cm	UG-5589	seeds	4600±25	–20.7	5449–5146
204–207 cm	UG-5590	plant fragments	4360±30	–13.3	5035–4854
210–213 cm	UG-7547	seeds	6480±25	–25.2	7436–7324
219–222 cm	UG-7548	seeds	7250±30	–25.6	8165–8001
234–241 cm	UG-10528	tree scar	9790±60	–26.3	11,329–10,908
241–245 cm	UG-5393	charcoal	25,960±60	–26.3	31,012–30,471

24 hours, and the duration of the combustion was 3 hours (Heiri et al. 2001). LOI of sediments indicates the percentage of organic material (Fig. 2).

Magnetic susceptibility (MS) was determined using a Kappabridge KLY-2 device (Agico, Czech Republic). The results were normalized to get mass-specific magnetic susceptibility in $m^3 \cdot kg^{-1} \cdot 10^{-9}$. Magnetic susceptibility provides information about import of clastic sediments eroded in the catchment area or sediment input by overland flow during floods and mass movements from adjacent sides of valleys in the Malé Karpaty Mts (Karlén & Matthews 1992, Shakesby et al. 2007) (Fig. 2).

X-ray fluorescence analysis (EDXRF) of geochemical properties of rocks and soils was carried out using a PANalytical MiniPal4.0 spectrometer with a Peltier-cooled silicon drift energy-dispersive detector. The ground samples were analysed after pouring into measuring cells with a Mylar foil bottom. The analyses were not calibrated and recalculated in terms of the content of particular elements. Measurements in counts per second (c.p.s.) were plotted, and only their relative changes were evaluated in terms of lithofacial or geochemical changes in the sediments (Grygar et al. 2010). In addition, EDXRF unequivocally identified the increase in regional industrial contamination during the 20th century (Grygar et al. 2010).

AMS radiocarbon dating was done by the Center for Applied Isotope Studies, University of Georgia. The quoted uncalibrated dates are given in radiocarbon years before 1950 (years BP). The error is quoted as one standard deviation and reflects both statistical and experimental errors. The date was corrected for isotope fractionation. The radiocarbon calibration program OxCal v. 4.1.7 (Bronk Ramsey 2009) and the calibration data set of IntCal09 (Reimer et al. 2009) were used for data calibration. Plant macrofossils and charcoal fragments were used for the dating (Table 1). A "classic" age-depth model based on linear interpolation between dated levels was applied to determine accumulation rates. The model was constructed using clam software (Blaauw 2010), with three dates considered as outliers (Fig. 3).

Palaeoecological analysis

Samples for the pollen analysis were processed in a standard way after acetylation using KOH, HCl and HF (Moore et al. 1991). Pollen atlases (Moore et al. 1991, Reille 1992, 1995, 1998, Beug 2004) were used for pollen grain identification. Green algae of the genus *Pediastrum* were determined according to Jankovská & Komárek (2000) and Komárek & Jankovská (2001). A pollen diagram including the determination of local pollen zones was constructed using the programme POLPAL (Nalepka & Walanus 2003), which includes analyses of RAREFACTION and PCA. The pollen sum in each sample was at least 500 grains. *Alnus* was not included in the sum of arboreal pollen.

Diatom preparation followed standard protocols for siliceous microfossils (Battarbee et al. 2001). Changes in diatom concentration were determined using divinylbenzene microspheres as described in Grygar et al. (2007). We analysed 23 samples from depths of 55 to 241 cm with resolution increasing with depth, from 10 to 2 cm. A minimum of 500 valves were identified and enumerated in samples within the interval 241–102 using an optical microscope, Olympus BX 40 at 1,000× magnification. Diatom taxa were identified following Krammer & Lange-Bertalot (1986–1991) and Schmidt et al. (2004) (Fig. 5).

Extraction of plant macrofossils from the sediments was done using standard flotation and wet-sieving procedures (Warner 1988, Pearshall 1989, Jackomet & Kreuz 1999), using a sieve with a mesh diameter of 0.25 mm. Biological remains were picked out from the recovered fraction and scanned using a stereo-microscope (×8 – ×56). Plant remains were identified using keys, atlases and other publications (Beijerinck 1947, Katz et al. 1965, Cappers et al. 2006, Velichkevich & Zastawniak 2006, 2008) and by comparisons with reference seed collections stored at the Department of Botany, Charles University, Prague. Quantitative and qualitative results are presented in macrofossil diagram plotted using TILIA programe for Windows and TGView version 1.5.12 (Grimm 2011).

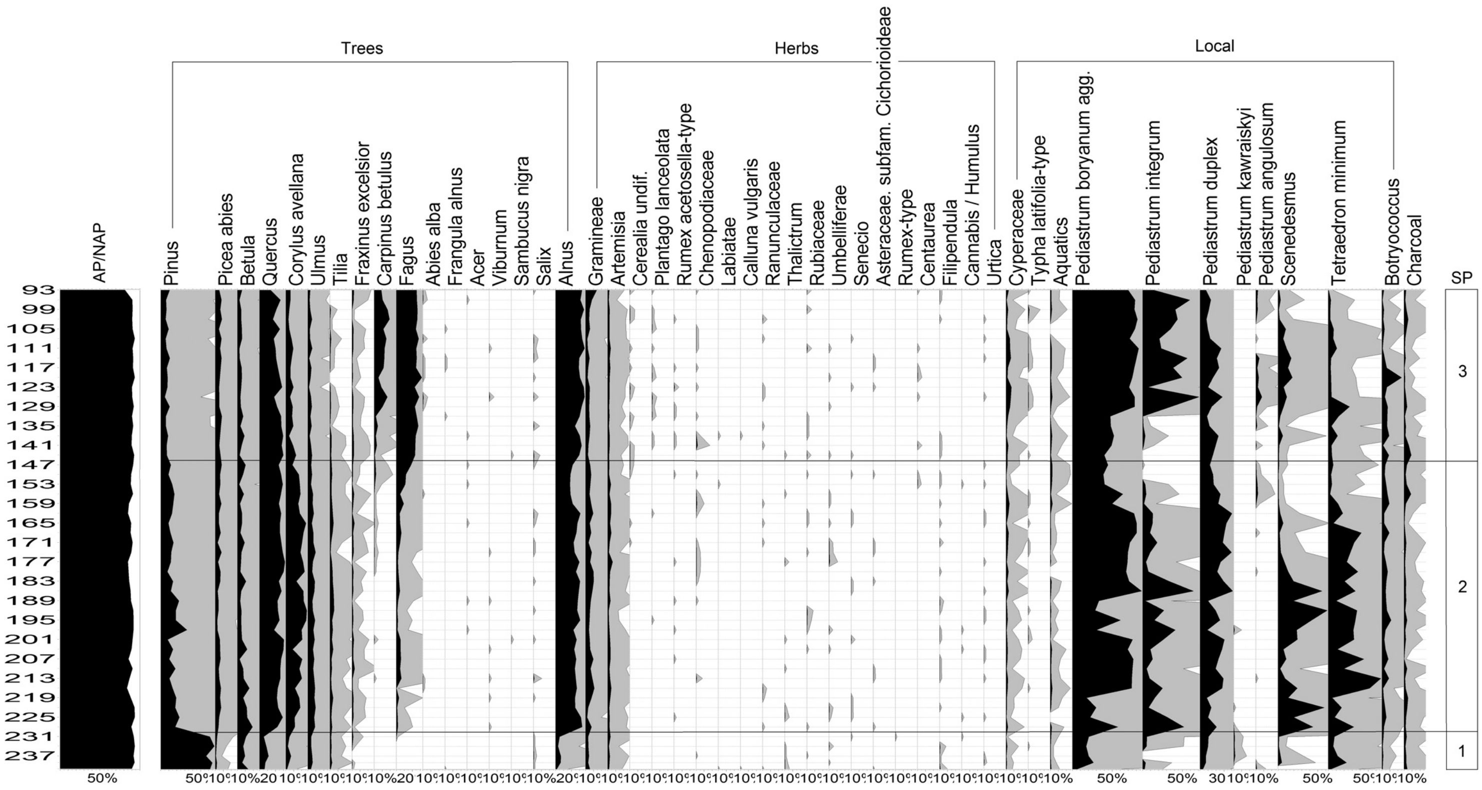

Fig. 4. – Pollen diagram of selected pollen types and occurrence of species of green algae at the Šúr site. Absolute values in 50 mL of sediment are given.

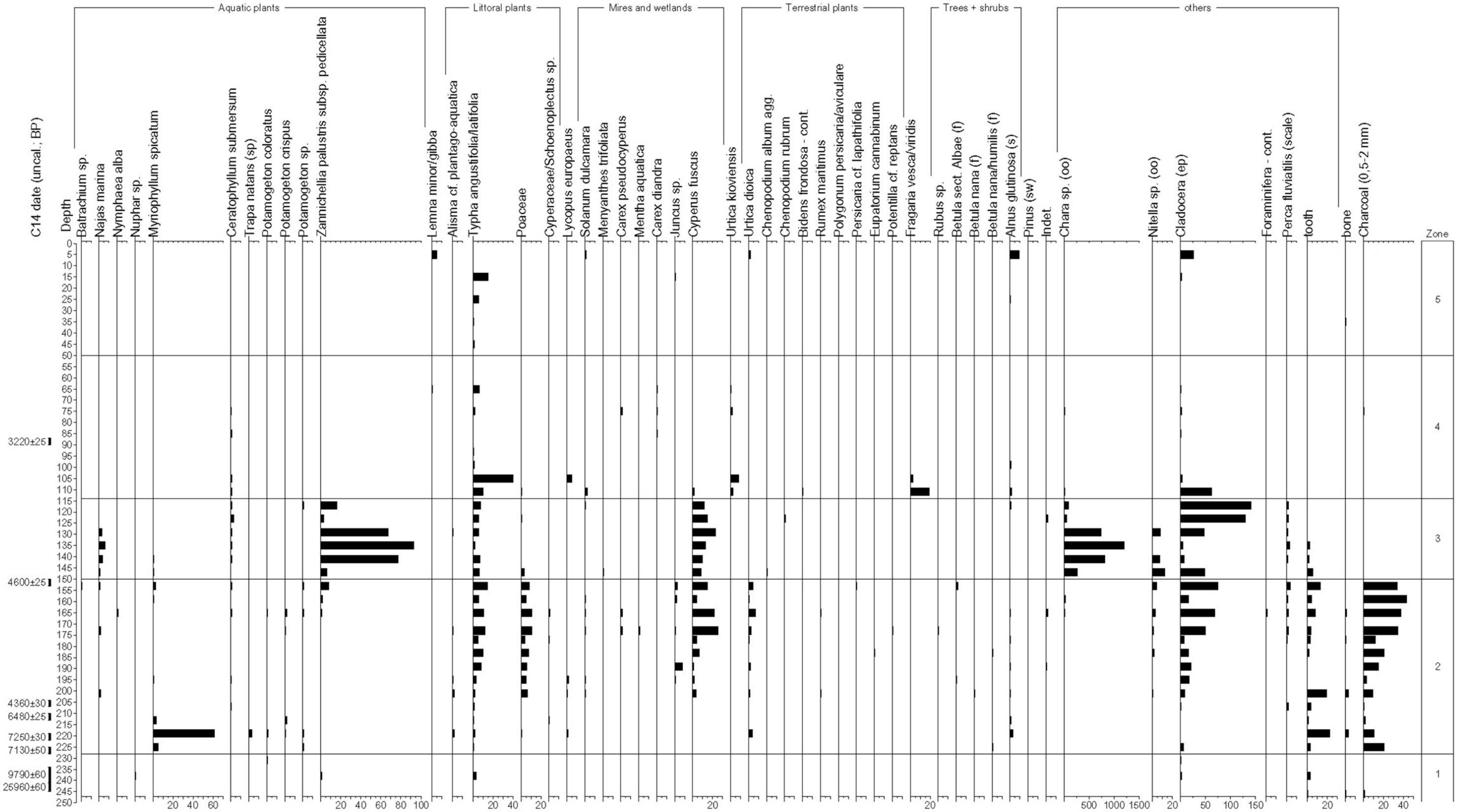

Fig. 5. – Diagram of macrofossils recorded at the Šúr site. (f – fruits, oo – oogonia, ep – ephipium, sp – spine). Absolute values in 50 mL of sediment are given.

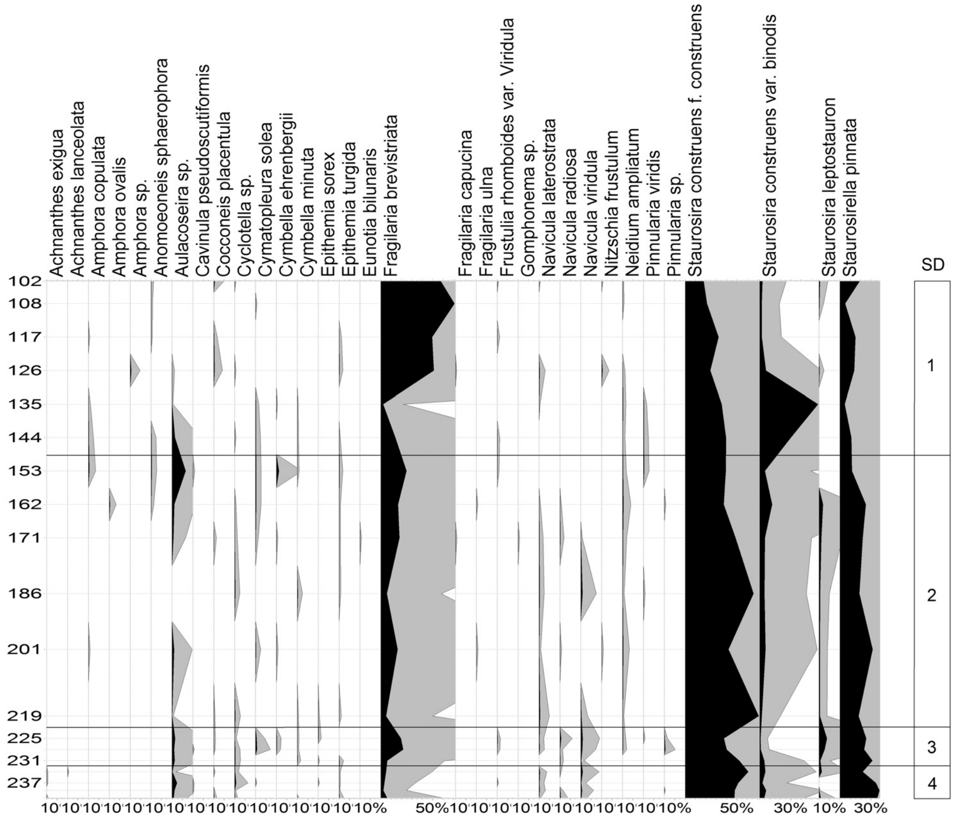

Fig. 6. – Diagram of relative frequency of occurrence of diatoms in the Šúr profile.

Results

Sedimentary settings

The entire basin is covered with fen in different stages of degradation (thickness of 50–150 cm). At the edges of the basin, however, the fen is covered by a layer that contains mineral soil. Below this layer there are horizontal and subhorizontal layers that vary in thickness from one locality to another. Layered diffractions on the radargrams form simple layers that are parallel or corrugated. These layers correspond to the stratified structure of gravel, sand, silt and loam laminated into thin to thick layers. In the western part of the basin, there is an increase in the proportion of finer-grained fractions containing loams, the thickness of sandy layers is reduced and their number becomes more variable.

Based on the above the sedimentation in the basin occurred periodically and each was characterized by a different sedimentation process, which corresponds with a lake environment and an environment with through-flowing water, indicated by layers of badly sorted sand. There is also an apparent difference in development between the eastern and western part of the basin. In the western part, there is a greater influx of material from the area of the Malé Karpaty Mts.

Description of the sediment

The sample of sediment obtained by drilling in the south-eastern part of the basin is composed of several layers (Fig. 2). At the base of the profile there is a fine, grey sand (241–250 cm) followed by a fine, grey organic sediment (198–241 cm) with a thin layer of a finer sand (217 cm). The next layer is a pale-brown organic sediment (92–198 cm) in which there is embedded a layer of greyish-brown organic sediment with a sublayer of coarser organic material (180–183 cm). A layered fen is found at a depth of 80–92 cm. The last layer is of brown decomposed fen peat with frequent remnants of wood (0–80 cm).

The bottom, sandy part of the profile (245 and 250 cm) contains nearly no combustible material (Fig. 2). The percentage of LOI gradually increases up to a depth of 237 cm, where it reaches 62%. In layers at depths between 102 and 237 cm, the percentage of LOI varies from 40 to 60%. This is followed by an increase in LOI, with a maximum of 83% at 93 cm followed by a moderate decrease to 65% in the surface layer.

Magnetic susceptibility (Fig. 2) ranges from 5 to $120\cdot10^{-6}$ SI, with the highest MS values recorded at the base of the profile (231–250 cm). There is a distinctive peak at a depth of 87 to 90 cm, otherwise MS is minimal. An increase occurs in the surface layers (1–20 cm).

Three geochemical zones (SG 1–3) can be distinguished using EDXRF proxy element analyses (Fig. 2).

SG-1 (92–250 cm). Mostly coarse siliciclastics deposited under conditions of good drainage, i.e. in an open water body. There were three episodes when deposited siliciclastics contained more alumosilicates, Ti and minerals, i.e. relatively less sand, which is denoted by arrows in the Al/Si log in Fig. 2. The relative amount of siliclastics markedly decreased in this zone

SG-2 (43–92 cm). While the substantial increase in the relative amount of Ca points to much poorer drainage, i.e. to the closing of the originally open water body. The element ratios indicate that there is more silt and/or clay than sand in the sediment. The increase in the content of S and P indicates eutrophication and the onset of anoxic conditions during and after sedimentation.

SG-3 (5–43 cm). The amount of siliciclastics is somewhat greater in the topmost layer, Ca content is still large, but S content is lower, which can be interpreted as indicating a more oxic environment during sedimentation. The top 10 cm contain a high concentration of Zn, which is good indicator of the most recent regional industrial contamination (Grygar et al. 2010).

The geochemical record in the upper 40 cm (SG-3) indicates intensive industrial pollution probably emanating from the industrial town of Bratislava. Indicators of industrial pollution are heavy metals such as Cd or Bi.

Pollen zones

SP-1 (230–241 cm). The AP percentage is around 90% (Fig. 4). *Pinus* prevails in the woody spectrum (90%). There is a strong presence of *Betula* and *Quercus* of around 10%. Other woody species are represented only marginally; this applies to *Picea*, *Ulmus*, *Tilia*, *Corylus*, *Fraxinus*, *Alnus* and *Salix*. Rarely detected were *Populus*, *Cornus*-type, *Frangula* and *Juniperus*. Grasses predominate in the herbaceous plant spectrum (5%). *Artemisia*, *Thalictrum* and *Filipendula* exhibit a closed curve. Other taxa were rare: *Labiatea*, *Calluna vulgaris*, *Asteraceae* subfam. *Cichorioideae*, *Ranunculaceae*, *Chenopodiaceae*, *Urtica*, *Umbeliferae* and *Pulsatila*-type (231 cm). Local and wetland vegetation is dominated by sedges, *Potamogeton*, *Myriophyllum spicatum*, *M. verticilatum* and *Typha* sp. The spectrum of green algae consists mainly of the genus *Pediastrum*. Predominant species are *P. boryanum* agg. and *P. duplex*, less so *P. kawraiskyi* and *P. angulosum*. Among other taxa, we detected *Tetraedron minimum* and the genera *Scenedesmus* and *Botryococcos*.

SP-2 (146–230 cm). The AP percentage varies between 80–90%. The woody spectrum is dominated by *Quercus* (20–30%) and *Corylus* (10–25%). Other important woody species with a percentage of around 5% are *Ulmus*, *Betula*, *Picea*, *Fraxinus*, *Tilia* and the newly appearing *Fagus*. A closed curve of *Carpinus* is present above 180 cm. Species of *Alnus* and *Salix* indicate presence locally of wetland vegetation. Rarely detected are *Acer*, *Cotinus coggygria* (207 cm), *Cornus*-type, *Viburnum* and *Sambucus nigra* pollen. The composition of herbaceous vegetation is very similar to that recorded in the previous zone S-1. Also dominating are grasses, reaching a percentage of 5–10%. Newly detected are the following pollen types: *Heliantemum* (216 cm), *Plantago lanceolata*, *Anthemis*-type, *Polygonum* and *Cerealia*. Local wetland and aquatic vegetation is also identical in composition to that in the previous zone S-1. Only *Nuphar*, *Iris* and *Caltha* occur. At the beginning of this zone, there is an increase in the concentration of green algae. Conversely, their concentration markedly decreases at a depth of around 156 cm. This is mainly due to the decrease in the following taxa: *Pediastrum boryanum* agg., *P. integrum*, *P. duplex*, genus *Scenedesmus* and *Tetraedrom minimum*. The percentage made up of the genus *Botryococcus* does not change and *Pediastrum kawraiskyi* completely vanishes in this period. In contrast, the percentage representation of *Pediastrum angulosum* increases at the end of this period.

SP-3 (93–146 cm). The ratio of AP to NAP remains around 90%. In the woody spectrum, the percentage of beech increases from 5% to 30%. Similarly, *Carpinus* increases from 3 to 20%. In contrast, the representation of *Corylus* decreases markedly from 25% to 5%. A similar trend is recorded for *Tilia* and *Ulmus*. The percentage of *Picea*, *Betula* and *Fraxinus* remains constant. Newly present is *Abies*, albeit sporadically. There is a slight increase in the percentage of *Alnus* pollen. *Salix*, *Frangula*, *Acer* and *Viburnum* are rarely detected. The spectrum of herbaceous plants is almost identical with that recorded in the previous zone. Cerealia and *Plantago lanceolata* have an almost closed curve. Local vegetation is also identical with that indicated in LPZ S-2. The low concentration of green algae at the beginning of the season changes at a depth of around 135 cm, where we see an increase in the percentage of *Pediastrum boryanum* agg., *P. integrum* and to a less extent *Tetraedron minimum* and the genus *Scenedesmus*. The ratio of *P. duplex* to the genus *Botriococcus* remains constant. The percentage of *P. angulosum* increases moderately. There is no pollen in samples from depths between 93 and 0 cm.

Macrofossils

The diagram for macrofossils is divided into five local macrofossil assemblage zones (SM 1–5), numbered from the bottom to the top (Fig. 5).

SM-1 (228–250 cm). Pioneer phase, characterized by poor taphonomic conditions and fluvial activity (Fig. 6). Earliest plants were aquatic species: *Zannichellia palustris* subsp. *pedicellata*, *Potamogeton* cf. *coloratus*, *Carex* sp. (3-sided seeds) and *Typha latifolia/angustifolia*. An aquatic environment is also indicated by the presence of *Chara* oogonia and *Cladocera* ephippia at 241 cm, almost at the start of sedimentation. Teeth and bones, probably remains of fish, are also present in this zone.

SM-2 (150–228 cm). Good sedimentation and taphonomic conditions in lake sediment (gyttja) facilitated the preservation of a number of plant macrofossils. Aquatic macrophytes, wetland and ruderal species are present, which indicate a higher trophic level of the environment; a number of them indicate eutrophic conditions. The aquatic environment is indicated by fossils of aquatic macrophytes (*Batrachium* sp., *Najas marina*, *Nymphaea alba*, *Ceratophyllum submersum*, *Trapa natans*, *Potamogeton* cf. *coloratus*, *P. filiformis*, *P. crispus*, *Zannichella palustris* subsp. *pedicellata*), the most abundant being *Myriphyllum spicatum*, which grows in shallow stagnant and flowing water at depths of between 0.2 m and 5 m. This species tolerates low water temperatures and freezing, but it also grows in warm waters. It occurs abundantly in eutrophic waters. Furthermore, a group of wetland species grew in the litoral zone: *Alisma* cf. *plantago-aquatica*, *Typha latifolia/angustifolia*, *Poaceae*, *Schoenoplectus lacutstris*, *S. tabernae-montanii*, *Lythrum* sp., *Lycopus europaeus*, *Solanum dulcamara*, *Carex pseudocyperus*, *Mentha aquatica*, *Carex* sp., *Juncus* and *Eleocharis*. The species *Cyperus fuscus*, which colonizes exposed pond bottoms and tolerates salt, occurred at a high frequency. In addition, there were terrestrial stress-tolerant species of plants that are able to colonize mineral-rich substrates, which indicate high levels of nutrients in the soil: *Urtica dioica*, *Rumex maritimus*, *Polygonum persicaria/aviculare*, *Polygonum lapathifolium*, *Eupatorium cannabinum*, *Potentilla* cf. *reptans*. Unusual is the occurrence of achenes of birches that grow recently on acidic, peaty soils: *Betula nana*, *B. nana/humilis* (apparently dispersed regionally). The occurrence of achenes of species of *Betula* sect. *Albae*, *Alnus glutinosa* and ovuliferous scales of *Pinus* is recorded. An aquatic environment is indicated by the genera *Chara* and *Nitella*, whose oospores occurred with a high frequency. This zone also contains ephippia of aquatic crustaceans of the order *Cladocera* and calcareous shells of a unicellular protozoan of the phylum *Foraminifera* (redeposition of tertiary marine sediments). The aquatic environment is documented by fragments of scales, small bones and pharyngeal teeth of European perch (*Perca fluviatilis*). This zone is also characterized by the presence of a large amount of charcoal (0.5–5 mm).

SM-3 (114–150 cm). Environmental conditions changed as the fossils indicate higher trophic levels and increased salinity. Taphonomic conditions in this zone were favourable; gyttja and a fen peat sediment facilitated good preservation of macrofossils. This zone is dominated by diaspores of aquatic macrophytes: *Najas marina*, *Myriophyllum spicatum*, *Ceratophyllum submersum*, *Potamogeton* sp., the most represented is the taxon *Zannichellia palustris* subsp. *pedicellata*, which could be identified down to the subspecies level. Species growing along the shore and on exposed pond bottoms also occur in this zone; many of these species grow in nutrient- and mineral-rich habitats: *Alisma* cf. *plantago-aquatica*, *Cyperus fuscus*, *Typha latifolia/angustifolia*, *Solanum dulcamara*, *Menyanthes trifoliata*, *Chenopodium album*, *C. rubrum*. There are also achenes of *Alnus glutinosa.* A very important taxon in this zone is *Chara* sp., which dominates in the macrofossil record, accompanied by *Nitella* sp. Also present were ephippia of crustaceans of the order *Cladocera* and scales of *Perca fluviatis*. Pharyngeal teeth of cyprinid fish are also preserved in this zone.

SM-4 (10–114 cm). There are no fossils indicating the presence of a lake but many indicating an inundated alder wetland with a high water table and periodically occurring pools. Aquatic species of vascular macrophytes in this zone were represented only by *Ceratophyllum submersum* and *Lemna minor/gibba*. Algae of the genus *Chara* and crustaceans of the order *Cladocera*, too, confirm the presence of open water. Dominant are *Typha latifolia/angustifolia* accompanied by other littoral species: *Lycopus europaeus*, *Solanum dulcamara*, *Urtica dioica*, *Carex pseudocyperus*, *Carex diandra* and *C. vulpina* . Exposed bottoms of periodic pools were colonized by *Cyperus fuscus.* Another species that occurred was *Urtica kioviensis*, a continental taxon growing at the edges of pools. Achenes of *Alnus glutinosa* are rare but suggest the presence of an alder carr. The occurrence of *Bidens frondosa* at this depth indicates possible contamination. Terrestrial light-loving species are represented by *Fragaria vesca* and *F. viridis.* Also present are fish bones and charcoal (0.5–2 mm).

SM-5 (0–10 cm; surface sample) contains a record of current vegetation. There are macroremains of aquatic plants: *Lemna minor/gibba* (seeds) and ephippia of crustaceans of the order *Cladocera*. Alder carr species are represented by *Solanum dulcamara* (seed), *Carex* sp., *Urtica dioica* (nutlet) and *Alnus glutinosa* (fruit).

Diatoms

Diatom assemblages in the samples from 102–241 cm (Fig. 6) are composed almost entirely (~90%) of small, colonial, alkaliphilous *Fragilaria* taxa sensu lato (e.g. *Staurosirella* or *Staurosira*), including *Staurosirella pinnata* (Ehrenb.) D. M. Williams et Round (1987), *Staurosira construens* (Ehrenb.) P. B. Hamilton, *S. pseudoconstruens* (Marciniak) Lange-Bertalot in Krammer et Lange-Bertalot, *S. binodis* (Ehrenberg) P. B. Hamilton, and *Fragilaria brevistriata* (Grunow) D. M. William. At least three major changes in conditions within the lake are easily discernable thanks to major decreases in diatom concentrations (Fig. 5) recorded at 228–225, 153–144 and 102–93 cm. The latter decrease was probably connected with lake burial, which could also explain the absence of diatoms in the following decimetres. We did find diatom communities in younger sediments but only at very low concentrations ($2{\cdot}10^6$ g^{-1}) and of a different composition from that when the lake was dominated by *Fragilaria* s.l. The most abundant genera were *Gomphonema*, *Cocconeis* and *Aulacoseira*. Based on changes in diatom assemblages, we define the following diatom zones (LDZ):

SD-1 (232–241 cm; nutrient-poor, shallow water lake stage). Total diatom concentration increased gradually to its highest value ($1100{\cdot}10^6$ g^{-1}). This zone is characterized by dominance of *S. pseudoconstruens*, and the highest concentration of *S. pinnata*.

SD-2 (223–232 cm). Diatom concentration decreased sharply to more than half of the value in the previous zone. *Fragilaria brevistriata* and *S. leptostauron* concentrations increased as *S. pseudoconstruens* and *S. pinnata* decreased. Among other species that appeared in both zones are *Aulacoseira* spp., *Cymatopleura solea* and *Navicula* spp., mainly *N. viridula*.

SD-3 (150–223 cm). Diatom concentration values gradually decreasing from 773 to $439{\cdot}10^{-6}$ g^{-1}. A slight decrease in the concentration of the dominant *S. pseudoconstruens* and *S. pinnata* and a slow relative increase in that of *F. brevistriata* is evident in this zone. This sequence can be related to higher nutrient input into the lake.

Sample at 153 cm is unique in containing the lowest concentration of diatoms and a relatively high concentration of diatom species other than *Fragilaria* s.l., mainly planktonic *Aulacoseira* spp. and the large *Cymbella ehrenbergii*. Diatom species composition indicates mainly an aquatic environment.

SD-4 (102–150 cm) zone represents eutrophic water body with a low water level. After the maximum in *S. binodis*, which is recorded at the beginning of this zone, *F. brevistriata* became dominant, which dwells in eutrophic and alkaline waters. The end of the zone is dominated by other species, most commonly *Amphora veneta* and *Cocconeis placentula.* Other present taxa are e.g. *Neidium ampliatum*, *Gomphonema* and *Pinnularia* spp. that regularly occur in wet and moist conditions (Van Dam et al. 1994).

Discussion

Last glacial period

The lake basin studied is part of a neotectonically active (Ruszkiczay-Rüdiger et al. 2005) subsidence depression bordering the eastern foothills of the Malé Karpaty Mts (Maglay 1999). The distinct character of sedimentation in the western part of the basin revealed by the ground penetrating radar (Fig. 1) and the punched probes suggests transport of material from the Malé Karpaty Mts, which is documented also by morphologically conspicuous alluvial fans (Urbánek 1966) extending into the basin. The detailed development of the Danube river basin around Bratislava is known only for the late Holocene (Pišút 2002, Lehotský et al. 2010). It is therefore a question of whether the layer of well-sorted sand (241–250 cm) was deposited by fluvial activity of the Danube river (Gábris 1994, Gábris & Nádor 2007) or is material carried down from the Malé Karpaty Mts. Evidence of mica, pine bark and charcoal, which was used for radiocarbon dating, indicates transport by water, not aeolian activities. Considering the short distance to the slopes of the Malé Karpaty Mts, the sand from the latter area would not be well sorted. In any case, significant neotectonic activity took place in this region during the Pleistocene (Nádor et al. 2003, Gábris & Nádor 2007). It coincided with glacial climate changes, which influenced not only the river regime (imbalanced water flow), behaviour (fluvial activity, branching) and the paths of watercourses but also their erosive activity such as changing longitudinal profile, water content and vegetation (Vandenberghe 2003). These changes are reflected in the variable sedimentary record at Šúr. The underlying fluvial sand (241–250 cm) contains carbonified pieces of wood and pine bark dated to 31,012–30,471 BP at a depth of 241–245 cm. Further numerous pieces of charcoal found in fluvial sand correspond with an increased incidence of fires in cold periods of the last glacial period (Daniau et al. 2010) and more intense erosion (sensu Vandenberghe 2003). During the full-glacial period there was a through-flow basin with sand sedimentation at this locality.

The pollen zone SP-1 (230–241 cm) based on biostratigraphy (dominance of *Pinus*) and the prediction of the depth-age model is of late-glacial age. Localities situated in the Tisza basin in the late-glacial period (Willis et al. 1995, Jakab et al. 2009, Magyari et al. 2010) have pollen spectra similar to those in our zone SP-1. Besides the prevalence of pine, mesophilous deciduous woody species are represented (*Corylus*, *Quercus*, *Ulmus* and *Tilia*). These broad-leaved woody species survived the Last Glacial Maximum in the Tisza river basin (Willis et al. 1995, 2000, Willis & Andel 2004). Also significant is the palaeoecological record of the glacial period (47,000±2300 uncal. yr BP to 25,050±530 uncal. yr BP) at the nearby palaeolithic locality Dzeravá skála cave (Kaminská et al. 2005). This consists of charcoal assemblages dominated by *Pinus*, *Betula*, *Salix* and *Picea*, and less frequent occurrences of *Larix*, *Corylus*, *Fagus* and *Ulmus* (Hajnalová & Hajnalová 2005). The profile also contains skeletal material of small woodland mammals (Horáček 2005). Layers corresponding to the LGM and late-glacial period, however, also contain archaeobotanical material from the Late Neolithic (Eneolithic) period (Hajnalová & Hajnalová 2005), so they can hardly be interpreted as unequivocal evidence of the existence of deciduous woodland communities in the Malé Karpaty Mts during the glacial period. Direct evidence of the survival of mesotrophic woody species during the late-glacial is missing also in the intermountain basins in northern Slovakia (Jankovská 1988a, Jankovská & Pokorný 2008). The sporadic presence of their pollen is probably a result of their long-distance transport (Jankovská 1988a). At Šúr, by contrast, the percentage of pollen of deciduous woody species is high, which indicates their presence locally in the late-glacial period. The discovery of *Betula nana* at Šúr (SM-1, depth of 228 cm), which is today extinct in Slovakia (Hendrych 1998), suggests a wider distribution of boreal and alpine species in the glacial period. In addition, there are tundra plants, such as *Dryas octopetala*, *Betula humilis* and *B. nana*, in the basal fen peat layers in Lake Balaton (Cserny & Nagy-Bodor 2000, 2005). This together with pollen evidence of *Artemisia* and *Pulsatilla* (231 cm) in the Šúr profile reveals there were both steppe and tundra species present in the glacial period.

During the late-glacial period the lake was oligotrophic. The low percentage of green algae in the palynomorph spectrum at a depth of 231–241 cm (SP-1) most likely indicates an oligotrophic environment and a colder climate than a lower water level in the lake. Also detected is the cold-tolerant species, *Pediastrum kawraisky*, which today is distributed in north-eastern Europe (Komárek & Jankovská 2001). *Pediastrum kawraisky* is also recorded in the late-glacial period at similar localities, such as the Komořanské jezero lake (Jankovská 1988b, 2000) and the Czech Cretaceous Basin in central Bohemia (Losert 1940, Petr 2005). Diatom assemblages from zone SD-1 (232–241 cm) corespond with late-glacial conditions. Records of the recent occurrence of small fragilaroid species of diatoms are for Arctic lakes (e.g. Guilizzoni et al. 2006, Antoniades et al. 2007, Ilyashuk et al. 2009) and those in mountainous regions (Schmidt et al. 2004). These lakes are usually small (up to 1 km) and oligotrophic. Considering the local conditions at each site, these lakes could have formed at different periods. It is likely, however, that the conditions during the late-glacial period in central Europe were ideal for the formation of these lakes. Cosmopolitan fragilariod species might therefore be used as a biostratigraphical marker in small areas of central Europe. We compared the results of our analysis with those from two other sites: former lake "Velanská cesta" in southern Bohemia (Bešta et al. 2009) and a buried lake in the floodplain of the Morava river near the village of Rohatec in southern Moravia (A. Píšková, unpublished results). Both these lake sediments contain a phase dominated by small *Fragilaria* taxa, namely *Staurosirella pinnata*, *Staurosira construens* and *S. pseudoconstruens*, all of which are associated mainly with the late-glacial period. The concentration of plant macrofossils is low (zone SM-1, 228–250 cm) and corresponds with an aquatic environment. A limnic environment is documented by the macrophyte species *Nuphar* sp. and *Zannichellia palustris* subsp. *pedicellata*, which tolerate water of high salinity, and *Potamogeton* cf. *coloratus*, which occurs in clean, more likely stagnant and shallow water (Hollingsworth & Vis 2010). *Typha* is also present, which colonizes the littoral zone of lakes. Also found were ephippia of aquatic crustaceans of the order *Cladocera*, pharyngeal teeth of fish and small pieces of charcoal. These finding indicate the presence of a shallow oligo- to mesotrophic lake, the environment of which is greatly affected by an increase in erosive activity.

Holocene

The late-glacial/Holocene interface is indicated in the profile by a rapid decrease in the amount of *Pinus* pollen at a depth 229 cm, the junction between pollen zones SP-1 and SP-2. The chronology of this key period in the Šúr profile although based on radiocarbon dating is very unclear; the sedimentation rate is very slow and existence of a hiatus cannot be excluded. But the absence of sand or any coarse clastic material in the sediment indicates no fluvial activity or erosion events. The early-Holocene pollen record indicates an increase in abundance of broadleaved trees such as *Quercus*, *Corylus*, *Ulmus* and *Fraxinus*. That the canopy of the surrounding woodland is not closed is supported by the presence of *Artemisia* pollen, which indicates steppe and disturbed habitats and does not reflect a glacial/Holocene transition. *Fagus* also appears in the early-Holocene period. Its spread outside of Danube lowlands in the early Holocene was, however, limited by the ridge of the Malé Karpaty Mts; at the southern-Moravian localities, Vracov and Anšov (Svobodová 1997), it starts to occur only at the beginning of the mid-Holocene, when it spreads through central Europe (Magri 2008). The abrupt expansion of *Alnus* during the early Holocene is associated with terrestrialization of a shallow lake by a process of autogenic succession. This profile questions the character of the woodland vegetation in the surroundings of this locality and interpretation of the pollen spectrum in terms of of the openness of European Holocene forests (Vera 2000, Mitchell 2005, Fyfe 2007). In the Šúr profile, there is a relatively constant percentage of *Gramineae* pollen and especially that of *Artemisia*, which generally declines at the beginning of the Holocene (Lang 1994) as a consequence of forest expansion and a rise in temperature (Davis et al. 2003). Considering the size of the former lake, the pollen immissions indicate a large area. The hypothesis that open forests existed in Pannonia is supported by interesting evidence from the nearby Mesolithic locality Sereď (Bárta 1957), where analysis of charcoal indicates presence of *Quercus*, *Pinus* and *Rosaceae*, along with the remains of large mammals, such as *Equus asus*, *Bos taurus* and *Sus scrofa*, and a malacozoological analysis that indicates presence of not only xerothermic to steppe, but also woodland species. This Mesolithic settlement might have influenced the landscape by burning the forest and by other activities. Thus the indications are that the landscape consisted of open-canopy forest, locally even of steppe character, as indicated by *Artemisia* pollen. In the lake record for Šúr there is practically no evidence of microcharcoal, even at the time of prehistoric agriculture in the mid-Holocene. Sporadic macroscopic charcoal mainly comes from grasses and indicates local events. The Holocene vegetation in Hungary, where an open-canopy woodland with numerous steppe elements occurred (Magyari et al. 2010), had a similar character. In the region of central Hungary, where saline (Hortobágy region) or sandy soils (Kiskunság) predominated, there is good evidence of the dominance of steppe from early to mid-Holocene (Jakab et al. 2004, Sümegi et al. 2005, Magyari 2011), which was due to the edaphic conditions prevailing at that time.

A change in the vegetation occurred around the time of the transition from pollen zones SP-2 to SP-3 (depth 146 cm), younger than 5449–5146 cal. yr BP (150–153 cm). There was a marked expansion in *Fagus*, while *Corylus*, *Ulmus* and *Tilia* retreated. *Carpinus* expands significantly, which is usually attributed to the effect of human activity on the landscape in central Europe (Ralska-Jasiewiczowa 1964) based on palynological evidence from Poland. But, Šúr is located in an environmentally diferent region. In the same period, this also occurred at, for example, localities in the Bílé Karpaty Mts north of Šúr (Rybníčková et al. 2005, Rybníček & Rybníčková 2008) and the Tisza Basin at Sarló-hát (Magyari et al. 2010), where an expansion of *Fagus* and *Carpinus* took place between 5500 and 4500 BP. This is the transition period between the Late Neolithic and Bronze Age (Furmánek et al. 1991), when southern Slovakia was intensively settled. This cultural change is indicated by a higher frequency of pollen of cereal grasses and *Plantago lanceolata* in the pollen record (SP-1), which is a good indicator of the presence of pastures (Behre 1986). These so-called secondary anthropogenic indicators are also recorded at localities in north-western Europe (Behre 1981, 1986). It is therefore necessary to consider the distinct natural conditions of the Pannonian Lowland, especially in the case of the genus *Artemisia*. Although the current appearance of the Hungarian steppe (Puszta) is a result of human activity (Magyari 2011), the presence of halophilous vegetation is mainly determined by climate (evaporation) and subsoil. In the case of Šúr, subhalophilous vegetation colonized this area only recently (Majzlan & Vidlička 2010).

At the beginning of pollen zone SP-2 (146–230 cm), the abundance of the cold-loving species *Pediastrum kawraiskyi* in the lake declined. Its slow decline during the early Holocene is also documented at the Komořanské jezero lake in north-western Bohemia (Jankovská 2000), which is attributed to the influence of the nearby Krušné hory Mts in terms of redeposition or, more likely, to gradual competitive exclusion of glacial elements by their Holocene vicariants. In the macrofossil spectrum (SM-2), the eurythermous species *Myriophyllum spicatum* increases, indicating shallow standing or gently flowing water. *Trapa natans* is also recorded, which indicates a warmer environment. In Bohemia, this species was abundant in the former lakes Švarcenberk (Chvojka et al. 2010) and Komořanské jezero (Řeháková 1986). According to Hannon & Gaillard (1997) *Trapa natans* colonizes water up to 3 m deep with the optimum depth between 1 and 2 m. The presence of lake sediments at depths of between 241 and 93 cm was confirmed by the analysis of diatoms. The absence of diatoms in the younger sediments (0–92 cm) indicates dry conditions. The ecological requirements of the worldwide, chainforming, low biovolume fragilaroid species that are present in our core are similar (SD 2–4). A shift from *Staurosirella pinnata* to other mainly larger species indicates the warming that occurred during the Holocene and shallow water (Perrin et al. 2006). *Staurosira pseudoconstruens* has an intermediate position on the gradient from glacial (*S. pinnata*) to interglacial conditions. The succession of diatoms from *S. pseudoconstruens* and *S. pinnata* through *S. binodis* to *F. brevistriata* indicates an increasing influx of nutrients (Marchetto et al. 2008). *Fragilaria brevistriata* is typical of shallow habitats that become warmer in summer, which is typical of coastal high-conductivity lakes (Schmidt et al. 2004). Above a depth of 162 cm, large subdominant species with higher nutrient needs occur, e.g. eutrophic *Anomoeoneis sphaerophora* (Lysáková et al. 2007). A lake dominated by small cosmopolitan fragilariod species (241–162 cm), which can be characterized using recent alpine analogues (Schmidt et al. 2004), indicate prolonged periods of low or moderate water temperatures, low levels of nutrients, clear-water phases with high light penetration. The lake was alkaline and oligo- to ultra-oligotrophic. Samples taken from a depth of 162 cm upwards indicate that the lake became richer in nutrients and the dominance of *F. brevistriata* points to a drop in the water level of the lake. Large shallow lakes are likely to be very sensitive to seasonal variations in temperature, which may affect species richness.

In the mid-Holocene (SM-3), the trophic level of the environment markedly increased, and the lake took on a eutrophic character. This is similar to the development in the Holocene at Lake Balaton (Cserny & Nagy-Bodor 2000). Macrofossils of mesotrophic to eutrophic water macrophytes are recorded there, such as *Batrachium* sp., *Najas marina*, *Nymphaea alba* and the rare *Ceratophyllum submersum*, which is limited to the warmest regions. The fossil records for central and eastern Europe indicate that this species only occurred in this area during the interglacial optima (Velichkevich & Zastawniak 2008). *Zannichellia palustris* subsp. *pedicellata* occurs in stagnant or flowing shallow eutrophic water and may also tolerate salinity, as does *Cyperus fuscus*, which colonizes exposed bottoms of ponds and is abundant at this locality.

At a depth of 162–132 cm the percentage of green algae decreases in the palynomorph spectrum (*Pediastrum* sp. div. and *Tetraedron minimum*). *Pediastrum angulosum* is an indicator of riparian vegetation (Komárek & Jankovská 2001). In adition, there is a decrease in the concentration of diatoms. Similarly, there is also a decrease in the numbers of fish scales and teeth. The mid-Holocene period was climatically stable and there are no similar records for the broader region (e.g. Davis et al. 2003, Starkel 2011) with which it was compared.

At the end of SP-3 zone (depth of 93 cm) there is the last layer of lake sediment, which is dated prior to 3480–3380 cal. yr BC. Fen-peat sediment, which is separated by a sharp lithological boundary, contains no pollen or diatoms. Plant macrofossils (SM-3) also do not indicate either a succession in the vegetation or the disappearance of open water. This locality was probably gradually overgrown by alder carr, which covers the locality today. Alder mechanically disturbs the sediment when it is uprooted (Šamonil et al. 2010) and with the aid of its symbiotic bacteria it chemically alters the subsoil. It can create a hiatus in the sediment, which can result in the loss of a clearly stratified palaeoecological record. This is a consequence of succession that depends only slightly on the surrounding environment or human activity. Our geochemical analysis (5–92 cm, SG-2 and 3) indicates a high sulphur content, which points to a mostly anaerobic environment. Plant macrofossils (SM-3) also occur very sporadically, showing that these sediments were considerably affected by water saturation. Floodplain sediments, although their geochemistry (SG-3) and appearance usually indicate substantial reductimorphic processes occurring in the past, are usually temporarily (seasonally) subjected to oxic conditions due to a lowering of the water table, which is detrimental to the preservation of pollen grains. Present were communities of tall sedges, *Typha latifolia*, alder and a transient mosaic of shallow pools inhabited by small aquatic crustaceans of the order *Cladocera*. Diatom concentration and composition in the last sample analysed (depth 56 cm) indicate wet or regularly wet and more acid conditions than in the lower lake zones. *Staurosira pinnata* thrives where there are very low concentrations of N and P and moderate concentrations of Si (Michel et al. 2006).

Conclusions

The unique ecosystem recorded at Šúr lake is the result of the gradual disappearance of a large late-glacial lake. Its sediments hold a record of the late-glacial period and a significant part of the Holocene. By combining the results of our sediment analysis with palaeobotanical evidence, we reconstructed changes that took place in the aquatic environment and in surrounding vegetation. In the late-glacial period, the lake had a cold, oligotrophic character. The surrounding landscape was covered by pine forest with frequently admixed broad-leaved trees (such as *Quercus*, *Ulmus*, *Tilia* and *Corylus*). The local landscape thus differed from areas in the northern part of the Western Carpathians and from areas west of the Carpathian arc. In the case of Moravia and Bohemia, the occurrence of mesophilous woody species in the late-glacial period is not documented. The Holocene warming is manifested in the pollen record as an expansion of mesophilous species to the detriment of pine. *Fagus* appears at this time. It later spreads north and west of the Carpathians. There is not a similar marked turnover of species in the aquatic environment. The increase in nutrient availability occurred gradually and steadily. The productivity of the aquatic environment reaches its maximum in the mid-Holocene period, which is demonstrated by the geochemical record, the concentration of diatoms and the presence of nutrient-demanding aquatic species. Littoral vegetation includes alder, which gradually takes over the whole locality. Around 4500 BP *Fagus* increases in abundance and *Carpinus* appears at the same time as an anthropogenic influence is indicated by abundant pollen of cereal grasses. There is no certain direct connection between these changes. Open water disappeared in the period after 3200 years BP. In the sedimentation record at the depth of 93 cm, this is manifested by a sharp border between lake sediments and organic layers, which originated in the anoxic environment of an alder forest. At the sample site, there is no record of a gradual succession in the vegetation from a lake environment to an alder carr, which is a result of disturbances caused by alder. Although the area of lake sediments at Šúr is still not precisely known, it was probably the largest Holocene lake in Slovakia.

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Souhrn

Práce se zabývá výzkumem sedimentů zaniklého jezera Šúr na západním Slovensku. Cílem je rekonstruovat vznik a vývoj lokality na základě propojení výsledků geomorfologie, sedimentologie a paleobotaniky. Jezero vzniklo na konci glaciálu, kdy ustala fluviální aktivita, a vzniklo rozsáhlé oligotrofní jezero. V holocénu došlo ke zlepšení přístupnosti živin a vzniklo eutrofní jezero. Okolní vegetace byla v glaciálu tvořena borovým lesem s výskytem listnatých dřevin (dub, líska, jilm a lípa). Na začátku holocénu expandovaly listnaté dřeviny a objevil se buk. V období okolo 4500 BP expandoval buk a habr a objevil se pyl obilovin. Jezero zaniklo v mladším holocénu, kdy lokalitu pokryl olšový les.

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