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A new paleobotanical method for the description of Late Quaternary organic sediments (Mire-development pathways and paleoclimatic records from S Hungary)

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A new quantitative paleobotanical method for the description of Quaternary organic sediments is presented. The Peat Component System, with the paleobotanical description of macroscopic organic material, allowed us to reconstruct the hydroseral succession. The modified "semi-quantitative quadrate and leaf-count macrofossil analysis technique" (QLCMA) was used to quantify the peat components. This quantitative plant macrofossil technique, together with pollen, mollusk, and radiocarbon analyses, was used to reconstruct the postglacial mire development of a eutrophic peat bog in S Hungary. The analysis of the Holocene peat sequence was used to reconstruct the development of a filling-up spillstream of the river Danube. Multiple cores made it possible to reconstruct vegetation development in space and time.

Key words: plant macrofossils, Late Quaternary, peat, sediment description, hydroseral succession, mire vegetation

Introduction

Before quantitative pollen analysis was invented by von Post in 1916 peat stratigraphy was the main source of evidence of paleoenvironmental investigations. Layers of scarcely humified Sphagnum peat were taken as indicators of rapid peat growth and therefore of wet climatic conditions. Layers of humified peat with wood fragments were taken to indicate a dryer mire surface and thus a more arid and warmer climate (Birks and Birks 1980).

Lakes, fens and bogs have different vegetation, depending upon water level and nutrient status, and produce characteristic sediments in these different environments. The Troels-Smith sediment description system (Troels-Smith 1955) is designed for a quick, logical and simple description of such sediments in the field, which accurately reflects their composition. This sediment description method is commonly used in Quaternary paleoecology. Different Troels-Smith sediment types were deposited under oligotrophic and eutrophic conditions

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(Birks and Birks 1980). The problem is that in some cases the same sediment type accumulated under different environmental conditions and vegetation type; hence a detailed plant macrofossil description is recommended.

The pioneering paleobotanical studies on Quaternary sediments in the 19th century were plant macrofossil analyses. This method, however, was later overshadowed by quantitative pollen analysis. Henceforth the plant macrofossil record was presented only in association with pollen diagrams. The methodical developments of the eighties (Birks 1980; Janssens 1983, 1987, 1990; Rybnícek 1973; Grosse-Brauckmann 1986; Wasylikowa 1996a, etc.) made this method essential in Quaternary paleoecology (Birks and Birks 2000). The invention of the QLCMA technique (semi-quantitative quadrate and leaf-count macrofossil analysis technique) in Southampton opened the door to detailed quantitative data processing (Barber et al. 1994).

Why is macrofossil analysis so important? Plant macrofossils provide at least tree types of important information in paleoecological investigations: (1) identification may be more detailed than for some pollen taxa because of the distinctive morphology, which provides good ecological interpretation (e.g. Gramineae, Cyperaceae, Bryophytes); (2) taxa not found or rarely found as pollen may produce good macrofossils; (3) for the assessment of local presence or absence the heavier macrofossils give a better clue than the easily transported pollen (Birks 1980; Wasylikowa 1996a; Grosse-Brauckmann 1986). A further advantage is the use of plant macrofossil analysis in the reconstruction of past mire vegetation (Rybnícek 1973; Rybnícek and Rybnícková 1968; Slack 1994; Jakab and Magyari 2000). In this way macrofossil analysis helps refine and amend paleoenvironmental interpretations made from pollen analysis alone (Birks and Birks 2000).

By comparing recent plant associations and fossil plant assemblages we can reconstruct past plant associations. Plant associations (units of vegetation) under some strong ecological influence (e.g.: salty soil, water) possess uniformity in space and permanency in geologic time. Rybnicek (1973) proved the permanency of mire vegetation during the Holocene in Central Europe. So we can reconstruct the vegetation of former (drained and destroyed) peat bogs, or the local succession (hydroseres). We can detect climatic and hydrological changes as well. With the use of modern vegetation science, plant macrofossil analysis can provide the most detailed description of local environment in Quaternary paleoecology.

There are some considerable problems with this method. Normally there are only relatively few macroremains in 1–5 cm^3 of sediment (e.g.: seeds); therefore large samples are required (50–100 cm^3) for detailed analysis. Some sediments, like oligotrophic lake sediments, are poor in macroremains. On the other hand, the most common remains, the vegetative plant tissues, are not commonly identified. The identification of rhizodermal tissues is not popular in Quaternary research because of a lack of detailed manuals and keys. Most paleobotanical studies do not deal with the description of moderately humified, unidentifiable material even though they can provide important paleoenvironmental information. Plant macrofossil analysis is particularly used in oligotrophic, acid Sphagnum peat samples (oligotrophic environment), but in Central Europe sedge peat and lake sediments (eutrophic environment) are much more common and important.

To resolve the problems detailed above, we describe in this paper a new quantitative method for the paleobotanical description of organic sediments. We present the so called Peat Component System for the holistic description of organic remains, and the modified QLCMA technique for the quantification of these components. In the second part of this article the use of these methods are illustrated with an example.

Methods

Plant macrofossil analysis

The Peat Component System

The term "peat component" is used by us to describe the macroscopic organic matter of the sediment that is retained in a 300 μm sieve. Peat components occur in peat, but of course in smaller quantities in lake sediments as well. They cause the characteristic physical features of peat. One physical feature is elasticity. This means that the sediment has an ability to regain its shape after deformation. Another feature is the ability to absorb large volumes of water.

Peat components can be divided into two main groups (see Table 1.). In the specific peat component group identification can be made at species level. The three main components of this group are seeds, mosses and rhizodermal tissues. There are many manuals and keys for the identification of seeds and mosses (Beijerinck 1947; Berggren 1968; Jávorka and Csapody 1991; Katz et al. 1965; Schermann 1967; Schoch et al. 1988; Smith 1978; Hedenäs 1993, etc.). The number of manuals dealing with the determination of rhizodermal tissues is limited (Grosse-Brauckmann 1972; Pydoplytcka 1936). Most of these keys use macroscopic features, so that large samples are needed. The most useful manual was recently published by Jakab and Sümegi (2004). The keys and descriptions are based on the microscopic features of tissues. The use of this manual is essential for the method described below.

The second group is the non-specific peat components. In this group identification is not possible at species level with this method. The main non-specific peat components are as follows.

Unidentifiable monocotyledons (Monocot. Undiff.): Mostly translucent tube-like rootlets or epidermis fragments with elongated cells. The young rootlets of Phragmites with hardly differentiated cells often fell into this category. Barber et al. (1994) used this category in a similar context.

Table 1
The main categories of peat components

Specific peat components : (identification possible at species level)	• seeds, fruits • bryophytes • rhizodermal tissues (e.g.: *Carex* spp.) • epidermal tissues • other tissues and organs (pine needles, hairs, tracheids, sporogons, etc.) • insect remains
Non-specific peat components : (identification not possible at species level with this method)	• Monocot. Undiff. – unidentifiable monocotyledons • U. O. M. – unidentifiable organic matter • U. L. F. – unidentifiable leaf fragment • U. B. F. – unidentifiable bryophyte fragment • Sphagna undiff. (Sphagnum stem) • charcoal • wood • Mollusca shell fragments

Unidentifiable leaf fragments (U. L. F.): Moderately humified deciduous tree leaf fragments. Easily recognizable by the remains of web-like veins.

Unidentifiable organic matter (U. O. M.): Strongly humified fragments with irregular shape. Insufficient for any further identification. Barber et al. (1994) used this category in a similar context.

Unidentifiable bryophyte fragment (U. B. F.): In humified peat, only the stem remains of bryophytes can be found that are insufficient for further identification. They are easily recognizable by their tube-like form and brown color. The nerve of the leaf frequently remains on the stem.

Unidentifiable Sphagna (Sphagnum stem): In less humified peat the stems of Sphagna occur in large quantities. They do not have any characteristic features that would allow specific identification.

Charcoal: Charred wood fragments larger than 300 μm (mostly between 1-3 mm). The origin of charcoal of this size is presumably terrestrial (allochtonous), so it permits correlating multiple cores in one location.

Wood: Uncharred wood fragments larger than 300 μm. Presumably terrestrial elements (allochtonous) in lakes and smaller peat bogs.

Mollusca shell fragments: It is not possible to identify Mollusca with this method, because most of them break into pieces during the extraction, but the volume of shell fragments can be detected.

The specific peat components help us reconstruct past plant associations, but the non-specific peat components also contribute to the reconstruction of environmental and hydrological changes.

Quantification of peat components

For the quantification of peat components we modified the QLCMA method (semi-quantitative quadrate and leaf-count macrofossil analysis technique) developed by Barber et al. (1994). With this method we can determine macrofossil concentrations from small samples (1–3 cm^3) using poppy seeds as marker grains (0.5 g = 959± 52) under a dissecting microscope. Barber et al. (1994) determined the volume of Sphagnum leaves with this method, and then identified Sphagna under a biological microscope.

In our study we took 3 cm3 samples and strained them through a 300 μm screen. The retained material was stored in water. Wet residues were then transferred to jars for storage, and covered by water. We also added a few drops of a glycerol: ethanol: formaldehyde mixture to discourage bacterial and fungal growth. Subsequently we placed the residues under a dissecting microscope and removed all seeds. In the diagrams the total number of seeds was marked in 3 cm^3. Thereafter we mixed the poppy seeds (which must be soaked beforehand) and the residue. When the poppy seeds were spread evenly, we counted all the peat components and the poppy seeds in a 1 cm^2-large quadrate (10×10 mm) in ten different parts of the material. It is not possible to identify the rhizomes and bryophytes under the dissecting microscope. Therefore we counted them as bryophytes and monocotyledons. Next we randomly selected 100 moss leaves and 100 tissue remains, and mounted them with water on microscope slides. The mosses and the tissues were identified under a biological microscope. The tissues are often quite long, so it is hard to determine the exact number of remains. We decided to scan the entire slide and count as much as is seen. In this way we obtained the species composition of these peat components.

The next equation shows the calculation of macrofossil concentrations. The macrofossil diagrams were prepared using PSIMPOLL Ver. 2.25 (Bennett 1992).

$$\text{macrofossil concentration} = \frac{\text{counted macrofossil (average)} \times 960 \text{ (total poppy seeds)}}{\text{counted poppy seeds (average)} \times \text{volume } (\text{cm}^3)}$$

Fig. 1
Quantification of peat components

Pollen analysis

Samples for pollen analysis were collected using a 1 cm^3 volumetric subsampler at 4 cm intervals. Pollen samples were prepared following the method described by Berglund and Ralska-Jasiewiczowa (1986) with *Lycopodium* spore (Stockmarr 1971) added to each sample in order to determine the pollen concentration. Pollen samples from peat were prepared according to the same method, but prior to the acetolysis samples were treated with 2% NaOCl in a water bath for two minutes.

Pollen and spores were identified with the aid of keys (Moore et al. 1991; Reille 1992, 1995, 1998). A minimum of 300 terrestrial pollen grains were counted in each sample. Since the aim of our investigation was the reconstruction of the mire-forming vegetation and its relation to changes in the terrestrial vegetation, pollen percentages were calculated in two different ways. For the description of changes in terrestrial vegetation the percentage calculation is based on the sum of all terrestrial taxa. The other pollen diagram depicts the curves of the peat-forming and water plants. The percentage calculation is based on their sum plus the terrestrial pollen sum and includes Pteridophyta spores.

The pollen diagrams were prepared using PSIMPOLL Ver. 2.25 (Bennett 1992). Zonation of both the terrestrial and aquatic diagram was performed using statistical procedures from among the results of optimal splitting by information content (Birks and Gordon 1985), and was used to guide decisions as to the number and position of the pollen assemblage zone (LPAZ) boundaries.

Mollusca analysis

Only the CSTII and HPII cores contain sufficient mollusk shell for further studies. The cores were cut into 10 cm-long pieces, and strained through a 800 μm sieve. The cores were analyzed in 20 cm-long sections because the amount of mollusk specimens did not attain a sufficient number (100 specimens) in the 10 cm-samples.

The species are assigned to different paleoecological groups (Lozek 1964; Meijer 1985; Fényes 1983; Krolopp 1983; Sümegi and Krolopp 1995; Sümegi 1996):

1. Species living in oxygen-rich living water: *Valvata piscinalis, Viviparus contectus, Lithoglyphus naticoides, Lymnaea stagnalis, Planorbis* cf. *carinatus, Unio* cf. *crassus, Pisidium amnicum.*

2. Species living in living or stagnant but permanent water: *Valvata cristata, V. pulchella, Bythinia leachi, B. tentaculata, Lymnaea palustris, L. peregra, Planorbis planorbis, Planorbarius corneus, Anisus vorticulus, A. vortex, Gyraulus albus, Armiger crista, Bathyomphalus contortus, Acroloxus lacustris, Segmentina nitida, Hippeutis complanatus.*

3. Species tolerating periodic water: *Lymnaea truncatula, Anisus spirorbis, Pisidium obtusale, P. casertanum.*

4. Hygrophilous, mostly marshland and terrestrial species: *Carychium minimum, Succinea oblonga, S. elegans, V. antivertigo,V. angustior, Vallonia enniensis, Zonitoides nitidus, Perforatella rubiginosa.*

5. Mesophilous and xerophilous terrestrial species: *Pupilla muscorum, Vallonia costata, Limacideae, Euconulus fulvus, Helicopsis striata.*

In addition the species are assigned to paleoclimatic groups: cold-resistant (*Valvata pulchella, Bithynia leachi, Succinea oblonga, Oxyloma elegans*), thermophilic (*Bithynia tentaculata, Lithoglyphus naticoides, Anisus vorticulus, Vertigo antivertigo, Vallonia enniensis, Helicopsis striata*) and eurithermic (the others).

We sorted the species on the basis of habitat requirements (Lozek 1964; Meijer 1985). Although the Mollusca species are not sufficient for the reconstruction of past plant associations (Evans 1972), some recent investigations (Deli and Sümegi

1999; Sólymos 1996; Sólymos and Nagy 1997) show the possibility of reconstructing general vegetation units (e.g.: woodland, ecotone, steppe – Sümegi and Krolopp 1995, 2001). The aquatic species have special habitat requirements as well (Ökland 1990; Meijer 1985). The samples are dominated by aquatic species; therefore the analysis focused on the changes of aquatic environment (e.g.: oligotrophy, vegetation density).

Chronology

From the Holocene layers four bulk samples were submitted for radiocarbon dating at the Nuclear Research Center of Hungarian Academy of Sciences, Debrecen, Hungary (Hertelendi et al. 1989). All samples were of unfiltered peat. The radiocarbon dates of Hajósi-kaszálók are presented in Table 2. The radiocarbon dates from Császártöltés (CSTII core) were later published by Cserny (2000).

Table 2
Radiocarbon dates from the Holocene sediments of Hajósi Kaszálók

Sample ID	Depth below peat surface (cm)	δ^{13}C(PDB) [‰]	^{14}C age years BP	Calibrated range years BC/AD (2σ)
Hajós-5	95–100	–28,17±0,02	1650±80	320–500 AD
Hajós-6	160–165	–28,73±0,01	1770±80	180–350 AD
Hajós-7	215–220	–26,84±0,04	3960±70	2560–2360 BC
Hajós-8	265–270	–27,58±0,07	7310±80	6230–6090 BC
Hajós-9	291–296	–28,03±0,02	9130±130	8510–8230 BC

Location description

The Great Hungarian Plain, called "Alföld" in Hungarian, is the biggest sedimentary basin in Central Europe, filled with a great thickness of Neogene sediment. The geologic evolution of the Pannonian Basin began in the Miocene; thus in this basin, 2000–3000 m-thick marine and 1000–2000 m-thick lacustrine sediments were deposited during the Late Tertiary (Rónai 1985).

Fluvial sedimentation started at about the beginning of the Quaternary. As a result of fluvial activity a 200–300 m, maximally 700 m-thick Quaternary sedimentary series accumulated in the deepest parts of the Great Hungarian Plain. Rivers entering the Alföld built extensive alluvial fans during the Quaternary (Sümeghy 1944); behind these alluvial fans, some lowlands within depressions were intersected at surface by innumerable rivers and brooks. The studied lowland Solt–Baja alluvial plain consists of two Late Quaternary neotectonic catchment sub-basins (Jaskó and Krolopp 1991; Scheuer et al. 1992). From the point of view of evolution the western part of the Alföld is one of the most specific region in Hungary. The relief conditions and network of rivers suffered the most dramatic transformation during the Late Pleistocene. All the watercourses coming from the northern part of the Carpathians and Alps played a role in the evolution of the alluvial fan plain, which is named Kiskunság. The Danube with its tributaries used to flow across the Kiskunság alluvial fan during the first phase of the Quaternary; thereafter, during the Weichselian glacial time, subsidence, more intense than ever before, began in the Solt–Baja Plain. As a consequence of this subsidence a completely new network of watercourses developed, which in the course of their erosion and deposition, transformed the sinking area into a floodplain. This subsidence counterbalanced for a time the aggradational work of the river. Thus, changes of the riverbeds were frequent in this plain (Pécsi 1959).

The Vörös-mocsár Mire and the Hajósi-kaszálók Mire (46°23'40" N 19°09'30" E) are the southern unit of the mire system of the Danube–Tisza Interfluve ("Turján, Őrjeg, Vörös-mocsár") running south in the former watercourse of the river Danube (Fig. 2). The mires are situated at the border of two significantly different regions. The Solti Plain belonging to the Danube floodplain is covered with the network of abandoned watercourses of the river Danube. The watercourses are in different step of infilling. The Solti Plain and the adjoining sand dunes of the Danube–Tisza Interfluve are separated by an approximately 10 meter-high, steep loess wall. Groundwater springs rise from the base of the loess wall. The sand dunes of the Danube–Tisza Interfluve are actually underlain by loess in these places (Marosi and Somogyi 1990).

The Danube–Tisza Interfluve lies in the warm temperate zone. It is characterized by mean January temperatures higher than -2 °C, and the duration of the winter is only three months. The climate of the region is semi-arid, and dominated by submediterranean rather than cool continental climate influences. The region is poor in precipitation. The total annual precipitation varies between 500 and 600 mm over most of the region (Borhidi 1961 1993).

The natural vegetation of the sand dunes was Junipero–Populetum scrub and sandy grasslands, formed by *Bromus squarrosus, Secale sylvestre, Stipa borystenica* and *Festuca vaginata*. Well-drained areas were occupied by oak forests (*Iridi variegatae–Quercetum roboris, Polygonato latifolii–Quercetum roboris*). More recently most of the area is a cultural landscape with ploughlands and vineyards and some patches of natural vegetation. The Solti Plain was a widespread peat land with patches of *Fraxino pannonicae–Alnetum* forests (Borhidi 2003; Tóth 1979 1996; Pócs 1991; Rakonczay 2001; Szujkó-Lacza 1993).

Regulating of water bodies begun in 1873 destroyed the original vegetation of this peat land. The artificial Danube Basin Channel ("Abzugskanal"), finished in 1929, drained the mires. Only some patches of the natural vegetation survived (Boros 1936; Molnár and Biró 2001). After the water bodies had undergone regulation, peat-cutting altered the landscape. Most of the areas (and sediments) of the Vörös-mocsár were destroyed by peat-cutting. One exception is that the Hajósi Kaszálók Mire remained intact. There is only little information about the original vegetation of these areas. Menyhárth in 1877 reported widespread Carex

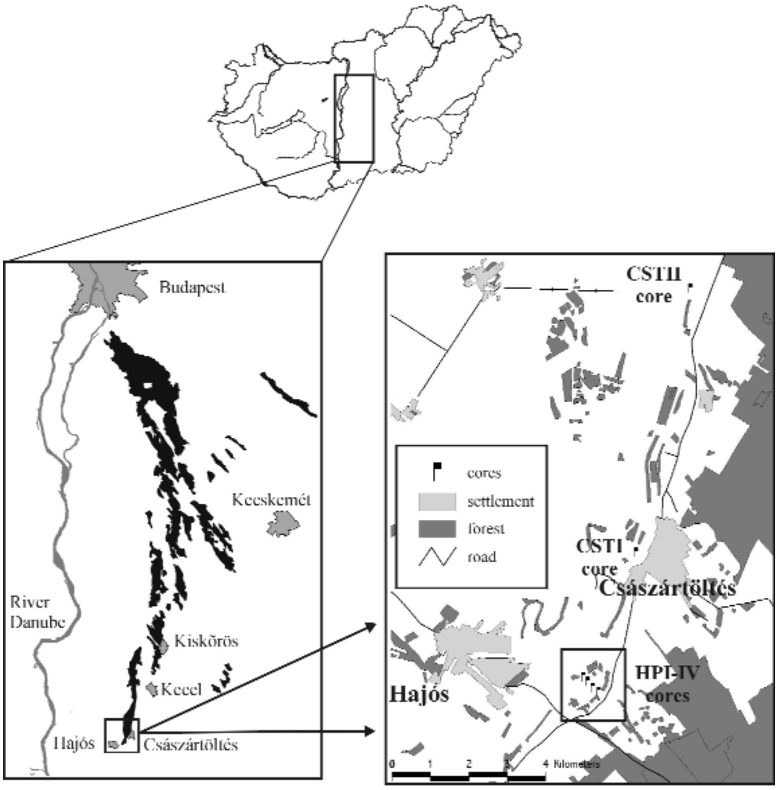

Fig. 2
The position of Hajós and Császártöltés and the distribution of peat lands (black areas) in the Danube–Tisza Interfluve. The map of the Vörös-mocsár and Hajósi-kaszálók Mires shows the approximate position of sampling sites for peat cores CSTI-CSTII and HPI-HPIV. The rectangle in the map to the left shows the position of the map in Fig. 3

elata stands (hummock-formation, "zsombék" in Hungarian) from the mire, and mentioned the occurrence of *Stratiotes aloides, Ranunculus lingua, Caltha palustris, Nuphar luteum, Dianthus superbus, Hippuris vulgaris, Galium palustre, Menyanthes trifoliata, Nymphoides peltata*, etc. Nowadays the peat lands are covered with secondary vegetation: meadows, reed swamps and sedge swamps.

Field sampling

Peat cores were retrieved using a 5 cm-diameter Russian corer (Aaby and Digerfeldt 1986). The position of the boreholes is shown in Figure 3. In the Hajósi-kaszálók Mire the boreholes were located along a transect. Core HPI was obtained from the deepest part of the basin and was used for pollen analytical and radiocarbon analysis. Only cores CSTII and HPII contained mollusk shells. Mollusca analysis was performed only on these sequences. All cores were used for plant macrofossil analysis. Detailed description of the peat cores follow the system described by Troels-Smith (1955).

Results

The pollen record

The reconstruction of the terrestrial vegetation development is based on the pollen analytical study of core HPI. The results of the pollen study are presented in Figure 4. Local pollen assemblage zones have been labeled using the following system: HP (Hajósi-pincék: Hajósi-kaszálók), I (number of core), P (local pollen zone), -zone number.

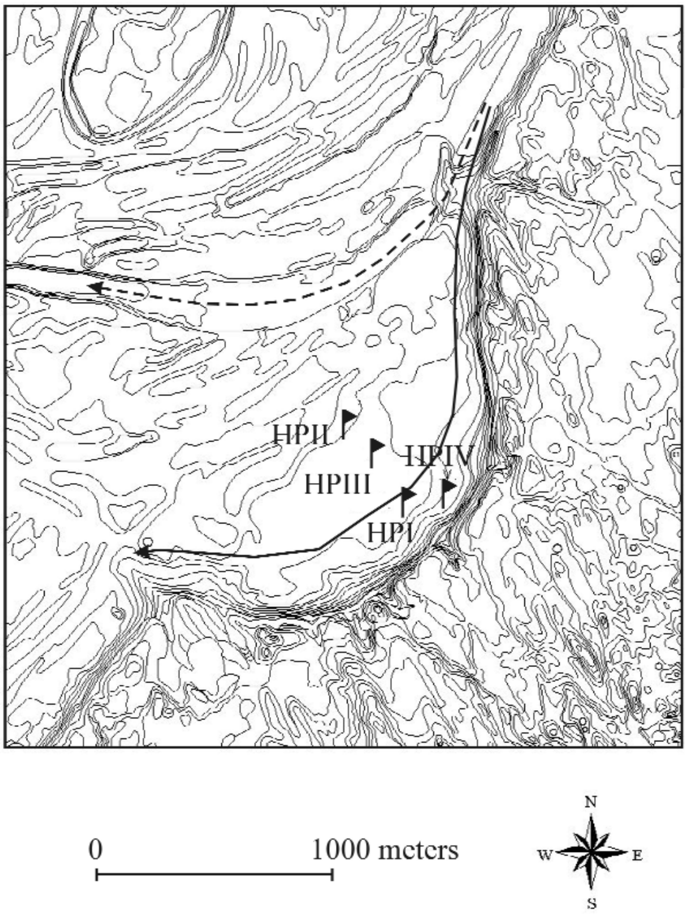

Fig. 3
The position of sampling sites for peat cores HPI–HPIV. Arrows show the presumed courses of the Danube in the Late Pleistocene (full line) and in the Early Holocene (dashed line)

In the samples between 92–138 cm and 326–402 cm the pollen concentration was insufficient for further study with this system. The pollen concentration between 156 and 250 cm, however, was optimal.

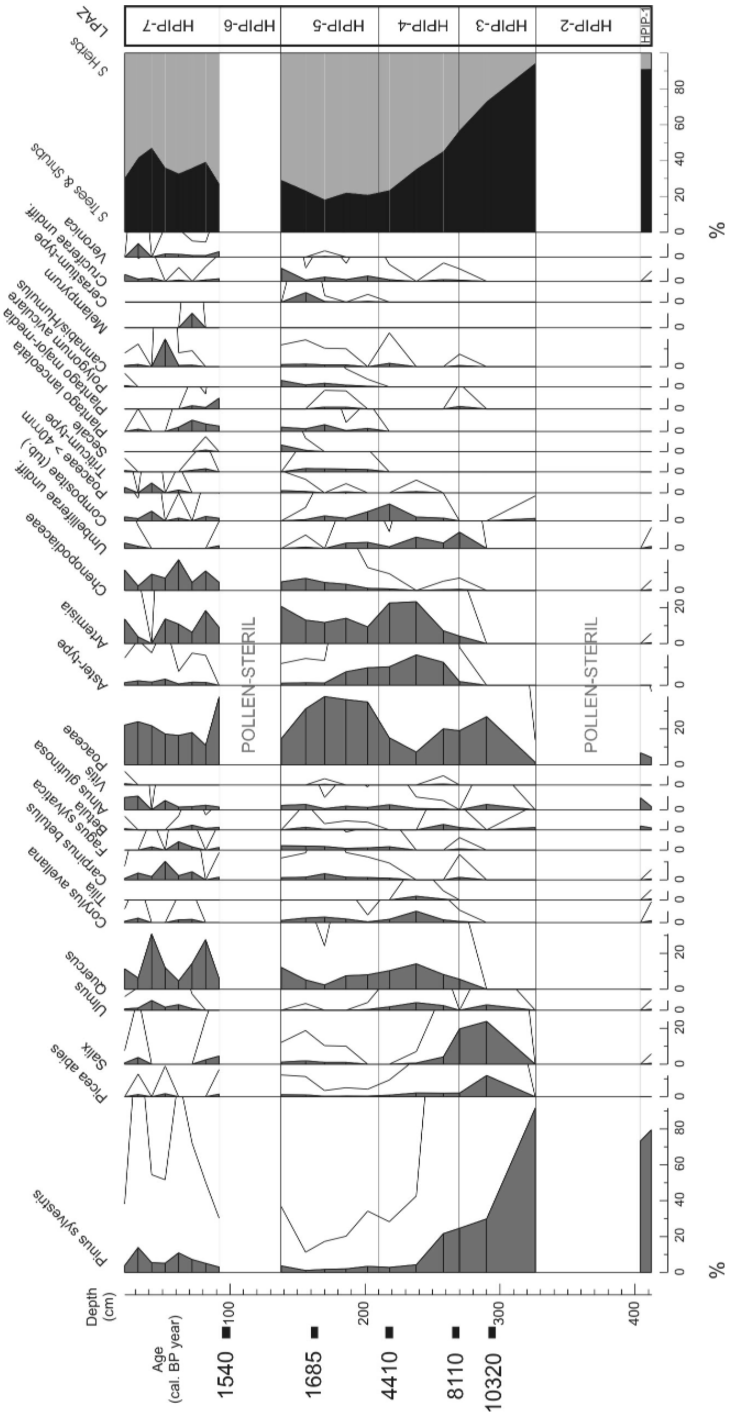

Fig. 4
Pollen percentage diagram of HPI core (LPAZ: local pollen analytical zones)

Table 3
Summary of the pollen stratigraphy of core Hajósi Pincék I

Local pollen zone	Zone description
HPIP-7. 20–92 cm Oak-hornbeam forests. Extensive steppe area.	The principal tree species in this zone are *Quercus, Carpinus betulus* and *Alnus cf. glutinosa*. Total arbor pollen accounts for 35-40%. Mixed oak and oak-hornbeam forests are typical. Strong anthropogenic signal and extensive forest-steppe area was detected in this zone. *Cyperaceae* pollen grains are frequent.
HPIP-6. 92–138 cm	Devoid of pollen.
HPIP-5. 138–210 cm Oak-hornbeam and hornbeam-beach forests. Steppe area increasing!	Oak-hornbeam and hornbeam-beach forests characterize this zone, but steppe area increased to 75-80%. Presumably beach forests increased on the floodplain of the River Danube, and steppe area and ploughland replaced the mixed forest-steppe on the sand dunes of the Danube-Tisza Interfluve. *Tilia* and *Ulmus* disappeared and *Quercus* decreased. Large number of weed species indicates strong anthropogenic influence, like *Polygonum aviculare, Cerastium sp., Plantago lanceolata, Spergula sp.*. *Triticum*-type cereal pollen is present in every sample.
HPIP-4. 210–270 cm Mixed forest-steppe with *Pinus sylvestris*. *Artemisia* steppe.	Principal tree species of the mixed forest-steppe dominate this zone: *Quercus, Ulmus, Corylus avellana, Tilia platyphyllos* and *Tilia cordata*. Up to 258 cm, *Pinus sylvestris* is an important species of the terrestrial vegetation, together with *Salix* and *Betula*. The most dominant herbaceous remains are the pollen of *Artemisia, Aster-type,* Poaceae and Umbelliferae. Other important herbaceous species are *Plantago major/media, Filipendula vulgaris, Pimpinella sp.*. The first anthropogenic signal was detected at 238 cm.
HPIP-3. 270–326 cm Boreal woodland with *Picea abies* and *Ulmus*. Gallery forests. Grasslands.	The first sample (326 cm) of the local pollen assemblage zone HPIP-3 shows similar pollen composition to the HPIP-1 zone with high representation of *Pinus sylvestris* and very few other pollen types (e.g. *Betula*, Poaceae, *Dipsacus*-type, *Galium*). Above 290 cm (c. 9500 cal. yr BP), total land pollen concentrations increase and attain the highest values throughout the core (max. 1.01 million grains/cm^3). Arboreal pollen frequencies decrease gradually from 50 to 37%. Declining values of scotch pine are counterbalanced by increases in *Salix, Picea abies* and *Ulmus*. *Vitis* pollen appears and there is a steady increase in Poaceae. From these data we can infer the development of a gallery forest around the study site made up of willow and abundant liana. Well-drained areas in the vicinity of the meander must have supported mixed stands of spruce (*Picea abies*) and elm (*Ulmus*); however, we can also surmise a spread in grassland dominated by Poaceae, Umbelliferae and *Aster* species.
HPIP-2 326–402 cm	Devoid of pollen.
HPIP-1 402–412 cm Boreal woodland with *Pinus sylvestris,* and tundra vegetation.	The principal tree species in this zone is *Pinus sylvestris*. Small quantities of *Pinus cembra, Pinus mugo, Larix decidua, Betula nana, Hyppophaë rhamnoides, Alnus cf. glutinosa* and *Selaginella selaginoides* were also found. The small quantity of herbaceous pollen (particularly *Artemisia* and *Chenopodiaiceae*) is a strange phenomenon. The pollen concentration in this zone is extremely low, suggesting selective fossilization, and probably extensive bare surfaces with patches of tundra vegetation.

Between 326 and 402 cm the pollen concentration is extremely low (6000–29000 pollen/cm^3); only the pollen grains of Pinus sylvestris were encountered in the samples, suggesting selective fossilization.

The sediment between 92 and 138 cm contained a large number of organic particles smaller than 250 μm. The use of the NaOCl treatment proved insufficient to dissolve these particles. Initially it was supposed that the large amount of organic particles is responsible for the low pollen concentration. However, the sufficient number of *Lycopodium* spores found on each slide suggests pollen sterility rather than imperfect pollen preparation.

The pollen stratigraphy is summarized in Table 3.

The malacological record

Only the CSTII and HPII cores contain sufficient mollusk shell for further studies. The results of the malacological study are presented in Fig. 5. The amount of mollusks in the HPII core was insufficient to produce histograms. The mollusk stratigraphy is summarized in Tables 4 and 5. Malacological zones were labeled using the following system: HP (Hajósi-pincék: Hajósi-kaszálók) or CST

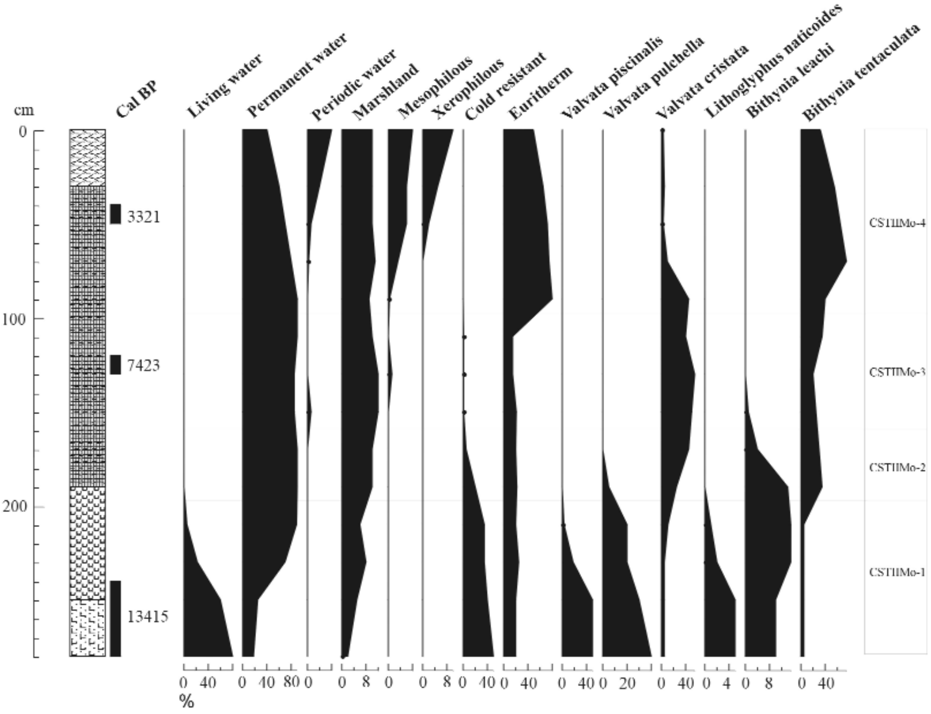

Fig. 5
Mollusk diagram of CSTII core

Table 4
Summary of the Mollusca stratigraphy of core Hajósi Pincék II

Mollusca zone	Zone description
0–95 cm	No mollusk remains
HPIIMo-3 105–95 cm Shallow eutrophic water.	*Valvata cristata* shells are frequent (more than 70 %). The frequency of aquatic *(Pisidium spp. Armiger crista)*, amphibious *(Succinea oblonga, Oxyloma elegans)* elements is the highest in this zone.
HPIIMo-2 130–105 cm Shallow eutrophic water with floating aquatic vegetation.	Some mollusks favoring a stagnant water environment (*Planorbarius corneus, Lymnaea palustris, Segmentina nitida*) appeared in this layer. This paleo-association suggests that a shallow lake developed in the analyzed paleochannel during this phase with emerged and submerged vegetation.
200–130 cm	No mollusk remains
HPIIMo-1 200–220 cm Living water.	Some rheophilous mollusk elements (*Valvata piscinalis, Lithoglyphus naticoides, Lymnaea stagnalis*), but only their few specimens can be found in this layer. This poor malacofauna is similar to malacofauna from the CSTMoI-1 level and indicates fluvial phase in the analyzed paleochannel.

Table 5
Summary of the Mollusca stratigraphy of core Császártöltés Vörös-mocsár II

Mollusca zone	Zone description
CSTIIMo-4 40–100 cm Dry mire surface.	Change in aquatic malacofauna. *Valvata cristata* declines, and the frequency of *Bithynia tentaculata* increases, indicating the eutrophication of water. The xerophilous and mesophilous elements *(Pupilla muscorum, Vallonia costata, Helicopsis striata)* emerge among the terrestrial species.
CSTIIMo-3 100–160 cm Shallow eutrophic water with floating aquatic vegetation.	The *Valvata cristata* shells are frequent (more than 50%). The frequency of aquatic *(Lymnaea palustris, Pisidium spp., Segmentina nitida)*, amphibious *(Succinea oblonga, Oxyloma elegans, Carychium minimum)* and strongly hygrophilous terrestrial elements *(Vertigo antivertigo, Vallonia enniensis)* is the highest in this zone. On the basis of radiocarbon dating the first agricultural human populations occupy the territory at this time. Presumably the high quantity of sediment and terrestrial mollusk shell which entered the channel was derived from the shore, because of human impact.
CSTIIMo-2 160–200 cm Deep and fluctuating stagnant water. Oxbow lake with decreasing oxygen level.	The rheophilous elements decline and disappear. The first terrestrial elements *(Succinea spp., Vallonia spp., Vertigo spp.)* emerge in this zone. The *Valvata cristata-Bithynia leachi-Bithynia tentaculata* paleo-association developed in this zone. Elements with different ecological requirements (deep/shallow water, open/dense aquatic vegetation) occur in the same quantity. This phenomenon can be explained by periodic flooding of the Danube.
CSTIIMo-1 200–280 cm Living water.	The number of rheophilous elements *(Valvata piscinalis, Lithoglyphus naticoides, Lymnaea stagnalis, Planorbis cf. carinatus, Unio cf. crassus, Pisidium amnicum)* is very high. This is the so called *Valvata piscinalis-Lithoglyphus naticoides* paleo-association (Sümegi 1996; Sümegi and Krolopp 2001), which includes cold-resistant (widespread in the Pleistocene) *(e.g.: Valvata pulchella, Bithynia leachi)* and thermophilic (widespread in the Holocene) *(e.g.: Lithoglyphus naticoides, Bithynia tentaculata)* elements as well. The paleochannel could have been a spillstream of the Danube.

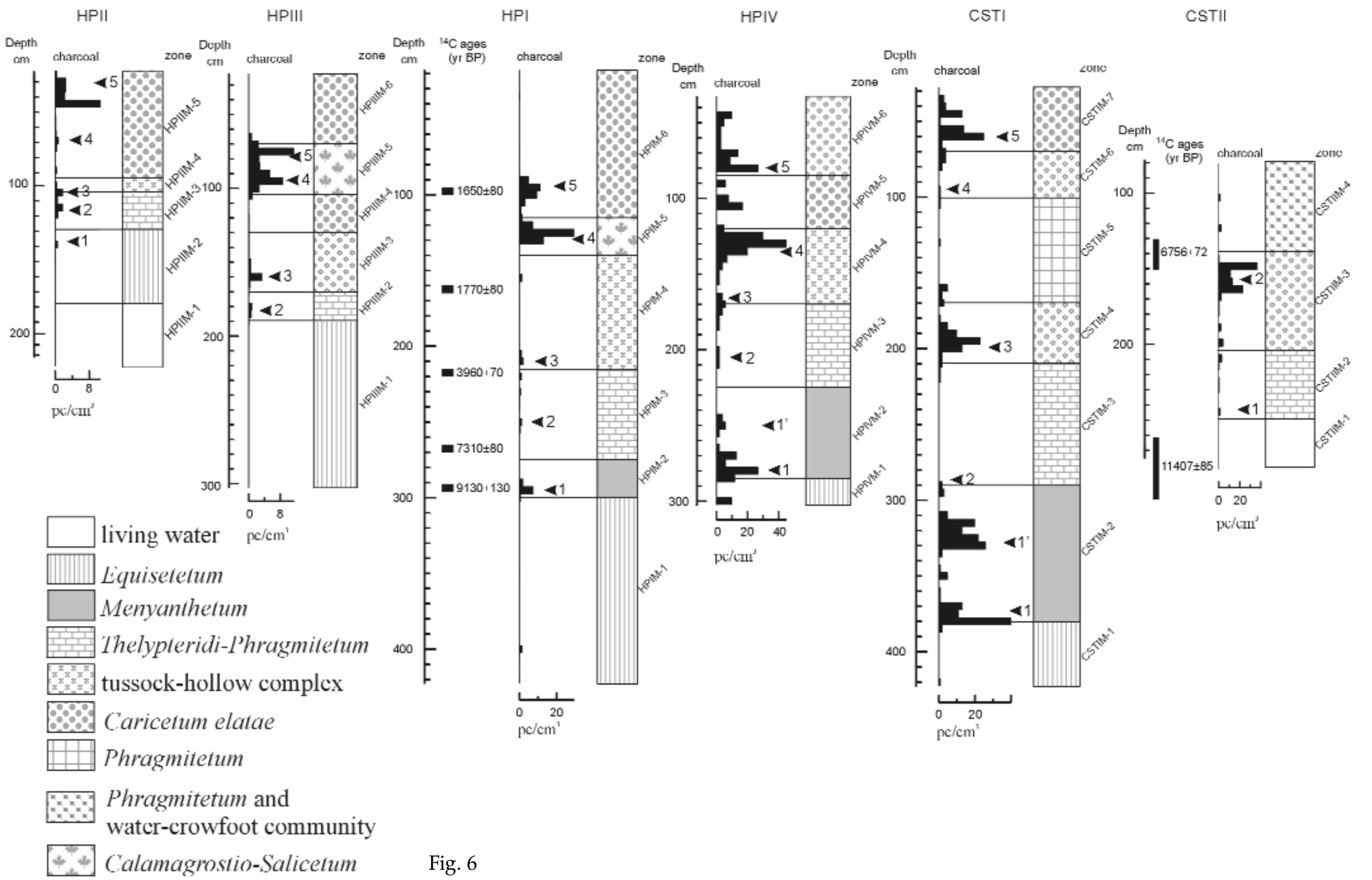

Fig. 6
Correlation of macrofossil diagrams

Table 6
Summary of the zonations for Hajósi Pincék I–IV

Location	Zone description	Detected plant community
Hajósi Pincék I.	HPIM-6 (20–115cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. Water tables somewhat higher.	*Caricetum elatae*
	HPIM-5 (115–140cm). Water tables decline in this zone. Zone contains high amount of charcoal and wood fragments. Hollow and *Cyperus fuscus* communities disappear in this zone.	*Caricetum elatae* *Calamagrostio-Salicetum cinereae*
	HPIM-4 (140–215cm). *Carex elata* becomes a permanent peat component. The presence of *Cyperus fuscus*, *Chara* and *Amblystegiaceae* mosses indicates a well-developed hummock-hollow structure and higher mire water levels. *Schoenoplectus tabernaemontani* appears in large quantities.	*Caricetum elatae* *Cypero-Juncetum bufonii*
	HPIM-3 (215–275cm). *Phragmites* is the major peat component, in combination with *Typha* and *Thelypteris palustris*.	*Thelypteridi-Phragmitetum* *Thelypteridi-Typhetum*
	HPIM-2 (275–300cm). Macrofossil density is higher. Peat accumulation begins. *Carex elata* appears in this zone. The high amount of unidentified organic matter indicates increased humification. *Menyanthes trifoliata* characterizes this zone.	*Phragmitetum communis* *Menyanthetum*
	HPIM-1 (300–420 cm). Macrofossil density is very low in this zone. *Phragmites* and *Equisetum cf. fluitans* are the main components. The sediment description suggests an open water habitat.	*Phragmitetum communis* *Equisetetum fluitantis* open water
Hajósi Pincék II.	HPIIM-5 (25–95 cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. *Cyperus fuscus* communities disappear in this zone, but *Menyanthes trifoliata* occurs.	*Caricetum elatae*
	HPIIM-4 (95–105 cm). *Carex elata* becomes the dominant peat component. Water tables somewhat higher in this zone. The presence of *Cyperus fuscus*, *Chara* and *Amblystegiaceae* mosses indicates a well-developed hummock-hollow structure and higher mire water levels.	*Caricetum elatae* *Cypero-Juncetum bufonii* *Nymphaeetum albo-luteae*
	HPIIM-3 (105–130 cm). *Phragmites* is the major peat component, in combination with *Typha* and *Thelypteris palustris*.	*Thelypteridi-Phragmitetum* *Thelypteridi-Typhetum*
	HPIIM-2 (130–180 cm). Macrofossil density is higher. Peat accumulation begins. *Carex elata* appears in this zone. *Phragmites autralis* and *Equisetum cf. fluitans* are the main peat components. The high amount of mollusk remains is a characteristic feature of this zone.	*Phragmitetum communis* *Equisetetum fluitantis* stagnant and well-oxygenated open water
	HPIIM-1 (180–220 cm). Macrofossil density is very low in this zone. *Phragmites* and *Equisetum cf. fluitans* are the only components. The sediment description suggests a living water habitat.	living water *Equisetetum fluitantis*

(Császártöltés: Vörös-mocsár), II (number of core), Mo (malacological zone), -zone number.

The macrofossil record

The results of macrofossil analyses are shown in Figs 7–12. Within the macrofossil diagrams unlinked histograms present only lower values. Local macrofossil assemblage zones have been labeled using the following system: HP (Hajósi-pincék: Hajósi-kaszálók) or CST (Császártöltés: Vörös-mocsár), I-IV (number of core), M (local macrofossil zone), -zone number.

The macrofossil stratigraphy is summarized in Tables 6–7.

The small charred wood fragments (larger than 300 μm, but mostly between 1–3 mm) are presumably terrestrial (allochtonous) elements in the macrofossil

Table 6
(cont)

Location	Zone description	Detected plant community
Hajósi Pincék III.	HPIIIM-6 (25–70 cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. Decreased *Carex elata* rootlets and the presence of *Calamagrostis* suggest a drier mire surface at the top of the sequence.	*Caricetum elatae*
	HPIIIM-5 (70–105 cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. The large amount of wood fragments suggest the spread of *Salix cinerea* swamp.	*Calamagrostio-Salicetum cinereae* *Caricetum elatae*
	HPIIIM-4 (105–130 cm). *Carex elata* becomes the dominant peat component. Water tables somewhat lower in this zone. *Cyperus fuscus* communities disappear in this zone.	*Caricetum elatae*
	HPIIIM-3 (130–170 cm). *Carex elata* appears in this zone. The presence of *Cyperus fuscus* and *Amblystegiaceae* mosses indicates a well-developed hummock-hollow structure and higher mire water levels.	*Caricetum elatae* *Cypero-Juncetum bufonii*
	HPIIIM-2 (170–190 cm). Macrofossil density is higher. Peat accumulation begins. *Phragmites* is the major peat component, in combination with *Typha* and *Thelypteris palustris*.	*Thelypteridi-Phragmitetum* *Thelypteridi-Typhetum*
	HPIIIM-1 (190–300 cm). Macrofossil density is very low in this zone. *Phragmites* and *Equisetum cf. fluitans* are the only components.	*Phragmitetum communis* *Equisetetum fluitantis* stagnant water
Hajósi Pincék IV.	HPIVM-6. (35–85 cm). *Carex elata* is the major peat component, in combination with *Phragmites autralis* and *Equisetum fluitans*. The presence of *Cyperus fuscus* and *Amblystegiaceae* mosses indicates a well-developed hummock-hollow structure and higher mire water levels.	*Caricetum elatae* *Equisetetum fluitantis* *Cypero-Juncetum bufonii*
	HPIVM-5. (120–85 cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. The lack of *Cyperus fuscus* indicates a poorly-developed hummock-hollow structure and lower mire water levels.	*Caricetum elatae*
	HPIVM-4. (120–170 cm). *Carex elata* is the major and almost only peat component, in combination with *Phragmites autralis*. The presence of *Cyperus fuscus, Nuphar lutea* and *Amblystegiaceae* mosses indicates a well-developed hummock-hollow structure and higher mire water levels.	*Caricetum elatae* *Nymphaeetum albo-luteae* *Cypero-Juncetum bufonii*
	HPIVM-3. (170–225 cm). Macrofossil density is higher. Peat accumulation begins. *Phragmites* is the major peat component, in combination with *Typha* and *Thelypteris palustris*.	*Thelypteridi-Phragmitetum* *Thelypteridi-Typhetum*
	HPIVM-2. (225–285 cm). *Menyanthes trifoliata* is the major and almost only peat component, in combination with *Amblystegiaceae* mosses. This is a so-called "brown moss community".	*Menyanthetum* "brown moss carpet"
	HPIVM-1. (285–300 cm). Macrofossil density is very low in this zone. The seeds of *Hippuris* and *Myriophillum* indicate an open water habitat.	*Hippuridetum vulgaris* *Myriophylletum verticillati* stagnant water

records. By comparing the charcoal histograms of the multiple cores with each other (see Fig. 6) the following statements can be made. The concentration of charcoal decreases from east to west (from the sand dunes toward the Danube). This phenomenon can be easily explained by the geographic features. The vegetation of the arid sand dunes could have burned down much more easily than that of the humid floodplain with its marshes and water courses. Therefore the winds blew the charcoal (scale) from the arid sand dunes of the Danube–Tisza Interfluve toward the floodplain. The sudden decrease of charcoal concentration suggests short range transport of this size of charcoal. The distance could be some hundreds of meters. The amplitude of the same charcoal peaks is different in the more distal locations. For example, the first peak is higher in the HPIV and CSTI cores than in the CSTII core. But the second peak is higher in the CSTII core than in the HPIV and CSTI cores. This phenomenon can be explained

Table 7
Summary of the zonations for Császártöltés Vörös-mocsár I–II

Location	Zone description	Detected plant community
Császártöltés I.	CSTIM-7 (30–70 cm). *Carex elata* and *Phragmites autralis* are the major peat components. Water table is somewhat lower.	*Caricetum elatae*
	CSTIM-6 (70–100 cm). Macrofossil concentration is higher. *Phragmites* is the major peat component, in combination with *Carex elata* and *Equisetum* remains. Remains of pioneer mud vegetation detected in this zone. Water table is higher and fluctuating.	*Phragmitetum* *Cypero-Juncetum bufonii*
	CSTIM-5 (100–170 cm). *Phragmites* is the major and almost only peat component.	*Phragmitetum*
	CSTIM-4 (170–210 cm). Macrofossil concentration is higher. *Typha, Phragmites* are the major peat components, in combination with *Carex elata* remains. Remains of water-lily communities detected in this zone. Water table is higher.	*Phragmitetum* *Nymphaeetum albo-luteae*
	CSTIM-3 (210–290 cm). Macrofossil density is low in this zone. *Phragmites* is the only component.	*Phragmitetum*
	CSTIM-2 (290–308 cm). Macrofossil concentration is higher. Peat accumulation begins. *Phragmites* is the major peat component, in combination with *Amblystegiaceae* mosses, *Comarum palustre, Menyanthes trifoliata, Sparganium minimum*, etc.	*Menyanthetum* *Sparganio minimi - Utricularietum* "brown moss carpet"
	CSTIM-1 (308–420 cm). Macrofossil concentration is low in this zone. *Phragmites* and *Equisetum* are the major peat components.	*Equisetetum fluitantis* living water
Császártöltés II.	CSTIIM-4 (80–135 cm). Macrofossil concentration is lower. *Typha, Phragmites* are the major peat components. Pioneer mud vegetation and water-crowfoot communities important in this zone. Water table is somewhat lower and fluctuating.	*Phragmitetum* *Ranunculetum aquatilis* *Cypero-Juncetum bufonii*
	CSTIIM-3 (135-200 cm). *Typha, Phragmites* are the major peat components, in combination with *Carex elata* remains. Remains of water-lily and pioneer mud communities detected in this zone. Water table is higher.	*Phragmitetum* *Nymphaeetum albo-luteae* *Cypero-Juncetum bufonii*
	CSTIIM-2 (200–245 cm). Macrofossil concentration is higher. *Typha, Phragmites* are the major peat components, in combination with *Glyceria* remains. *Mollusca* and *Ostracoda* remains become frequent.	*Phragmitetum* *Glycerietum* stagnant water
	CSTIIM-1 (245–275 cm). Macrofossil concentration is low in this zone. *Typha, Phragmites* and *Equisetum* are the major peat components.	living water *Equisetetum fluitantis*

by short-range dispersal as well. Probably the intensity and spread of fire was different in the different parts of the sand dunes.

The position of charcoal peaks, together with the radiocarbon data, suggest that all important vegetation changes took place at the same time in the entire channel (see Fig. 6), but local environmental factors and the geomorphological position modified the main trend of hydroseral succession. The main trend of succession is discussed below. The hydroseral succession of Hajósi-kaszálók Mire is presented with vegetation maps as well as drawings (Fig. 13).

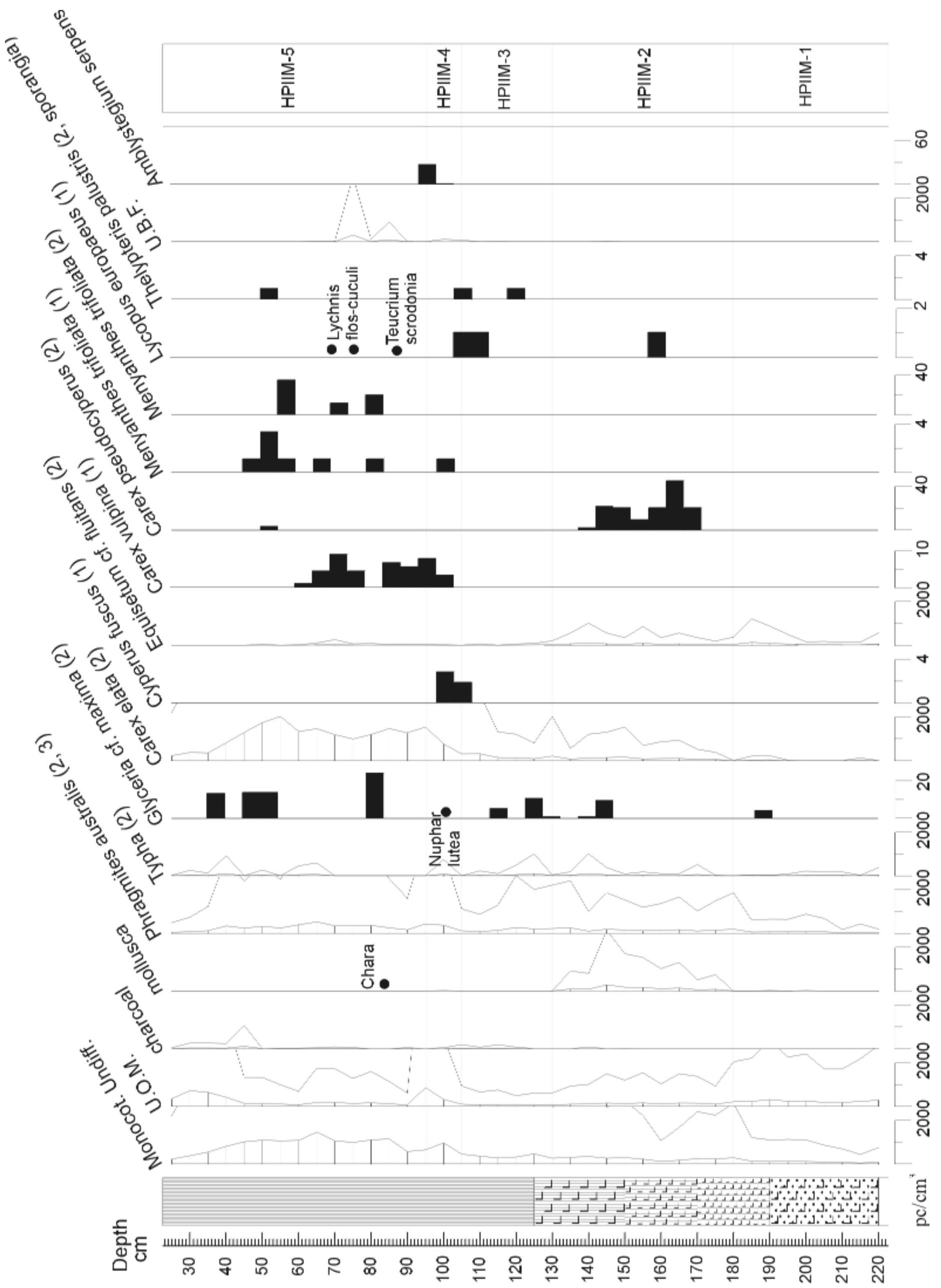

Fig. 7
Macrofossil diagram of HPI core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

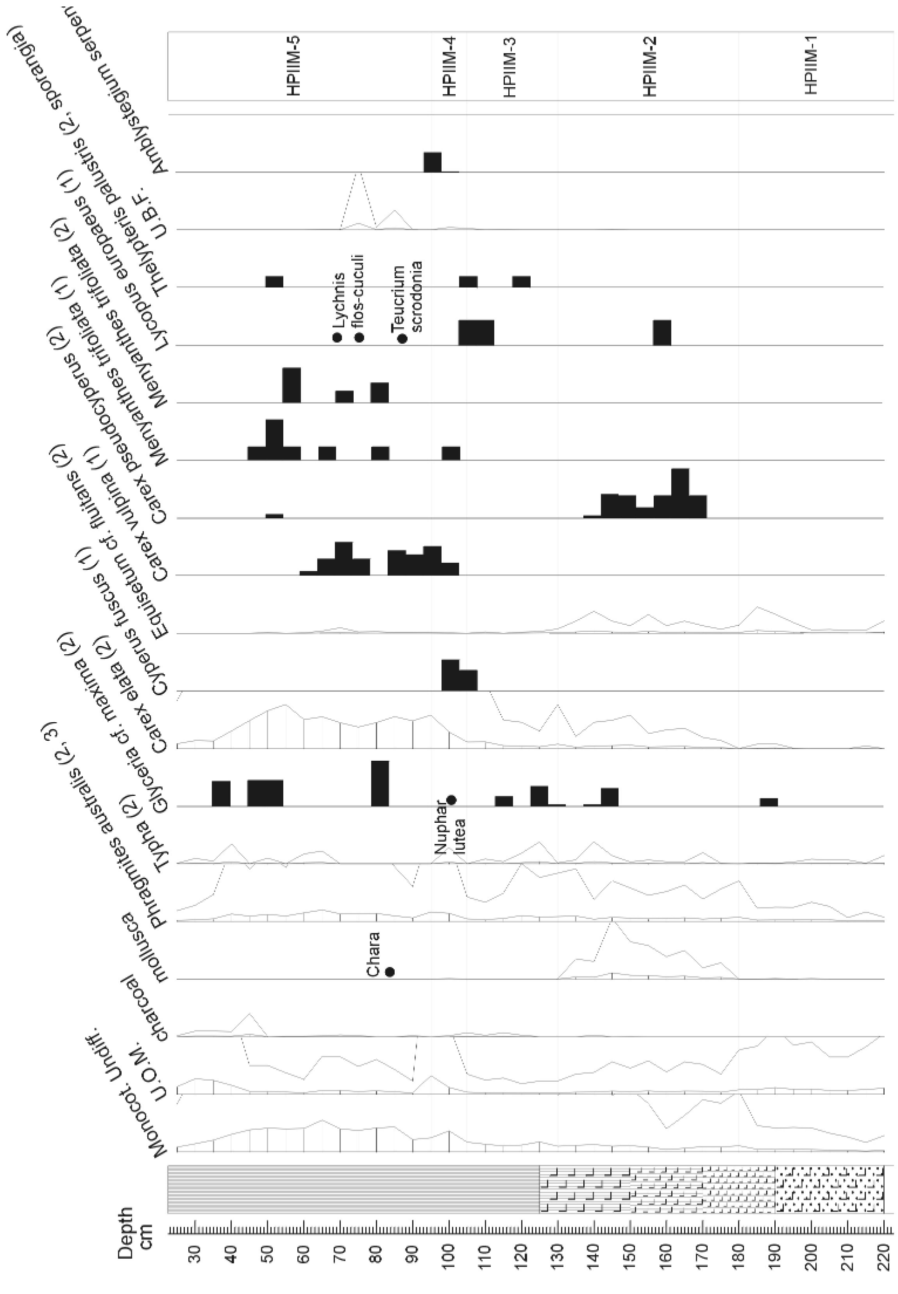

Fig. 8
Macrofossil diagram of HPII core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

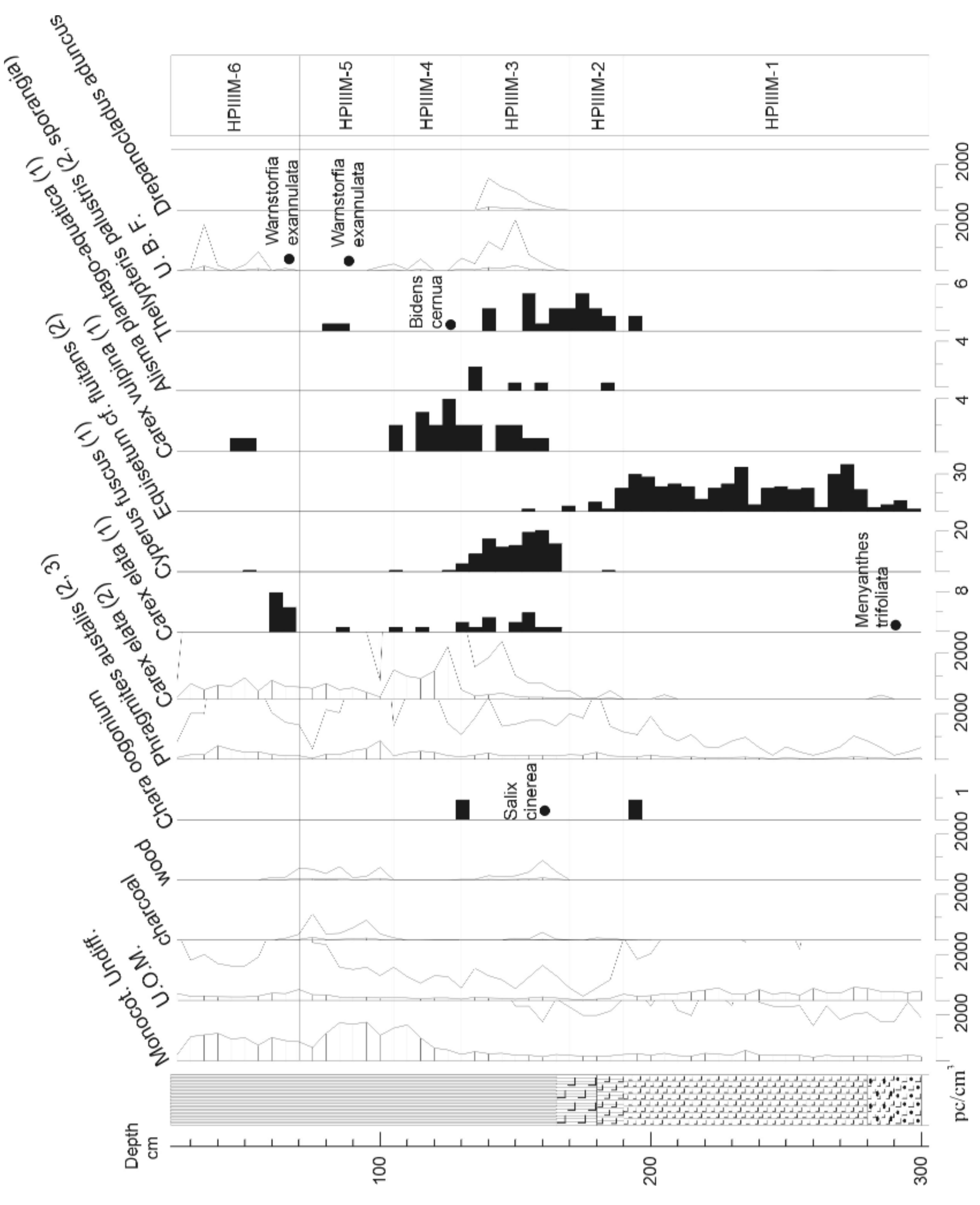

Fig. 9
Macrofossil diagram of HPIII core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

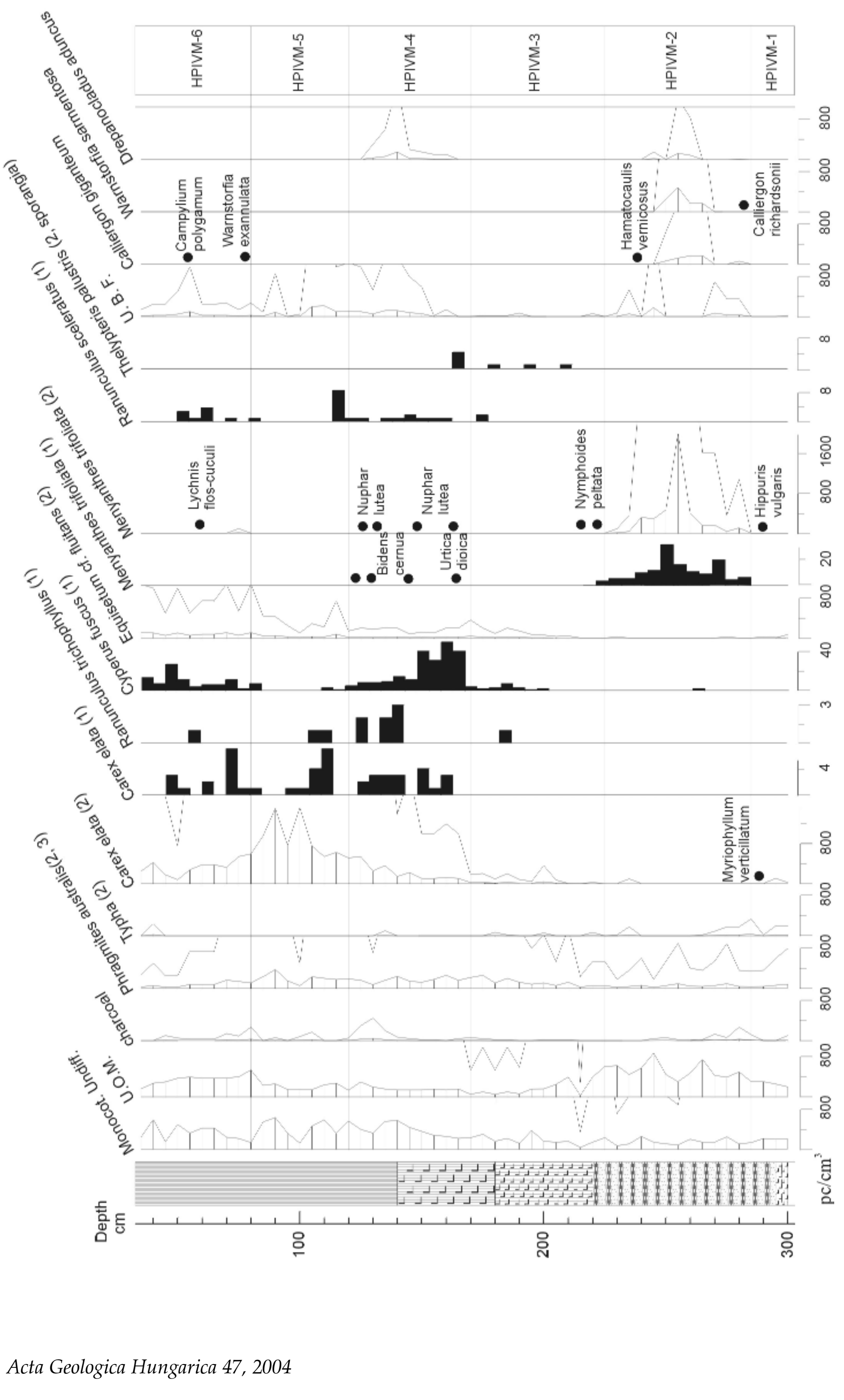

Fig. 10
Macrofossil diagram of HPIV core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

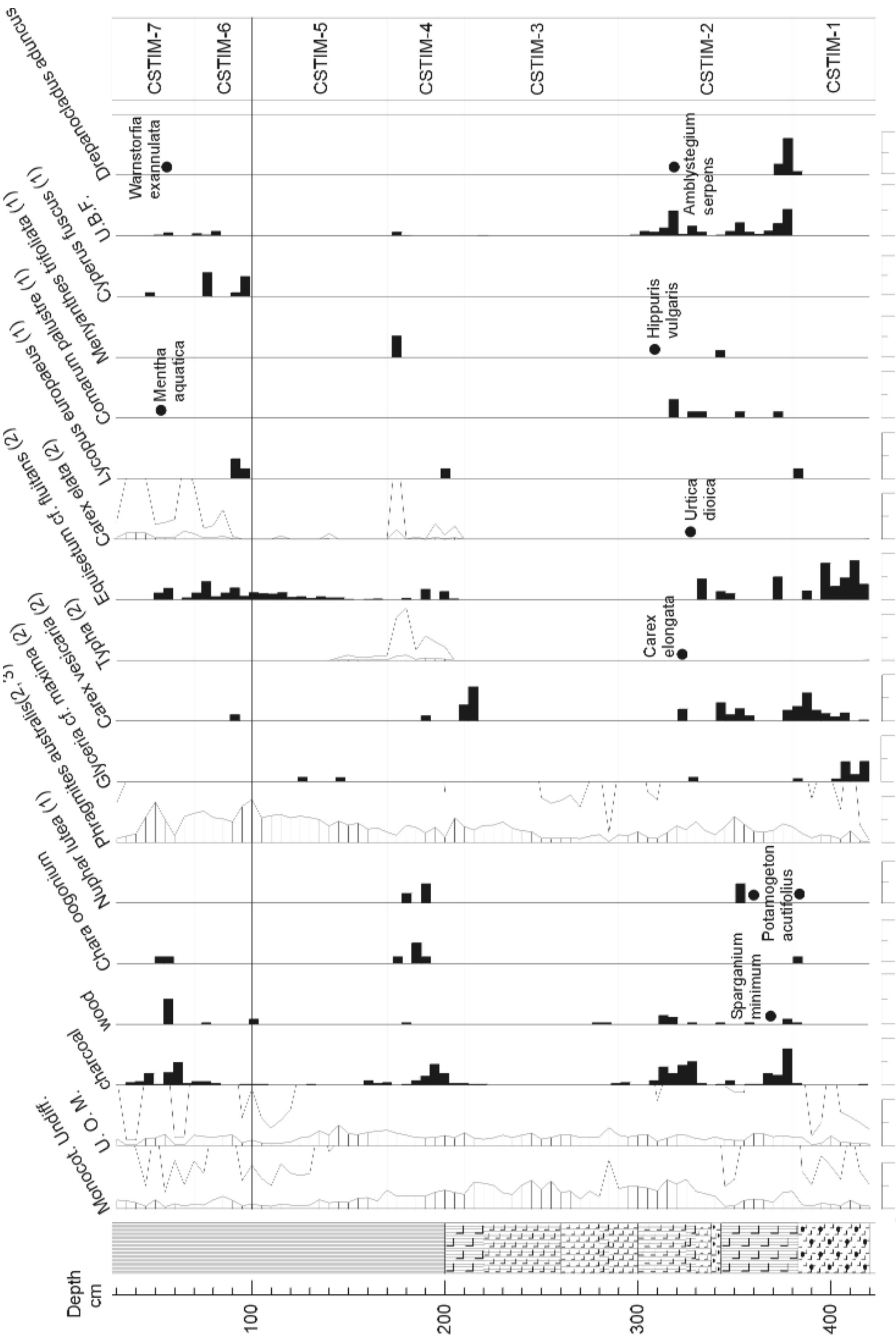

Fig. 11
Macrofossil diagram of CSTI core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

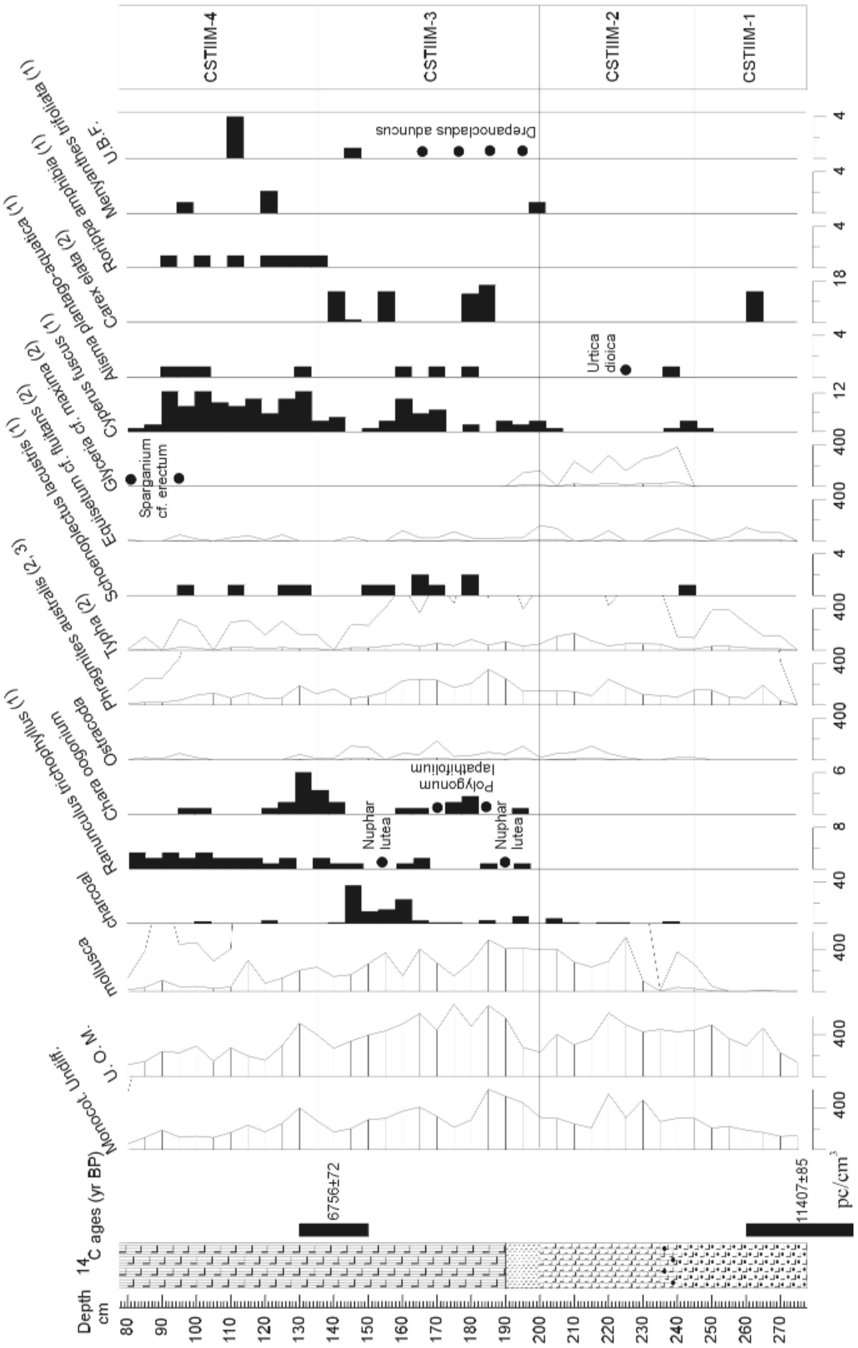

Fig. 12
Macrofossil diagram of CSTII core (1: seed, 2: rhizodermal tissue, 3: epidermal tissue)

Mire vegetation development

Riparian phase

The radiocarbon and paleoecological data suggest that the analyzed filled up paleochannel was cut off from active river system of the Danube during a neotectonic subsidence process; thus a long, unusual oxbow lake developed at the transition phase of the Pleistocene/Holocene boundary. This long canal-like oxbow lake became fragmented as a result of the filling process of the Holocene. The 47 km-long peat land was broken up by small alluvial fans (Dömsödi 1972) (see Fig. 3).

Jaskó and Krolopp (1991) and Scheuer et al. (1992) proved intensive neotectonic subsidence processes from the near Paks–Sárköz Depression. They showed that the Danube appeared in the area only in the Early Holocene (10800 ±150 ^{14}C age years BP). The neotectonic subsidence processes continued in the Holocene.

The bottom sediment of the cores was fine sand rich in muscovite and small-sized gravel. After the deposition of the coarse-grained sandy riverbed, the paleochannel (spillstream) separated from the river Danube, and parts of it filled in differently. Different vegetation types developed because of the introduced terrestrial sediment, the different geomorphological position and the springs of the loess wall with varying chemical composition.

Therefore different paleo-associations and different sediments developed in the paleochannel during the Late Pleistocene and Early Holocene. A wide range of hydrophyte vegetation and habitats emerged in the channel from the living water to the rich fen communities, depending on water supply and geomorphological position.

The first phase of mire succession occurred up to the year 7310 BP, when living water communities and riparian habitats dominated the channel. Even though the influence of surface waters decreased gradually because of intensive neotectonic subsidence processes, their importance is certain up to 7310 BP. According to radiocarbon dating the first part of this phase can be assigned to the Late Glacial, and the second to the Early Holocene (after 9130 BP). The first charcoal peak at 9130 ±130 ^{14}C age years BP in the macrofossil record marks the beginning of the Holocene (Fig. 6). It coincides with a sharp decline in Pinus sylvestris pollen, and so most likely indicates that the loose pine forest burnt down around the paleochannel belt, most probably as a consequence of relatively dry winters and springs, followed by warm summers. The water level of the paleochannel was high, with living as well as stagnant water.

The living water was without macrophytes, well oxygenated and relatively nutrient-rich. This is indicated by the number of rheophilous mollusks (*Valvata piscinalis, Lithoglyphus naticoides, Lymnaea stagnalis, Planorbis* cf. *carinatus, Unio* cf. *crassus, Pisidium amnicum*).

The living water was fringed by a horsetail marsh (*Equisetetum fluitantis*) paleo-association. This association emerged in almost every core (HPIM-1, HPIIM-2, HPIIIM-1, CSTIM-1 and CSTIIM-1 zones).

In the embayments of the paleochannel poorly oxygenated oxbow lakes developed without macrophyte vegetation and mollusk associations.

At the margins of these lakes a rich macrophyte vegetation emerged: floating and submerged aquatic vegetation with *Hippuridetum vulgaris* and *Myriophylletum verticillati* associations. These associations emerged in the HPIV core (HPIVM-1 zone).

Peat formation began in the near-shore zone of these lakes, with rich fen associations (*Menyanthetum, Sparganio minimi–Utricularietum*). The most important vascular plants were *Menyanthes trifoliata, Comarum palustre, Sparganium minimum, Phragmites australis* and *Carex vesicaria*. This community was very rich in bryophytes. The most important bryophytes were *Calliergon richardsonii, Warnstorfia sarmentosa, Calliergon giganteum, Drepanocladus aduncus, Pseudephemerum nitidum* and *Hamatocaulis vernicosus*. This is the so called "brown moss carpet", frequently reported from Pleistocene sediments in Hungary (Boros 1952), but has not been reported form the Early Holocene until now. This community is very similar to the Late Pleistocene moss assemblage of the Nagy-Mohos Peat Bog in NE Hungary (Magyari et al. 1999, 2000; Juhász et al. 2003). These associations were encountered in the HPI, HPII and CSTI cores (in the HPIM-2, HPIVM-1 and CSTIM-2 zones).

The pollen concentration in the first part of this phase (402–412 cm) is extremely low, suggesting selective fossilization. The principal tree species in this zone was *Pinus sylvestris*. Small quantities of *Pinus cembra, Pinus mugo, Larix decidua, Betula nana, Hyppophaë rhamnoides, Alnus* cf. *glutinosa* and *Selaginella selaginoides* were also found. This indicates that extensive, bare surfaces with patches of tundra vegetation and boreal woodlands dominated the terrestrial vegetation.

The second part of this phase (326–402 cm) is devoid of pollen. The lack of sufficient pollen can be explained by erosion. In the macrofossil diagram of the HPIV and CSTI cores (HPIV 215 cm, CSTI 285 cm) there is a conspicuous decrease in the macrofossil concentrations (U.O.M. and Monocot. Undiff. histograms) suggesting peat degradation, probably as a consequence of the low water table. The HPIV and CSTI cores are at the margin of the marsh, so lack of water mostly affected this part of the channel, leading to peat decomposition.

In the third part (HPIP-3 zone) of this phase the pollen data suggest development of a gallery forest around the study site, made up of willow and abundant liana. Well-drained areas in the vicinity of the meander must have supported mixed stands of spruce (*Picea abies*) and elm (*Ulmus*); however, we can also surmise a spread in grassland dominated by Poaceae, Umbelliferae and Aster species.

Although the pollen-sterile sediment layer (between 402 and 326 cm) has not yet been dated by absolute techniques, judging from the radiocarbon data above it (291–296 cm: 10460–10180 cal. BC), it certainly represents the final stade of the Late Glacial, that is the Younger Dryas (YD: ~ 12680–11590 cal. BP). Pollen evidence from this period is rather scanty in the southern part of the Danube–Tisza Interfluve. The only sequence with well-preserved YD pollen assemblages is Ócsa (Járai-Komlódi 1966ab 1968). Here the stadial pollen spectra are characterized by the dominance of Gramineae and Artemisia; arboreal pollen declines sharply with *Pinus* and *Betula* most affected. Járai-Komlódi argued that cold continental *Artemisia* steppe with parkland boreal forest characterized the landscape in the area of Ócsa. Temperate deciduous tree taxa (*Quercus, Ulmus* and *Corylus avellana*) that were present in the preceding Allerød interstadial also survived the YD, but their frequency decreased. The paleochannel at Ócsa is situated in extensive wetland area that is a former floodplain of the Danube. Sand dunes and sand formation took place at some distance from the floodplain, whereas Hajós is located at the fringe of the sand dunes of the Danube–Tisza Interfluve; therefore the YD vegetation must have differed remarkably. Lake Kolon and Bócsa are located in the heart of the blown sand area. Their paleoenvironmental records (Borsy et al. 1991; Lóki et al. 1995) go back to the YD. In both lakes the sediment contains large quantities of wind-blown sand in this phase, hinting at the intensification of sand movements. The pollen preservation is poor in these levels; therefore we have no information on the terrestrial vegetation. However, pollen assemblages from the Allerød interstadial abound in Gramineae, Artemisia and Chenopodiaceae; NAP frequencies attain 70–75%, suggesting that the area was predominantly a treeless, cold continental steppe. Similarly to Ócsa, pockets of warm, temperate deciduous trees occurred (Lóki et al. 1995); however, the vegetation must have been predominantly treeless, as opposed to Ócsa. On the basis of the YD blown sand movements (Gábris et al. 2000; Borsy et al. 1991) we can assume that during this phase large areas lost their vegetation cover and became barren in the vicinity of Hajós as well.

Reed swamp phase

Sediment composition and fossil assemblage changed at about 7300 BP. Peat accumulation began in every part of the channel. The 2nd charcoal peak marks the beginning of this phase in the macrofossil record.

The onset of the reed swamp development coincides with a dramatic change in terrestrial vegetation. The thick Salix scrub fringing the wetland in the vicinity of HP-I in the Early Holocene disappears; *Quercus, Corylus, Ulmus* and *Tilia* expand, whereas *Pinus sylvestris* and *Picea abies* withdraw from the area. This change to a predominantly deciduous canopy is accompanied by the occurrence and immediate increase of Aster-type and Artemisia pollen. Both taxa attain frequencies near 20%; their increase occurs at the expense of Gramineae species, suggesting a major change in steppe vegetation. Instead of the forestation or forest expansion characteristic elsewhere (e.g. Báb-tava (Magyari 2002), Ócsa (Járai-Komlódi 1966a), Tiszagyulaháza (Magyari 2002), Pocsaj (Félegyházi 1998)), in the area of Hajós we witness the expansion of warm continental loess and sand 'pusztas' rich in Artemisia, Compositae and Umbelliferae species. The increase of these taxa suggests increasing aridity in this area around 8000 cal. BP (Fig. 4), that is at the end of the Boreal chronozone. Artemisia and Aster-type pollen retain high values throughout the Atlantic chronozone and arboreal pollen frequencies decline gradually. If we assume that sedimentation was continuous throughout the Atlantic phase in HP-I, then we can conclude that the sand area to the east of Hajós must have remained open throughout the mid-Holocene, with only pockets of mixed-oak forests.

The mollusk paleo-association (*Planorbarius corneus, Lymnaea palustris, Segmentina nitida* in the HPIIMo-2 zone) suggests that a shallow lake developed in the studied paleochannel during this phase, with emerged and submerged vegetation.

The vegetation of the channel became uniform. Reed swamp covered the entire basin. The occurrence of *Thelypteris palustris* remains suggest the presence of floating reed swamps (Thelypteridi-Phragmitetum, Thelypteridi-Typhetum) in the deeper part of the basin. This fossil plant association is very poor in species. The macrofossil record does not suggest submerged vegetation during this phase.

This sedimentary phase can be traced everywhere in the basin with varying thickness; only 20 cm at HPIII, but 80 cm at CSTI. The latter (CSTIM-3 zone) contains a large quantity of inorganic material (silt) washed into the basin by a nearby stream coming from the sand dunes. The increased erosional activity can be explained by continuing neotectonic subsidence processes. The changing relief caused increased sediment infilling via the loess canyons. A large amount of terrestrial material infilled some parts of the channel, and separated the embayments near the loess wall. The result of erosion activity of this period can be seen in Fig. 3. Arrows show the presumed courses of the Danube in the Late Pleistocene and in the Early Holocene. The infilled northern part of the Hajósi Kaszálók Mire is shown as an important, and about only available crossing point across the peat land in medieval military maps (Molnár and Biró 2001).

The Hajósi-kaszálók Mire was separated from the inundations of the Danube. Thereafter this part of the paleochannel could have been supplied with poorly-oxygenated underground water. The connection with the Danube must have remained continuous in the northern part of the Vörös-mocsár (CSTII), where reed swamp, water-crowfoot and water-lily communities dominate the entire sequence, in combination with different mollusk communities.

Initiation of the "zsombék"-formation

After 3900 BP the climate became much milder. The 3rd charcoal peak indicates the beginning of this phase in the macrofossil record. Oak-hornbeam and hornbeam-beech forests emerged, but steppe area increased to 75–80% as well. Presumably, beech forests increased on the floodplain of the Danube, and grazing meadows, crop-fields and hay meadows replaced the mixed forest-steppe on the sand dunes. Although the climate must have become more humid in this phase, the strong anthropogenic signal suppresses the arboreal vegetation change.

Mollusca remains were found only in HPII (HPIIMo-3 zone). *Valvata cristata* shells are frequent (more than 70%), and the frequency of aquatic (*Pisidium* spp. *Armiger crista*) and amphibious (*Succinea oblonga, Oxyloma elegans*) elements are the highest in this zone. Due to the wetland vegetation succession that entailed a decrease in pH, mollusk shells are absent in the upper part of the sediment in Hajósi Kaszálók Mire.

The water table became higher and a diverse mire vegetation developed in the channel of the Hajósi-kaszálók Mire. The tussock-hollow formation ('zsombék-semlyék') becomes the dominant vegetation type. Large tussocks of *Carex elata* standing in shallow, fluctuating water is a typical mire vegetation type (*Caricetum elatae* plant association) of the Hungarian Lowlands. This association frequently forms complexes with hollow associations (pioneer mud and floating aquatic associations), and is very rich in species. The joint occurrence of pioneer mud (*Cypero-Juncetum bufonii*) and floating aquatic (*Nymphaeetum albo-luteae*) associations suggest a high but fluctuating water table. High water table occurred in spring and early summer, but low water table and bare mud surfaces likely prevailed in late summer. This association emerged in almost every core (HPIM-4, HPIIM-4, HPIIIM-3 and HPIVM-4 zones).

Breaking down of the "zsombék"-formation

In the first part of this phase, between about 1700 and 1650 years BP (92–138 cm) high-amplitude charcoal peaks in the macrofossil record suggest intensive burning in the area. Pollen preservation in this part of the sediment was poor, most likely related to the high charcoal content. Since the pollen record below 138 cm points at intense human disturbance of the natural vegetation (crop production, grazing, trampling, hay cutting), it is conceivable that the charcoal peak represent fires of human origin, but a natural origin cannot be excluded.

The first part of this phase is between the 4th the 5th charcoal peaks. The increase of wood in the macrofossil record (emerging willow swamp) suggests low water table. According to historic data (Györffy 1995) and some pollen diagrams with high-resolution pollen spectra representing the 1st millennium AD (Györffy and Zólyomi 1996; Magyari 2002), there was a period between ca. AD 700 and 1100 when the climate of the Carpathian Basin became more arid.

This is indicated by a gap in sedimentation in the Tapolca Basin accompanied by high Pinus pollen frequencies and poor pollen. Similar changes were found in the pollen record of the Sarló-hát sedimentary sequence in the northeastern part of the Great Hungarian Plain (Magyari 2002); according to the radiocarbon data this event occurred in this area between ca. AD 200 and 500.

The water table in the channel became lower. The diverse tussock-hollow vegetation complex degraded. *Caricetum elatae* became the dominant plant association. Pioneer mud and floating aquatic (hollow) associations disappeared. Willow swamp (*Calamagrostio-Salicetum cinereae*) emerged in the deeper part of the channel (HPIM-5 and HPIIIM-5 zone). This type of hydroseral succession is common in recent mires under anthropogenic influences (water body regulation). The structure of the hummock-hollow complex becomes much denser and the bare mud surfaces disappear (Szodfridt and Tallós 1968). This association was encountered in almost every core (HPIM-6, HPIIM-5, HPIIIM-4, HPIIIM-6 and HPIVM-5 zones).

In the second part of this phase, after 1650 year BP (20–92 cm) the climate became mild, warm and moderately arid. Mixed oak and oak-hornbeam forests emerged. A strong anthropogenic signal and extensive forest-steppe area was detected in this zone.

The hollow associations and Equisetum fluitans return in the HPIV core (HPIVM-6 zone), suggesting the importance of periodic springs at the bottom of the nearby loess wall. These springs fed the marshes with groundwater in humid periods. One of this springs is located very close to the HPIV borehole.

Alternative pathway in the Vörös-mocsár Mire

The connection with the river Danube remained continuous in the northern part of the Vörös-mocsár, and inundations reached the area. The largest flood was reported in 1873, but smaller one occurred in 1941 1945 and 1956 as well.

The oxygen, nutrient and carbonate-rich waters altered the main direction of hydroseral succession. Phragmites-dominated plant associations emerged in the entire sequence. For example, at 3960 BP (3rd charcoal peak), when the shift of the *Caricetum elatae* community is noticeable in the Hajósi-kaszálók Mire, the humid climate results in the shift of Phragmitetum associations in the CSTI core. In this core the shift of *Carex elata* was only a periodic event (CSTIM-4 zone). Finally, *Carex elata* occurs in remarkable quantity only in the CSTIM-7 zone after 1700 BP.

It is highly important to note that there is a hiatus in the upper part of the CSTII core. The absence of younger charcoal peaks (3rd–5th peaks) in this core and the radiocarbon data, support the concept of this hiatus. This can be easily explained by the water body regulations and peat-cutting in this part of the peat land.

Conclusions

A new quantitative paleobotanical method for the description of organic sediments (lake sediments and peat) is presented by the authors. The Peat Component System with the paleobotanical description of macroscopic organic material allowed us to reconstruct the hydroseral succession and hydrological changes. The modified "semi-quantitative quadrate and leaf-count macrofossil analysis technique" (QLCMA of Barber et al. 1994) was used to quantify the peat components. The specific peat components help us to reconstruct past plant associations, but the non-specific peat components also contribute to the reconstruction of environmental and hydrological changes (water level changes). The small charred wood fragments (larger than 300 μm) are mostly allochtonous elements in the macrofossil records. By comparing the charcoal histograms and radiocarbon data of the multiple cores with each other it is possible to describe the hydroseral succession in space and time (Figs 6 and 13).

This quantitative plant macrofossil analysis technique together with pollen, mollusks, and radiocarbon analyses, has been used to reconstruct the postglacial mire development of an eutrophic peat bog in S Hungary. The analysis of the Holocene peat sequence was used to reconstruct the development of a filling up spillstream of the Danube. The reconstructed paleohydrological and hydroseral changes were compared with the coincident terrestrial vegetation alterations.

The Vörös-mocsár Mire obtained well oxygenated, nutrient and carbonate-rich surface water since sediment accumulation began. Phragmites-dominated plant associations were encountered in the entire sequence. The rise of *Carex elata* was only a periodic event; it emerged only after 1700 BP. The Hajósi-kaszálók Mire, isolated from the flood waters of the Danube, received only ground water since the Early Holocene, when increased erosional activity caused by the Holocene neotectonic subsidence of the Solti Plain, put large amounts of inorganic sediment into the cannel. Phragmites-dominated plant associations emerged only in the Early Holocene. The tussock hollow-forming *Caricetum elatae* plant association emerged in the fragmented channel, because of the increasing oligotrophy and improving climate after 3900 BP.

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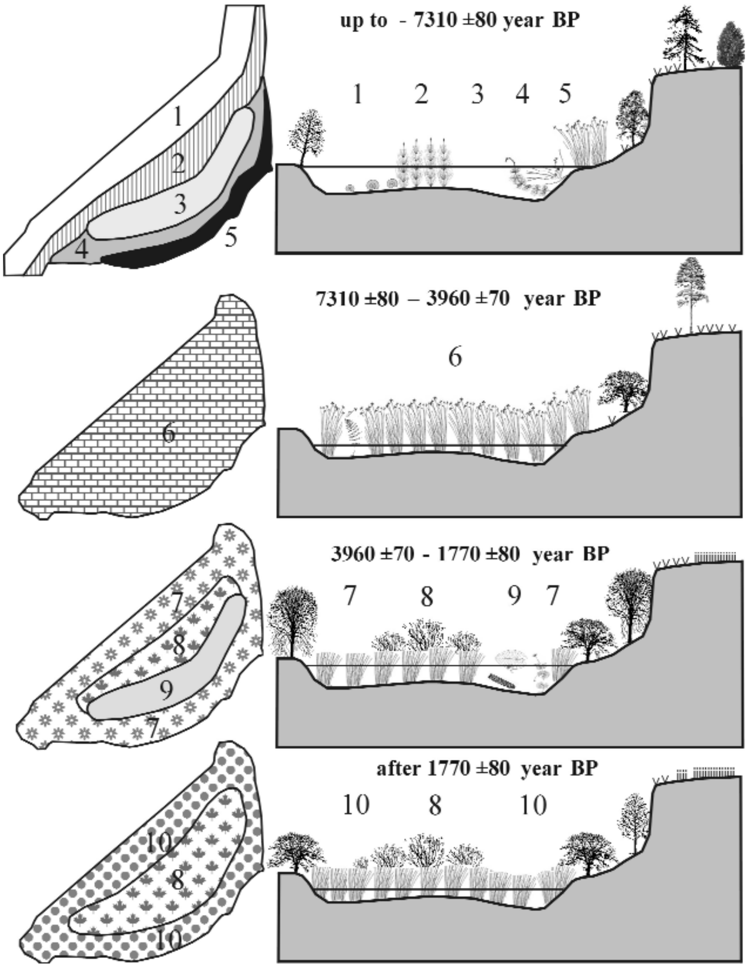

Fig. 13
Hydroseral succession of Hajósi-kaszálók Mire. Wetland plant communities: 1. living water; 2. Equisetetum; 3. stagnant water; 4. Myriophylletum; 5. Menyanthetum; 6. Thelypteridi–Phragmitetum; 7. Caricetum elatae; 8. Calamagrostio–Salicetum cinereae; 9. Nymphaeetum and Cypero–Juncetum

References

Aaby, B., G. Digerfeldt 1986: Sampling techniques for lakes and bogs. – In: Berglund B.E. (Ed.): Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley and Sons Ltd. pp. 181–194.

Barber, K.E., F.M. Chambers, D. Maddy, J. Brew 1994: A sensitive high resolution record of the Holocene climatic change from a raised bog in northern England. – The Holocene, 4, pp. 198–205.

Berglund, B.E., M. Ralska-Jasiewiczowa 1986: Pollen analysis and pollen diagrams. – In: Berglund, BE. (Ed.): Handbook of Holocene palaeoecology and palaeohydrology. John Wiley and Sons, New York, USA., pp. 455–479.

Bennett, K.D. 1992: PSIMPOLL – A quickBasic program that generates PostScript page description of pollen diagrams. – INQUA Commission for the study of the Holocene: working group on data handling methods, Newsletter, 8 pp. 11–12.

Beijerinck, W. 1947: Zadenatlas der Nederlandsche Flora. – H, Veenman and Zonen, Wageningen 316 p.

Berggren, G. 1968: Atlas of Seeds. 2. Cyperaceae. – Swedish Natural Science Research Council, Stockholm 68 p.

Birks, H.H. 1980: Plant macrofossils in Quaternary lake sediments. – Arch. Hydrobiol. Beith. Ergebn. Limnol., 15, pp. 1–60.

Birks, H.J.B., H.H. Birks 1980: Quaternary palaeoecology. – University Park Press, Baltimore, 289 p.

Birks, H.H., H.J.B. Birks 2000: Future uses of pollen analysis must include plant macrofossils. – Journal of Biogeography, 27, pp. 31–35.

Birks, H.J.B., A.D. Gordon 1985: Numerical Methods in Quaternary Pollen Analysis. – Academic Press, London, 317 p.

Borhidi, A. 1961: Klimadiagramme und klimazonale Karte Ungarns. – Annales Univ. Sci. Budapest., 4, pp. 21–50.

Borhidi, A. 1993: Characteristics of the climate of the Danube–Tisza Mid-Region. – In: Szujkó-Lacza, J., M. Rajczy (Eds.): The Flora of the Kiskunság National Park I. Magyar Természettudományi Múzeum, Budapest, pp. 9–20.

Borhidi, A. 2003: Magyarország növénytársulásai. (Plant associations of Hungary) – Akadémiai Kiadó, Budapest, 610 p.

Boros, Á. 1936: A Duna–Tisza köze kőriserdői és zsombékosai (Ash forests and marhes of the Danube–Tisza Interfluve). – Botanikai Közlemények, 32, pp. 84–97.

Boros, Á. 1952: Pleisztocén mohák Magyarországon (Pleistocene mosses in Hungary). – Földt. Közl., 82/7–9, pp. 294–301.

Borsy, Z., E. Félegyházi, E. Hertelendi, J. Lóki, P. Sümegi 1991: A bócsai fúrás rétegsorának szedimentológiai, pollenanalitikai és malakofaunisztikai vizsgálata (Sedimentological, pollen analytical and malakofaunistic studies on the series of strata in the drilling near Bócsa). – Acta Geographica Debrecina, 28–29, pp. 263–277.

Csernyi, T. 2000: Komplex földtani kutatások hazai tavakon, lápokon és mocsarakon (Complex geological investigations of lakes, peatbogs and marshes in Hungary). – In: Szurdoki, E. (Ed.):Tőzegmohás élőhelyek Magyarországon: kutatás, kezelés, védelem (Habitats of peat mosses in Hungary: Research, Management, Conservation). CEEWEB Munkacsoport, Miskolc, pp. 27–41.

Deli, T., P. Sümegi 1999: Biogeographical characterisation of Szatmár–Bereg plain based on the mollusc fauna. – In: Hamar, J., A. Sárkány-Kiss (Eds): The Upper Tisa Valley. Tiscia Monograph Series, Szeged, pp. 471–477.

Dömsödi, J. 1972: A magyarországi Duna-völgy déli szakaszának lápi eredetű szervesanyag tartalékai (Peat-Resources in the Southern Part of the Hungarian Danube Valley). – Agrokémia és Talajtan, 213–4, pp. 337–354.

Evans, J.G. 1972: Land Snails in Archaeology. –Seminar Press, London–New York.

Félegyházi, E. 1998: Adalékok a Tisza és a Szamos folyóhálózatának alakulásához a felső-pleniglaciális időszakban (Contribution to the development of the drainage network of the Tisza and Szamos Rivers in the Upper Pleniglacial Period). – Acta Geographica Debrecina, 34, pp. 203–218.

Fényes, J. 1983: A Duna–Tisza közi tőzeges tavak fejlődéstörténete Mollusca-fauna vizsgálatok alapján (Evolution of peat lakes in the Danube-Tisza Interfluve Based on investigation of their mollusc fauna). – Alföldi Tanulmányok, 8, pp. 7–30.

Gábris, Gy., E. Horváth, Á. Novothny, K. Ujházy 2000: Environmental changes during the last- late, and post-glacial in Hungary. – In: Kertész, Á., F. Schweitzer (Eds): Physico-geographhical Research in Hungary. Studies in Geography in Hungary 32, Geographical Research Institute HAS, Budapest, 267 p.

Grosse-Brauckmann, G. 1972: Über pflanzliche Makrofossilien mitteleuropäischer Torfe. I: Gewebereste krautiger Pfanzen und ihre Merkmale. – Telma, 2, pp. 19–55.

Grosse-Brauckmann, G. 1986: Analysis of vegetative plant macrofossils. – In: Berglund, B.E. (Ed.): Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley and Sons Ltd. pp. 591–618.

Györffy, Gy. 1995: Hová lettek az avarok? (Where the Avars disappeared?) – História, 17/3, pp. 3–9.

Györffy, Gy., B. Zólyomi. 1996: A Kárpát-medence és Etelköz képe egy évezred előtt (The landscape of the Carpathian basin and the Etelköz a thousand year ago). – Magyar Tudomány, 8, pp. 899–918.

Hedenäs, L. 1993: Field and microscope keys to the Fennoscandian species of the Calliergon–Scorpidium–Drepanocladus complex, including some related or similar species. – Biodetector AB, Märsta, 79 p.

Hertelendi, E., E. Csongor, L. Záborszky, I. Molnár, I. Gál, M. Györffy, S. Nagy. 1989: Counting system for high precision C-14 dating. – Radiocarbon, 31, pp. 399–408.

Jakab, G., E. Magyari 2000: Új távlatok a magyar lápkutatásban: szukcessziókutatás paleobryológiai és pollenanalitikai módszerekkel (Progresses in the Hungarian mire succession studies: the use palaeobryological and palynological techniques in the reconstruction of hydroseres). – Kitaibelia, 5/1, pp. 17–36.

Jakab, G., P. Sümegi 2004: A lágyszárú növények tőzegben található maradványainak határozója mikroszkópikus bélyegek alapján (Keys and descriptions for the determination of fossil plant remains occure in peat). – Kitaibelia, 9/1,pp. 93–129

Járai-Komlódi, M. 1966a: Palinológiai vizsgálatok a Magyar Alföldön a Würm glaciális és a holocén klíma- és vegetációtörténetére vonatkozóan (Palynological investigations of climate and vegetational history of the Great Hungarian Plain in the Würm and Holocene period). – Kandidátusi értekezés. ELTE, Budapest. 280 p.

Járai-Komlódi, M. 1966b: Adatok az Alföld negyedkori klíma és vegetációtörténetéhez I. (Quaternary climatic changes and vegetational history of the Great Hungarian Plain I). – Botanikai Közlemények, 53/3, pp. 191–201.

Járai-Komlódi, M. 1968: The late glacial and holocene flora of the Great Hungarian Plain. – Ann. Univ. Sci. Budapest., de Rolando Eötvös Nominatae. Sect. Biol., 9–10, pp. 199–225.

Jaskó, S., E. Krolopp 1991: Negyedidőszaki kéregmozgások és folyóvízi üledékfelhalmozódás a Duna-völgyében Paks és Mohács között (Quaternary crustal movements and stream alluviation in the Danube Valey between Paks and Mohács). – MÁFI Évi Jel. 1989-ről, pp. 65–84.

Jávorka, S., V. Csapody 1991: Iconographia florae partis austro-orientalis Europae centralis. – Akadémiai Kiadó, Budapest, 576 p.

Janssens, J.A. 1983: A quantitative method for stratigraphic analysis of bryopytes in holocene peat. – Journal of Ecology, 71, pp. 198–196.

Janssens, J.A. 1987: Ecology of peat land bryophytes and palaeoenvironmental reconstruction of peat lands using fossil bryophytes. – Manual for Bryological Methods Workshop. Satellite Conference of the XIV. International Botanical Conference International Association of Bryologists, Mainz, 67 p.

Janssens, J.A. 1990: Methods in Quaternary Ecology 11. Bryophytes. – Geoscience Canada, 17/1, pp. 13–24.

Juhász, I., P. Sümegi, G. Jakab, Zs. Szántó, M. Molnár 2003: Jégkorszaki reliktum Sphagnum láp Magyarországon (A glacial relic Sphagnum mire in Hungary). – In: Dombos, M., G. Lakner (Eds): 6. Magyar Ökológus Kongresszus, Előadások és poszterek összefoglalói, Gödöllő p. 126.

Katz, N.J., S.V. Katz, M.G. Kipiani 1965: Atlas and keys of fruits and seeds occurring in Quaternary deposits of the USSR. – Publishing House "NAUKA", Moscow, 364 p.

Krolopp, E. 1983: Biostratigraphic division of Hungarian Pleistocene Formations according to their Mollusc fauna. – Acta Geol. Hung., 26, pp. 62–89.

Lóki, J., P. Sümegi, E. Félegyházi, E. Hertelendi 1996: A Kolon-tó fenékiszapjába mélyített fúrás rétegsorának szedimentológiai, pollenanalitikai és malakofunisztikai elemzése (Sedimentological, pollen analytical and malakofaunistic studies of the ground layers of Lake Kolon). – Acta Geographica Debrecina, 33, pp. 93–115.

Lozek, V. 1964: Quartärmollusken der Tschechoslowakei. – Rozpravy Ústavu ústedniku geologichkého, 31, 374 p.

Marosi, S., S. Somogyi 1990: Magyarország kistájainak katasztere II (Regions of Hungary II). – MTA Földrajztudományi Kutató Intézet, Budapest 1023 p.

Magyari, E. 2002: Climatic versus human modification of the Late Quaternary vegetation in Eastern Hungary. – Ph. D. Thesis, Department of Mineralogy and Geology, University of Debrecen, 150 p.

Magyari, E., G. Jakab, E. Rudner, P. Sümegi 1999: Palynological and plant macrofossil data on the Late Pleistocene short-term climatic oscillations in North-Eastern Hungary. – Proceedings 5th EPPC, Acta Paleobot. Suppl. 2, pp. 491–502.

Magyari, E., G. Jakab, P. Sümegi, E. Rudner, M. Molnár, M. 2000: Paleobotanikai vizsgálatok a keleméri Mohos-tavakon (Paleobotanical investigations in the Lake Mohos at Kelemér). – In: Szurdoki, E. (Ed.): Tőzegmohás élőhelyek Magyarországon: kutatás, kezelés, védelem (Habitats of peat mosses in Hungary: Research, Management, Conservation). CEEWEB Munkacsoport, Miskolc. pp. 101–131.

Meijer, T. 1985: The pre-Weichselian nonmarine molluscan fauna from Maastricht-Belvedere (Southern Limburg, the Netherlands) – Mededelingen Rijks Geologische Dienst, 39, pp. 75–103.

Menyhárth, L. 1877: Kalocsa környékének növénytenyészete (Flora of Kalocsa). – Hunyadi Mátyás Intézet, Budapest 198 p.

Molnár, Zs., M. Biró 2001: A tervezett Dél-Őrjegi Tájvédelmi Körzet botanikai és tájtörténeti felmérése és értékelése (Botanical and landscape historical investigations in the planned Dél-Őrjeg Landscape Protection Area). – Mscr. MTA Ökológiai és Botanikai Kutató Intézet, Vácrátót, 167 p.

Moore, P.D., J.A. Webb, M.E. Collinson 1991: Pollen analysis. – Second edition. Blackwell Scientific Publications. Oxford, 216 p.

Ökland, J. 1990: Lakes and Snails. Environment and Gastropoda in 1500 Norwegian lakes, ponds and rivers. – Backhuys Press, Oegstgeest, 516 p.

Pécsi, M. 1959: A magyarországi Dunavölgy kialakulása és felszínalaktana (The development and geomorphology of the Hungarian Danube Valey). – Akadémiai Kiadó, Budapest, 466 p.

Pócs, T. 1991: Növényföldrajz (Biogeography of plants). – In: Hortobágyi, T., T. Simon (Eds): Növényföldrajz, társulástan és ökológia (Biogeography, plant sociology and ecology). Tankönyvkiadó, Budapest pp. 27–166.

Post, L., von 1916: Forest tree pollen in south Swedish peat bog deposits. [translated: Davis, M. B., Faegri, K. (1967)] – Pollen et Spores, 9, pp. 375–401.

Pydoplytcka, A. P. 1936: Identification of herbaceous remains and green mosses (Bryales) in peat. – Publishing House of the Academy of BSSR, Minsk, 41 p. (In Russian.)

Rakonczay, Z. (Ed.) 2001: A Kiskunságtól Bácsalmásig, A Kiskunság természeti értékei .(From Kiskunság to Bácsalmás. Natural values of Kiskunság) – Mezőgazda Kiadó, Budapest 387 p.

Reille, M. 1992: Pollen et spore D'Europe et D'Afrique du Nord. – Laboratoire de Botanique Historique et Palynologie Marseille, France, 517 p.

Reille, M. 1995: Pollen et spore D'Europe et D'Afrique du Nord. Supplement 1. – Laboratoire de Botanique Historique et Palynologie Marseille, France, 329 p.

Reille, M. 1998: Pollen et spore D'Europe et D'Afrique du Nord. Supplement 2. – Laboratoire de Botanique Historique et Palynologie Marseille, France, 523 p.

Rónai, A. 1972: Negyedkori üledékképződés és éghajlattörténet az Alföld medencéjében (Quaternary sedimentation and climate history in the Great Hungarian Plain). – MÁFI Évk., 61. Műszaki Könyvkiadó, Budapest, 421 p.

Rónai, A. 1985 Az Alföld földtana (Geology of the Great Hungarian Plain). – Acta Geol. Hung., 21, pp. 412

Rybnícek, K. 1973: A comparison of the present and past mire communities of Central Europe. – In: Birks, H.J.B., R.G. West (Eds): Quaternary Plant Ecology. Blackwell, Oxford. pp. 237–261.

Rybnícek, K., E. Rybnícková 1968: The History of Flora and Vegetation on the Bláto mire in Southeastern Bohemia, Czechoslovakia (Palaeoecological Study). – Folia Geobot. Phytotax., 3, pp. 117–142.

Schermann, Sz. 1967: Magismeret I–II. (Identification of seeds I-II.).– Akadémiai Kiadó, Budapest, 861 p. 208 p.

Scheuer, Gy., F. Schweitzer, E. Hertelendi, Gy. Szöőr 1992: Megsüllyedt és eltemetett vörösagyagok és löszösszletek lito és geokémiai fácieselemzése és rétegtani értékelése (Sedimentological and geochemical investigations of subsided and buried red clay and loess sequences). – In: Szöőr, Gy. (Ed.): Fáciesanalitikai, paleobiogeokémiai és paleoökológiai kutatások (Faciesanalitical, paleobiogeochemical and paleoecological investigations). – MTA Debreceni Bizottsága, Debrecen, pp. 65–80.

Schoch, W.H., B. Pawlik, F.H. Schweingruber 1988: Botanical macro-remains. – Paul Haupt Publishers, Berne and Stuttgart, 227 p.

Slack, N.G. 1994: Can one tell the mire type from the bryophytes alone? – J. Hattori Bot. Lab., 75, pp. 149–159.

Smith, A.J.E. 1978: The moss flora of Britain and Ireland. – Cambridge University Press, Cambridge, 706 p.

Sólymos, P. 1996: Ecological and biogeographical investigation of the recent mollusc fauna of Szársomlyó (S Hungary), southern side. – Malakológiai Tájékoztató, 15, pp. 61–67.

Sólymos, P., A. Nagy 1997: The recent mollusc fauna of the Szársomlyó (S Hungary): spatial pattern and microclimate. – Malakológiai Tájékoztató, 16, pp. 35–42.

Stockmarr, J. 1971: Tablets with spores used in absolute pollen analysis. – Pollen et Spores, 13, pp. 614–621.

Sümeghy, J. 1944: A Tiszántúl (The Tiszántúl). – Magyar tájak földtani leírása (Geological description of the regions of Hungary) 6/1–2, p. 208.

Sümegi, P. 1996: Az ÉK-magyarországi löszterületek összehasonlító őskörnyezeti és sztratigráfiai értékelése (Comperative paleoecological and stratigraphical valuation of the NE Hungarian loess-areas). – Kandidátusi értekezés, 120 p. Debrecen.

Sümegi, P., E. Krolopp 1995: A magyarországi würm korú löszök képződésének paleoökológiai rekonstrukciója (Paleoecological reconstruction of loess deposition in the Würm in Hungary). – Földt. Közl., 124, pp. 125–148.

Sümegi, P., Krolopp, E. 2001: Új adatok a holocén rétegtani és őskörnyezeti vitás kérdéseihez (New data to the controversial matters of holocene stratigraphy and paleoecology). – 4. Magyar Őslénytani vándorgyűlés előadásainak kivonatai, Pécsvárad, p. 33.

Sümegi, P., R. Kertész, E. Hertelendi 2002: Environmental Change and Human Adaptation in the Carpathian Basin at the lateglacial/postglacial transition.– British Archaeological Report, 1043, pp. 171–177.

Szodfridt, I., P. Tallós 1968: A Felsőnyirádi-erdő láp- és ligeterdei (Fenwoods and Groves within the Felsőnyirád Forest). – Veszprém Megyei Múzeumok Közleményei, 7, pp. 193–201.

Szujkó-Lacza, J. 1993: Flowering plants of the Kiskunság National Park and the other region between the Danube and Tisza Rivers. – In: Szujkó-Lacza, J., M. Rajczy (Eds): The Flora of the Kiskunság National Park I. Magyar Természettudományi Múzeum, Budapest, pp. 43–467.

Tóth, K. 1979: Nemzeti park a Kiskunságban (National Park in the Kiskunság). – Natura, Budapest, 519 p.

Tóth, K. (ed.)1996: 20 éves a Kiskunsági Nemzeti Park 1975–1995 (Kiskunság National Park is 20 years old 1975–1995). – Kiskunság National Park Directorate, Kecskemét, 234 p.

Troels-Smith, J. 1955: Karakterisering af lose jordater. – Danmarks Geologiske Undersogelse, 4/3, pp. 10.

Wasylikowa, K. 1996a: Analysis of fossil fruits and seeds. – In: Berglund B.E. (Ed.) Handbook of Holocene Palaeoecology and Palaeohydrology. John Wiley and Sons Ltd. pp. 571–590.

Wasylikowa, K. 1996b: Environmental changes during Neolithic times in the Cracow area. – In: Frenzel, B. (Ed.): Palaeoclimate Research Volume 8. Evaluation of land surfaces cleared from forests by prehistoric man in Early Neolithic times and the time of migrating Germanic tribes. Gustav Fisher Verlag, Stuttgart, pp. 73–91.