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Confinia et Horizontes

THE ENVIRONMENTAL HISTORY OF THE PREHISTORIC SÁRKÖZ REGION IN SOUTHERN HUNGARY

ESZTER BÁNFFY (ED.)

RGK

1

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CONFINIA ET HORIZONTES VOL. 1

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Lectori salutem!

The launching of a new monograph series is a matter of courage and confidence. Courage that it is worthwhile to publish new books in this digital age of ours, and confidence in readers that they will be willing to take yet newer thick volumes in their hand and use them for their academic work or read them out of pure interest in prehistoric archaeology. The host institute, the Romano-Germanic Commission (RGK) of the German Archaeological Institute, has established, edited, and published several monograph series during its long life since it was founded in 1902: suffice it here to refer to the *Römisch-Germanische Forschun*gen, the *Kolloquien zur Vor- und Frühgeschichte*, the series *Die Ausgrabungen in Manching*, and to the *Limesforschungen*. So, one may rightly ask, wherefore yet another one?

During the past few years, research in the RGK has been organised around two major themes and two logistically separate work teams, which are nevertheless bound by many strands scientifically. Under the umbrella of *Forschungsfeld* 2, the research topics related to the Iron Age and the Roman provincial period, research on the Roman *limes* and on the Barbaricum, i. e. the regions not occupied by the Romans, as well as research on the Late Antique period are addressed through related overarching questions such as "border studies". *Forschungsfeld* 1, established at a later date, brings together fields of research and grand themes that had commanded scholarly interest during the first half of the 20th century and were revived during the past decade as part of the RGK research agenda. These cover the Late Mesolithic and the transition to the Neolithic, alongside themes from the Neolithic to the Bronze Age. Currently, there are several RGK and collaborative projects with various institutions and colleagues based in different countries within the framework of this research group. Similarly to the work group focusing on later prehistoric and early historic periods, the basic research questions in Neolithic and Bronze Age studies are few, but they are closely related to each of the running projects and those in plan.

While members of the *Forschungsfeld* 2 work team have had several options for publishing their findings in the traditional RGK monographs, the early periods could not be fitted into any of the already existing series. Hence the idea of establishing *Confinia et horizontes.* The title of the new series matches the major theme of *Forschungsfeld* 1, "Marginal zones, contact zones". The choice of one Latin and one Greek word was wholly intentional: marginal, liminal zones would be ideal settings for potential interactions between different groups initially separate from each other, which then established contacts through exchanges and trade, and later expanded the contacts to a mutual sharing and transferring of innovations and knowledge. And, as is usually the case, these contacts can be traced in the genetic make-up of the once separate population groups. Our goal is to publish cutting-edge new research: principally the projects of the RGK community, but since the time of individual research and authorship has since long passed, these publications, as a rule, will present the findings of dynamic collaboration with other institutions. The monographs will be grouped according to the various collaborative projects. Although it is not our intention to break up *Confinia et horizontes* into subseries, we shall quite clearly indicate if a major project is published in more than one volume that these volumes are closely related. Even more importantly, individual volumes will never be publications released solely by the RGK, but will be equally owned by our partner institutes. This can also be seen as a symbolic gesture: these days, archaeological research generally involves the joint effort of specialists of fieldwork, environmental and non-invasive landscape research, geo- and bioarchaeology, all brainstorming together. The evaluation will then be based on data coming from each field of investigation. It needs to be repeatedly stressed that there is no difference between the two *Forschungsfelder*, between the different periods and phases of archaeological periodisation. Prehistory and history are equally important chapters of the human past. The ultimate goal of *Confinia et horizontes* is to integrate the data provided by various disciplines and interpret them jointly, in the hope that the result will contribute to a reconstruction and better understanding of the various dimensions of past societies. In other words, we truly hope that our prehistoric data will ultimately lead to history writing.

Eszter Bánffy

Pál Sümegi, Katalin Náfrádi, Tünde Törőcsik, Gusztáv Jakab, Elvira Bodor, Mihály Molnár, Balázs Pál Sümegi, Réka Orsolya Tapody, István Knipl, Rozália Kustár and Eszter Bánffy

Prehistoric environment of the Sárköz region in the Danube Valley, southern Hungary. Case studies from infilled oxbow lakes

Keywords: environmental history, Late Pleistocene, Holocene, climatic changes, human impact, Early Neolithic, Late Neolithic

Schlagwörter: Umweltgeschichte, spätes Pleistozän, Holozän, klimatischer Wandel, menschlicher Einfluss, Frühneolithikum, Spätneolithikum

Kulcsszavak: környezettörténet, késő pleisztocén, holocén, klímaváltozás, emberi hatások, kora újkőkor, késő újkőkor

Introduction

This study offers a broad and comprehensive overview of the geographic setting and environment on the alluvial plain known as the Sárköz ("mudland") in the southern Danube Valley in the Carpathian Basin. Our main focus is on the onset of the Neolithic (early 6th millennium cal BC) and the ensuing two millennia.

On the testimony of the archaeological record, this region can be regarded as the last arena of the Neolithic transition in Central Europe, which led to the emergence of the food-producing economies and the shift to sedentary lifeways. This period, designated as the time of the "first farmers" across the vast loess areas of Europe, is generally correlated with the Linearbandkeramik (LBK). This analysis offers a broad outline of the environmental background of a region that can be regarded as one of the key areas in the transition to sedentary life in Central Europe.

According to the currently available archaeological, archaeobotanical, and archaeozoological record, the major centres of the slow transition to food production emerged independently in several regions in the world *(Fig. 1)*. Food-producing communities first appeared in the Middle East and Anatolia (Vavilov 1926; 1992; Childe 1935; Gebauer / Price 1992; Bellwood 2005; Barker et al. 2009) as shown by chronological data, leading to the appearance of Neolithic farming, involving both plant cultivation (Zohary et al. 2012) and animal husbandry. This process of Neolithisation in the Near East, which ultimately determined the transition to farming in Europe, including the Carpathian Basin, occurred at the close of the Pleistocene and the onset of the Holocene, around the turn of the 11th–10th millennia cal BC. Neolithisation was originally conceptualised as a rapid, revolutionary process in the course of which hunter-foragers turned into sedentary farmers in the course of a uniform process (Childe 1935).

The Neolithisation process did not affect the entire South-West Asian region, but was mainly restricted to areas with the most favourable natural conditions, usually lying at the interface of foothills and lowlands, a region known as the Fertile Crescent. This region is regarded as the centre of origin of domesticated plants (Zohary / Hopf 1988; Hopf / Zohary 2001; Zohary et al. 2012), although our understanding of the term has altered since its introduction, after it was pointed out that the beginnings of agrarian civilisations also are attested in Egypt and Mesopotamia (Breasted 1916). In his seminal papers, Harlan (1968a; 1968b; 1995; Harlan / Zohary 1966) used the term Fertile Crescent to denote a core area of origin, a focused area (cf. also

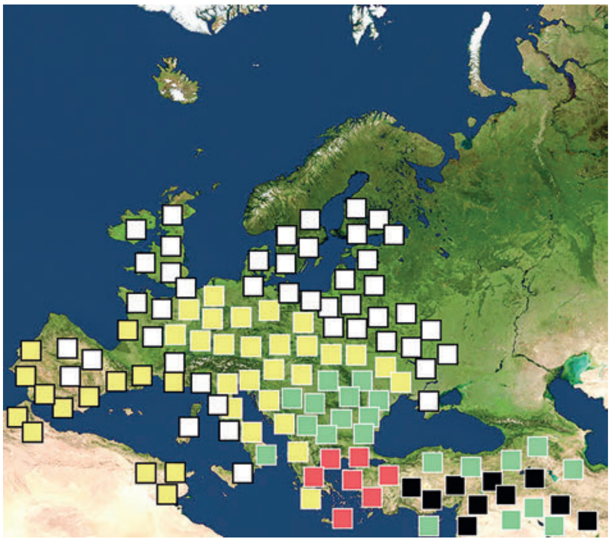

Fig. 1. The spread of the Neolithic transition obtained by interpolating the dates in uncalibrated years before present (uncal BP) of Neolithic sites (squares) in Europe and the Near East. Black squares: before 9000 uncal BP; red squares: 9000–8000 uncal BP; green squares: 8000–7000 uncal BP; yellow squares: 7000–6000 uncal BP; white squares: 6000–5000 uncal BP.

Fuller et al. 2011). According to the latter model, a package of crops was domesticated simultaneously, as opposed to assuming a "non-centre" of diffuse origins of crops that then spread out in space and time, of which the sub-Saharan savannah was perhaps the classic Harlanian example. However, the probable region where the transition took place has gradually shifted towards the Near East, with new evidence that domestication may have spanned a more extended period, as long as 3000–4000 years (Fuller et al. 2011; 2012). The actual location of the shift cannot be pinpointed to one particular area (Abbo et al. 2010; Fuller et al. 2011; 2012). The process probably involved as many dead-ends for proto-domesticates as paths eventually leading to crop cultivation and farming systems known for later prehistory or history.

There is a long tradition of using radiocarbon dates for modelling the diffusion of farming and the arrival and spread of Neolithic culture across Europe. Clark (1965) was the first to map the earliest Neolithic settlements in various regions. He distinguished a pattern in the spread of farming from the Fertile Crescent to Europe along the Danube. In his view, this process took a very long time before farming eventually reached Western and Northern Europe *(Fig. 1)*. Ammerman / Cavalli-Sforza (1971; 1984) proposed a wave of advance model, while other models used spatial analyses to describe the average rate at which farming spread (Gkiasta et al. 2003).

Even though both climatic and soil conditions were favourable for the emergence of food-producing communities in Southern Europe, several important elements of this process lacked across the rest of the European continent, resulting in the preservation of the Mesolithic hunting-foraging lifestyle on the continent. The satellite, temporary hunting camps of the Mesolithic communities indicated the presence of several minor and highly mobile human groups. The scattered Mesolithic communities of Southern Europe became familiar with and began to adopt the Neolithic type of food production around 7000 cal BC as a result of the cultural and ethnic impacts to the region from Anatolia that ultimately originated from the Fertile Crescent *(Figs 1–2)*.

The groups advancing along the river valley routes of the Aegean and the Balkans introduced the Danubian type of Neolithisation in the southern Carpathian Basin *(Fig. 2)*, a region that played a key role in the Neolithisation of Central Europe owing to its favourable geographic location (Clark 1965; Ammerman / Cavalli-Sforza 1971; 1984; Gkiasta et al. 2003).

The Carpathian Basin thus became one of the most important regions in the process of European Neolithisation (Gimbutas 1973; Zohary / Hopf 1988; 1993; Gronenborn 1999; Price 2000; Zvelebil 2001; Zohary et al. 2012). This was the last region colonised by South-East European migrants (Szécsényi-Nagy et al. 2014; 2015). This last stage became the starting point for the expansion towards the continent's northerly and westerly regions. The Carpathian Basin marked the northernmost boundary of the expansion of the Anatolian-Balkanic agricultural civilisation, as embodied by the Körös, Criş, and Starčevo cultures (Banner 1937; Trogmayer 1968a; 1968b; Kalicz 1970; Kalicz / Makkay 1976; 1977; Makkay 1981; 1982; 1992; 1996; Bánffy 2000; 2004; 2005; 2006; 2008; 2009; 2012; Whittle 2004; 2007; Raczky et al. 2010; Raczky 2012a; 2012b; Anders / Siklósi 2012). The environment north of this frontier zone differed fundamentally and was populated by scatters of hunter-forager Mesolithic communities (Kertész et al. 1994; Kertész / Sümegi 2001; Sümegi / Kertész 2001; Bánffy et al. 2007b; Sümegi et al. 2013c). Given that there are no prominent geomorphologic features, hills, or rivers in this boundary area, we tried to seek an answer to the obvious question of why the northward expansion of the earliest Neolithic culture originating from the Balkans came to a halt in the central part of the Carpathian Basin.

The Carpathian Basin is characterised by a large-scale mosaic-like complexity regarding its climate and natural environments at the micro-, meso-, and macro-scales (Sümegi 1996; 2003c; 2004a; 2007a; Sümegi et al. 2012a; 2013c). The formation of a macro-scale mosaic patterning or complexity can be attributed to the overlap

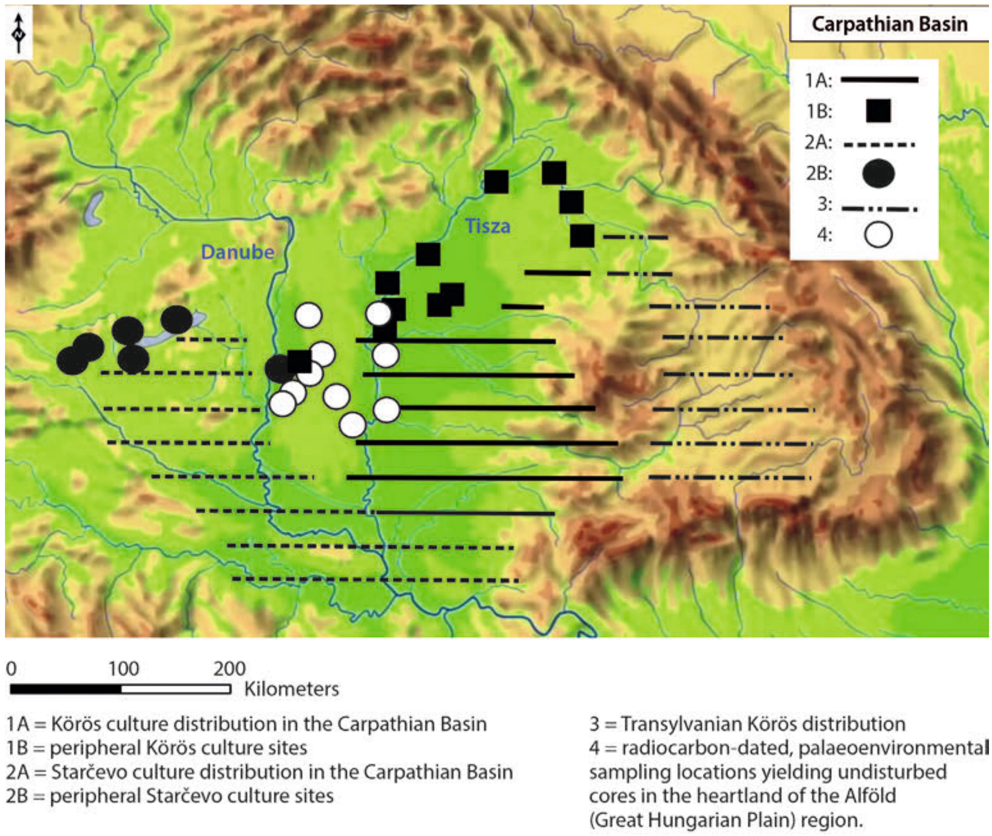

Fig. 2. Distribution of Early Neolithic cultures in the Carpathian Basin and of palaeoenvironmental sampling locations in the Danube-Tisza interfluve.

of three major climatic zones (Köppen's Cf, BS, and Df zones) or eco-regions in the Carpathian Basin (Sümegi 1996; Sümegi et al. 2012a; 2015a). This situation is further complicated by the gently decreasing continental effect from east to west, complemented by an increasing oceanic effect in the same direction. Furthermore, an increasing sub-Mediterranean influence from north to south as well as a sub-Carpathian-Carpathian influence in the hilly areas and mountains can be observed.

The archaeological record suggests that while the Lower Danube played an important role in the advance of Neolithic groups arriving from the Balkans – the descendants of the earliest Neolithic communities in the Fertile Crescent and Anatolia –, the process of Neolithisation came to a temporary halt in the ecologic interface in the Middle Danube Valley and its drainage following the emergence of a secondary centre of Neolithisation, after a dual – cultural and environmental – adaptation had taken place. The role of the Middle Danube Valley in separating diverse environments and cultures is quite obvious in this process, and the river and its tributaries also played a key role in the diffusion of communities that had adapted to the local Central European loessy and loess-covered areas, who advanced along the Middle Neolithic infiltration channels along the valleys extending into the western areas of Central Europe (Bánffy / Sümegi 2012; Sümegi 2003c; 2011).

One of the most important regions in terms of the Neolithisation of the Carpathian Basin and Europe is the Middle Danube Valley where the closed forests of Transdanubia and the forest steppes of the Great Hungarian Plain meet. Apart from transitional zones flanking eastwards and westwards, the main area for the climatic and vegetational change between the two eco-regions currently runs in the Danube Valley, and this was the case in the Neolithic as well (Sümegi 1995; Sümegi et al. 2012a). At the same time, a sub-Mediterranean climate effect can also be detected in the valley (Sümegi 1996; 2011; 2013a). Thus, regions with very diverse environmental conditions meet in the Hungarian Danube Valley, and particularly along its southern Hungarian section, in the alluvial marshland and its broader area known as the Sárköz region.

The Tolna Sárköz, the western part of the Sárköz region, lies in the Mecsek belt in the northernmost zone of the Tisza Mega-Unit, the western structural unit of the Tisza-Dacia Plate. The Mórágy Granite Formation that evolved in the Lower Carboniferous lies on the western edge of this landscape: the surface part of the formation covers a roughly 18 x 11 km large area in the Mórágy block. Its rock is migmatic granite that was formed by ultrametamorphism during Variscan orogeny. The granite disappears east of Mórágy, near Bátaszék, on the northern side of the valley of the Lajvér Stream, where it is overlain by later formations. The granite-migmatite series extends to the eastern part of the Tisza Mega-Unit, the area of the Great Hungarian Plain, where corings have demonstrated its presence.

South of Szekszárd, the granite rock is penetrated by the Mecsekalja zone in a south-west to north-east direction. The rock formations to its north lie deeper than the ones south of the Mecsekalja zone, as shown by the corings, which indicate the presence of granite at a depth of 885 m at Szekszárd and at 112 m at Bátaszék. A granite outcrop has been documented in the basement of the Sárköz region near Sárpilis, where the granite lies at a depth of 86 m.

At Báta, lying on the southern fringes of the Sárköz region, a Middle Triassic (Anisian) bluish-grey Muschelkalk overlies the granite block. On the testimony of the corings near Báta, its thickness exceeds 200 m, but it does not extend to the base of the rock. The limestone subsided and rose together with granite rock; today, it lies a few metres under the current surface. During the Holocene, this rock blocked the southward flow of the Danube (and later the Sárvíz), forcing the river to turn eastward (Pataki 1955).

Pannonian layers were deposited onto the Carboniferous granite and Triassic limestone formations across the Sárköz region. During the Pannonian period, the greater part of the granite rock in the Mórágy area was a dry elevation (Leél-Őssy 1953; Wein 1974), on which Pannonian formations can be found but sporadically and usually in thin layers. In the areas east and north of the granite block, including the Sárköz region, the Pannonian layers conform to the granite and the Triassic limestone is highly diverse and forms a thick layer in the basin (Pataki 1955).

These Pannonian layers wreathed the island-like Mecsek Mountains (Wein 1974). Moving away from the one-time shoreline, one first encounters abrasional pebble and sand layers, followed by silt, sandy clay, and finally clay. The Sárköz region is dominated by silty clay and clay, whose thickness can amount to several hundred metres. The margin of the Mórágy block is characterised by abrasional sand (Wein 1974), confirming the prominence of the granite rock in the Pannonian. The Pannonian formations have no outcrops in the Sárköz region, while they can often be found on hillsides and in valleys in the Szekszárd Hills (Pataki 1955). The Pannonian formations are sealed by a bluish clay layer.

The Sárköz region is covered with Quaternary sediments that have a thickness of 40–60 m and a varied stratification, depending on the extent of the subsidence, the nature of accumulation, and the diversity of morphological conditions. The thickness of the Quaternary sediments increases from west to east.

The alluvial fan of the rivers arriving from Transdanubia and, later, from the Upper Pleistocene onward, the alluvial sediment of the Danube was deposited on the Pannonian formations. A fluvial sediment sequence of gradually more fine-grained sediments deposited by the Danube accumulated in the depression between Kalocsa and Mohács since the Middle Würmian (Marosi / Somogyi 1990).

The thickness of the Pleistocene river beds is some 20–40 m and is made up of medium, coarse-grained, and unsorted sand. The grains are medium or barely worn and rounded. Pebbly intercalations, mostly made up of quartz, quartzite, flint, limestone, and the occasional inwashed limestone concretion, occur frequently, while thin, calcareous, sandy-clayey intercalated veins are rarer (Wein 1974). Similar sediments can be found to a depth of several hundred metres in the sediments of the palaeo-Danube in the Danube-Tisza interfluve (Molnár 1964).

Similarly to the entire territory of Transdanubia, there was intensive loess formation in the Sárköz region. Some 40–60 m thick loess layers with loam zones were deposited in the hilly region bounding the study area in the west. The Lower and Middle Pleistocene loess is predominantly deluvial slope loess that accumulated on slopes and in depressions. The Upper Pleistocene (Würmian) loess was deposited on the peneplain surface of these deluvial-type loess layers. The loam zones in the loess layers enable the identification of wetter, warmer climate periods in the Pleistocene. The Lower and Middle Pleistocene slope loesses contain three to four clayey loam zones, while the Upper Pleistocene loess has no more than one or two loam zones, which can be easily distinguished by their brick red, brownish-red, and brownish colour, and they are also helpful to determine the extent of the displacements caused by Pleistocene movements (Wein 1974).

Infusion loess, a loess type of predominantly alluvial nature, was also formed in the wetter area of the Danube Valley, where it accumulated to a thickness of 3–5 m and covers areas lying above the floodplain.

Aeolian sand can be found on the terrace islands rising slightly over the Danubian floodplain (Pataki 1955). While extensive territories covered with aeolian sand can mostly be found east of the Danube Valley, some patches have also been documented in the Sárköz region. It originates from the modern Danube Valley: the fluvial sediment was transported to the Sárköz region by the wind (Miháltz 1953). The disintegration and uplift of the Pannonian Hills with fault scarps on the northern and eastern margins lying on the western fringes of the Sárköz region occurred in the Upper Pleistocene (Endrédi 2001).

The Sárköz region is covered with Holocene sediments that accumulated to a thickness of 5–15 m. The sediment transported by the Danube became significantly finer during the Holocene owing to the decline of the river's gradient and the decrease of relief energy, and predominantly fine-grained silty sediments accumulated. The sediments currently transported by the Danube to the Sárköz region are fine-grained since the pebble load is deposited by the time the river reaches Kalocsa.

Large areas covered with loess silt layers with a thickness of 1–3 m can be found on the low floodplain on the western side of the Danube Valley. Loess silt is a typical formation of the Danube Valley, formed by the wash-out and redeposition of Pleistocene loess. Its colour and porosity resemble that of loess, but its calcareous content is higher, it is generally ungraded, and contains a higher proportion of silt. A formation of this type can be found on Pandúr Island near Bátaszék.

The lower floodplain areas are made up of more compact, silty-clayey sediments, while the higher-lying floodplains of silty-sandy sediments. The erosion of the typical loess of the hilly region began at the close of the Pleistocene, a process that continued during the Holocene and can still be noted at present. The denuded material was transported to the foothills by precipitation and streams, where the redeposited brownish-grey loess layer accumulated to a thickness of 3–8 m (Leél-Őssy 1953). Humic loessy soil can also be found on the Sárköz terraces (Pataki 1955). The depositional effect of the Danube was extremely strong in the Sárköz region: in times of flood, the Early Holocene sediments were often washed out by the river, and an alluvial cone-like new sediment layer was deposited.

The Tolna Sárköz region, the western part of the Sárköz region, is an alluvial plain lying 88–162 m a.s. l. Its southern part, where the study area lies, is a high floodplain lying 95 m a.s. l. on the average with terrace islands and alluvial cones on its western fringes deposited by the stream arriving from the Tolna-Baranya Hills. The area has an average relief of 1–2 m / km^2. The Tolna Sárköz region was once covered with oxbow lakes, most of which became infilled as a result of natural processes or human intervention. The area is prone to inland water, and extensive areas were covered by wetlands until the river regulations (Marosi / Somogyi 1990).

In terms of its climate, the Sárköz region is part of the warm-moderately dry climate area (Péczely 1979). The average values of the climatic and weather elements (temperature, hours of sunshine, and precipitation) are generally higher in the region's southern areas than in its north. The mean annual temperature is 10.8 °C in the south, a figure exceeding the national mean. However, the annual mean temperature range – the difference between the mean temperature of the warmest and coldest months – reveals more about a region's climate than the mean annual temperature. In the Bátaszék area, this value is 22–23 °C, which is well below the 24.5 °C characterising the Great Hungarian Plain, and reflects the moderation of the continental effect towards the west in Hungary. The hours of sunshine exceed an annual 2100, making the region into one of the richest areas in sunshine of Hungary. The mean precipitation is over 650 mm (Mayer 1997). Winds arise mostly from the north-west, the second most frequent being southerly winds. In winter, the ground is covered with snow for an average of 33–35 days, the greatest thickness of the snow cover is 23–25 cm. The freeze risk period lasts from mid-February to early April, and from late October to mid-December. The temperature does not fall below freezing point in the vegetation period and the mean temperature between April 1 and September 30 is 17.2–17.3 °C.

The soil cover of the Tolna Sárköz region is predominantly made up of meadow soils (94 %), which are mostly poorer clayey-loamy meadow alluvial soils. A forest economy is pursued over about one-third of the region (e. g. Gemenc Forest), while about one-half is cultivated. More fertile meadow chernozems occur occasionally on higher areas, where most ploughlands and settlements can be found. Brown forest soil occurs on the western fringes of the region adjacent to the neighbouring hilly region (Marosi / Somogyi 1990).

The Danube played a key role in the hydrography of the Sárköz region from the close of the Pleistocene. The palaeo-Danube appeared in the Würmian (Bulla 1953; Pécsi 1959), when the river abandoned its previous channel in the Danube-Tisza interfluve because the Kalocsa-Baja-Zombor subsidence gradually drew the river towards itself. The river changed its course several times in the Sárköz region during the Holocene and finally abandoned it towards the east. The abandoned Danube channel was then filled by the Sárvíz River (Mayer 1997).

The Sárvíz River was fed by the Séd, Pát, and Inota streams flowing from the Bakony Mountains; the river also received the water of the Sió and Kapos rivers. It flowed on the western edge of the Sárköz region until the river regulation of 1855 and joined the Danube at Báta (Pataki 1955). Currently, the channel of the Sárvíz River does not extend as far the Sárköz region; the river flows north-westward of Szekszárd and joins the Sió River near Sióagárd. The Sárköz is thus a roughly 400 km^2 large water catchment, fed by the precipitation, the surface, and subsurface waters of the neighbouring hills, and the groundwater of the Danube.

The most significant watercourse of the water catchment is the Lajvér Stream with a catchment of 90 km^2 that reaches the plainland north-west of Bátaszék. The stream is not particularly abundant in water: its discharge is 0.2 m^3/s, although it can reach 14.8 m^3/s after violent summer showers, and it carries a high amount of loess sediment. Its alluvial cone is the largest in the Sárköz region, but after the stream leaves it, it occupies the former Sárvíz Channel and flows towards Báta after skirting Bátaszék in the east. Two other streams enter the plain from the hilly region: the Kövesdi and the Szentai-víz streams. Both flow into a drainage canal and then into the Lajvér Stream. The Sárköz is traversed by the Szekszárd-Báta Main Canal, once a by-channel of the Danube (Pataki 1955) that shrunk and now functions as a drainage for inland water and as an irrigation canal. It unites with the Lajvér Stream near Báta.

Similarly to other regions of the Hungarian Plain, groundwater can cause serious problems in the Sárköz region. The groundwater is fed by the region's precipitation, the water seeping to the region from the Danube and the Sió–Sárvíz rivers, and the water seeping through the loess layers down to the Pannonian aquiclude layer and then flowing eastward (Pataki 1955). The precipitation water in excess of the evaporated amount remains in the soil because the permeable alluvial layers covering the entire Sárköz region store water, and because the drainage canals have an extremely low gradient (Mayer 1997).

Precipitation is stored in various depressions, oxbows, channels, streams, and lakes, and lies at a depth of 1–2 m. The groundwater table is not uniform because, despite its apparent flatness, the Sárköz region is characterised by an immense geomorphological diversity (Pataki 1955). The region's groundwater is heavily polluted, principally owing to agricultural chemicals and the household sewage of the region's settlements.

The decline of the discharge has been documented over the past decades in the region's artesian wells tapping into artesian water owing to the large-scale and continuously increasing exploitation, reflecting the depletion and exhaustion of the pre-Pleistocene, non-renewing water table. The exploitation locations are continuously shifted closer to the Danube because drawing water from greater depths is constrained by the granite layer lying at a depth of 110 m (Mayer 1997).

In terms of its phytogeography, the Sárköz region is part of the Hungarian Plain floristic region (Eupannonicum), regionally of the Mezőföld floristic province (Colocense). The plainland-like areas of the Sárköz region are part of the forest steppe zone, while the hilly regions on its western fringes can be assigned to the deciduous forest zone.

Before the river regulations of the 19th century, there were two major plant associations in the forest steppe zone: water and floodplain associations and steppe associations. The greater part of the region is now a typical cultural landscape and the former wetlands with their rich diversity of plants and animals have retreated to the active floodplain beyond the dike (Gemenc Forest).

The following zonation of associations can be noted on the floodplain: willow scrubs *(Salicetum triandrae, Salicetum purpureae)* can be found along the Danube and the oxbow lakes, on the lowest-lying, constantly water-covered areas. The slightly higher-lying areas with seasonal water cover are dominated by poplar-dominated *(Querco-Ulmetum populetosum)* willow-poplar groves (softwood groves) *(Salicetum albae-fragilis)* and oak-elm-ash groves (hardwood groves) *(Querco-Ulmetum hungaricum)*, while the highest-lying areas are dominated by oak forests *(Convallario-Quercetum danubiale)* (Endrédi 2001). Currently, the natural vegetation has been replaced by ploughland and planted poplar forests in the plainland areas.

In terms of zoogeography, the region is part of the Great Plain (Eupannonicum) fauna region and the Pannonian (Pannonicum) fauna province. The protected species and large game stock of Gemenc Forest are of outstanding value (Marosi / Somogyi 1990).

The surface of the Sárköz region was dominated by the Danube until the close of the Early Holocene as shown by the eroded margins in the foothill region (Pécsi 1959). The warmer and wetter climate at the onset of the Holocene led to a rise in the river's water level and the river split into several branches which criss-cross the entire Sárköz region. The river's dominance in the region ceased after the river regulations in the 1880s when the larger meanders were cut off, the waterlogged marshland areas were drained, and the river was channelled between dikes. Gemenc Forest lies beyond the dike towards the Danube. Although the river mechanism is not expressly depositional in the Sárköz region, the infilling of the floodplain can nonetheless be noted because the Danube carries a minimal coarse bedload along this section, while the fine-grained suspended load originating from bank erosion is deposited on the floodplain (Pécsi 1959). The areas beyond the outer side of the dike are predominantly made up of cultivated land, despite the presence of the depressions that had once been oxbow lakes, which are filled with water during wetter periods and with meltwater in spring.

The region's eastern part known as the Kalocsa Sárköz region is part of the Danube-Tisza interfluve. The ridge rises above the Danube and Tisza Valleys by some 40–70 m. One characteristic trait of the geological structure of the Danube-Tisza interfluve is that the earlier, deeper-lying geological layers are covered by the sediments of the Quaternary alluvial fan of the Danube's palaeo-channels (Sümeghy 1944; Miháltz 1953). The

Pliocene-Pannonian layers lie on the surface on the north-western fringes of the Kiskunság Ridge (e. g. at Tétel-halom), while farther to the east, they lie much deeper as a result of tectonic subsidence. At Kalocsa, the Pannonian layers lie 80 m under the modern surface, at Nyárszentlőrinc, east of Kecskemét, they lie 237 m deep, while at Szentes, the same layers can be found at a depth of 800 m (Molnár 2015). The river load deposited by the palaeo-Danube during the Quaternary overlay these layers. The Danube flowed across the Danube-Tisza interfluve at the close of the Pleistocene and the beginning of the Quaternary; by depositing its load, the river built a traverse alluvial fan towards Szeged (Molnár 2015).

The river's discharge was probably higher during this period, and its course changed dynamically owing to the greater extent of periglacial areas and the greater summer meltwaters (Jaskó / Krolopp 1991). It is possible that the river separated into parallel branches on the alluvial fan, forming a braided channel system, with channels of differing discharge and activity. Probably evolving at the close of the Quaternary, the Kalocsa subsidence had a major impact on the Danube's course: the river's channel shifted westward, incising a new channel into its own alluvial fan conforming to the movement of the subsidence and created its currently known north-to-south course. In effect, the river slid off its own alluvial fan. The river channels on the alluvial fan during the preceding Pleistocene period were cut off from the main channel; lying at a relatively high altitude owing to the neotectonic subsidence, living water inflow was restricted to periods of flooding. The life of these north-west to south-east oriented former channels leading the Danubian floodwaters towards the lower-lying Tisza Valley did not cease after the end of the active river phase.

The sand deposited in the often several dozen kilometres long channels by the movement of aeolian sand on the dried-out alluvial fan divided the channels into several parts; lacustrine and marshland sediment formation began at the close of the Glacial in the lower-lying basins barred by aeolian sand, some of which became entirely covered (the so-called *semlyék*), in association with the changing groundwater table. These fragmented channels can still be clearly made out on the digital elevation model of the Danube-Tisza interfluve, despite the later aeolian sand movements principally caused by human activities and the evolution of the Holocene sand cover that concealed the original fluvial formations. Marshland, bog, and lacustrine sediment formation began in the lower-lying sediment catchment basins, depending on the height of the groundwater table and the phytomass coverage. Given that the height of the groundwater table depended on the Danube's discharge and local precipitation, the freshwaters in the Danube-Tisza interfluve were shaped by the effect of natural elements until the river regulations.

Research history

New evidence has been published on the dense settlement pattern of the Early Neolithic Körös groups on the eastern, left side of the Danube, on the Great Hungarian Plain covered with forest steppe (Bánffy 2012; 2013a; 2013b; Bánffy et al. 2014; Kustár 2013).

This region played an important role in the Early Neolithic, as well as in the later phases of the Neolithic as shown by the earliest archaeological assemblages of the Middle Neolithic commencing from the later 6th millennium cal BC (Bánffy et al. 2007a; 2007b; 2014; Bánffy 2009; 2012; Bánffy / Oross 2010; Bánffy / Sümegi 2012). The westernmost Neolithic tell settlement in Europe, Fajsz-Kovácshalom, featuring Late Neolithic layers and finds (Bánffy 2003; 2012; Rassmann et al. 2015a; 2015b), and the similarly stratified Fajsz-Garadomb site in its neighbourhood on the left (eastern) Danube bank, as well as several large sites of the Late Neolithic Lengyel culture on the right (western, Transdanubian) bank (Osztás et al. 2012), are all of key importance. Although these sites are located farther, at a distance of some 12–15 km from the sampling locations at Hajós and Császártöltés, a number of Middle and Late Neolithic archaeological finds were brought to light 1–2 km from the sampling location (Knipl / Sümegi 2012). Thus, we have obtained data on local archaeological and environmental circumstances as well as on Middle and Late Neolithic populations and their natural milieu that can be interpreted on a regional scale in order to explain the natural environment of the archaeological sites such as Fajsz-Garadomb and Fajsz-Kovácshalom investigated in the broader area. Regarding the Great Hungarian Plain, several environmental archaeological profiles have been created and analysed (radiocarbon, sedimentology, geochemistry, macrobotany, pollen, malacology) as part of collaborative projects between the Quaternary Palaeoenvironmental and Geoarchaeological Research Group of the Department of Geology and Palaeontology of the University of Szeged and the Institute of Archaeology of the Research Centre for the Humanities of the Hungarian Academy of Sciences. Some of the investigated areas lie in infilled marshy river basins located in the Körös distribution in the southern part of the Danube-Tisza interfluve (Császártöltés, Hajós, and Kecel: cf. Jakab et al. 2004a; 2004b; 2014; Sümegi et al. 2011b; 2015a; Jakab / Sümegi 2015; Törőcsik et al. 2015).

Although these earlier studies shed light on the vegetation development of the sites and provided information about the human impact on the vegetation, their

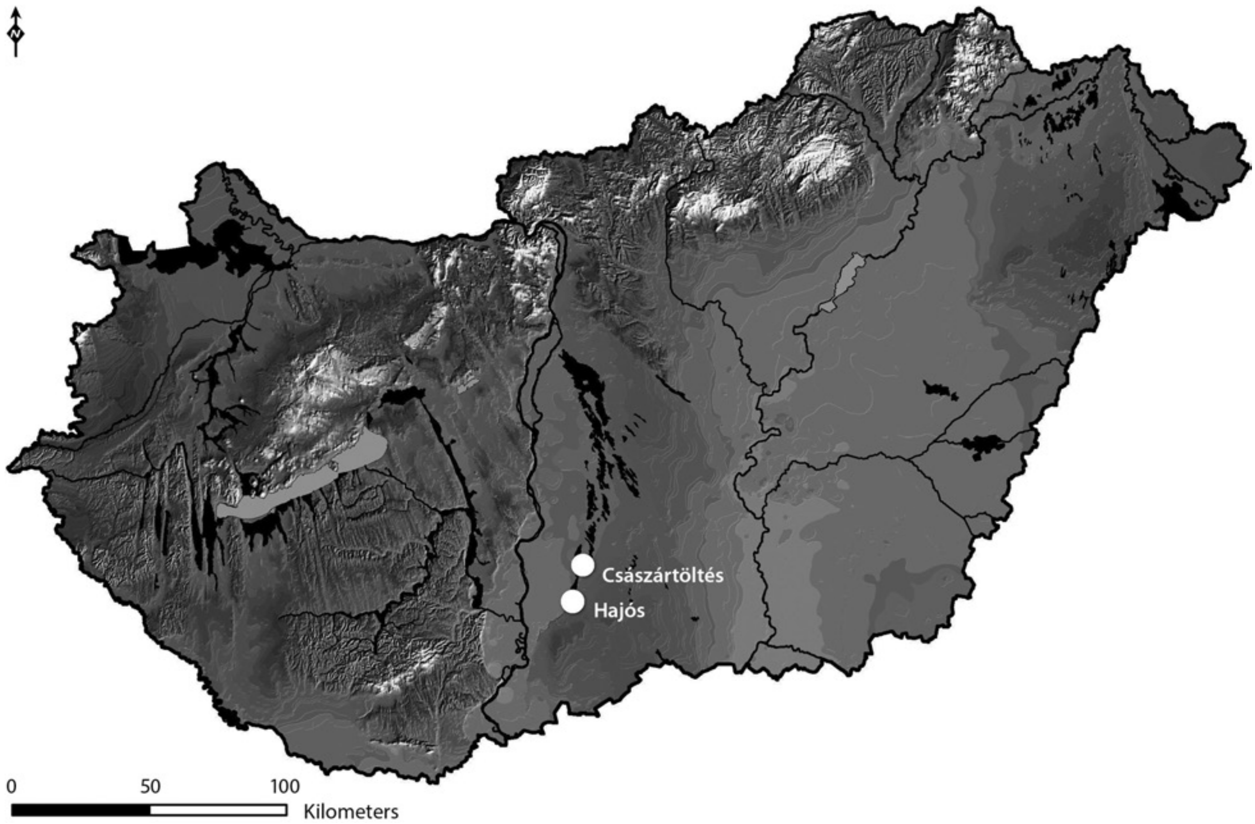

Fig. 3. The location of the Hajós and Császártöltés sites within sedge / reed peatlands (black colour) in the Carpathian Basin.

main focus was not the study of human-environment interaction but the development of bogs and bog vegetation. There were major differences between pollen and macrobotanical data, the depth of the profile (Jakab et al. 2004a; 2004b), and the original description of the core (Sümegi 2003a). It would appear that the interpretation of the sedimentological profile was erroneous on some points (Jakab et al. 2004a; 2004b) and an additional problem was that the geological information was not presented together with the pollen data, meaning that it was impossible to correlate sedimentological changes with individual pollen phases and with changes in the pollen compositions. In other words, the question of whether former vegetation changes should be ascribed to the transformation of the depositional environment or to human impact remained unanswered.

The most important problem regarding the identification of anthropogenic impacts can be ascribed to the sampling technique: the 4–8 cm intervals taken for the pollen analysis (Jakab et al. 2004a; 2004b). Radiocarbon data taken for such long intervals correspond to a 200–500-year span per pollen sample. This resolution is too large for palaeoenvironmental studies, particularly regarding the Neolithic (Magyari et al. 2010a; 2010b; 2012; Chapman et al. 2010). Specifically, the several hundred years long resolution does not enable a differentiation in the environmental background of particular Neolithic cultures (Magyari et al. 2010a; 2010b; 2012; Chapman et al. 2009; 2010).

A further problem was caused by the low number of pollen grains in the profiles for several periods, including the Pleistocene-Holocene transition, and thus a statistical evaluation was not possible (Jakab et al. 2004a; 2004b). Today, the statistically evaluable number of pollen grains within one sample is 500 (Chapman et al. 2009; 2010; Magyari et al. 2010a; 2010b; 2014), compared to the previous 300 terrestrial pollen grains in 2004 (Maher 1972; Magyari et al. 2001; Magyari 2002).

Being aware of the problems of earlier pollen and lithological analyses (Jakab et al. 2004a; 2004b), we undertook a new palaeoenvironmental analysis and examined the full length of the profile, with a pollen analysis and radiocarbon dating at a much finer resolution. In the course of this new analysis, we doubled the sediment volume and were thus able to present a statistically evaluable pollen material.

Our case study offers the first results of new macrobotanical, pollen analytical, and malacological analysis from the end of the Pleistocene throughout the Holocene in the southern part of the Danube-Tisza interfluve. One of our goals was a full environmental reconstruction

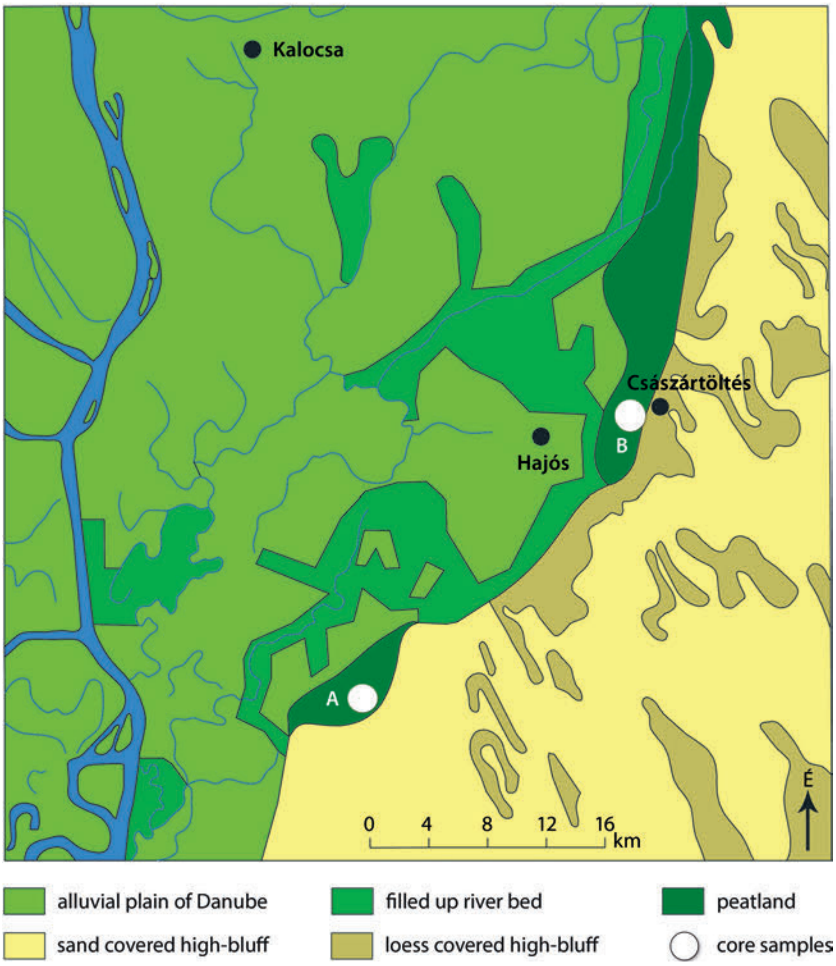

Fig. 4. The location of the peatland the sites at Hajós and Császártöltés in the Danube-Tisza interfluve (DTM). A: location of the analysed core samples from Kaszálók Mire at Hajós; B: location of the analysed core sample from Vörös marshland at Császártöltés; black circle modern town / village.

from the Upper Palaeolithic to the close of the Medieval period, with a special focus on the environmental background of the late Mesolithic and the Neolithic, the period spanning the 7th–5th millennia cal BC.

The identification of human impacts in long-term pollen sequences is one of the basic aims of this paper in order to determine the relative importance of local anthropogenic and environmental factors in accounting for major phases of climatic, environmental, and socio-cultural changes.

Although the relationship between a particular population and the local environment is extremely intricate and environmental impacts can take a diverse range of forms, human and environmental relations can be traced through the radiocarbon, palynological, and macrobotanical analysis of the profiles (Jakab / Sümegi 2004; 2011; Jakab et al. 2004a; 2004b) and pollen analysis (Behre 1981; Willis et al. 1995; 1998; Berglund 2003; Willis 2007).

The second main goal of this article was to test the model proposed by Willis / Bennett (1994) on the spread of farming, based on pollen analysis, in the most important area of Neolithisation, namely the Sárköz region in the southern Hungarian Danube Valley. In southern Hungary, the earliest Neolithic finds can be assigned to the onset of the 6th millennium cal BC.

We also wanted to test models of the steppean environment on the Great Hungarian Plain that emerged over the past 3000 years according to some studies (Chapman 2008; Magyari et al. 2010a). As we have already pointed out (Sümegi et al. 2011a; 2011b), wholly different processes of human colonisation and food production can be identified in some lowland areas, implying that the development of the vegetation was hardly uniform across the vast lowland area (Sümegi 2004a; 2004b). River valleys, loess- and sand-covered surfaces, and sodic areas cannot be treated as homogeneous, and neither can the human impact on these areas (Zolitschka et al.

2003; Sümegi 2004a). These lowland areas vary both in terms of their regional and micro-regional environment and are made up of different vegetation mosaics (Sümegi 1989; 1995; 1996) that were affected by human impacts at different times, and human activities themselves varied considerably, depending on environmental conditions and social development (Sümegi 2003b; 2004b; 2008).

The study areas

On the Great Hungarian Plain and in the adjacent Danube-Tisza interfluve, fluvial sedimentation began around the beginning of the Quaternary. As a result of fluvial activity, a 200–300 m, maximum 700 m thick Quaternary sediment sequence accumulated in its deepest parts. The rivers entering the Great Hungarian Plain built extensive alluvial fans in the Quaternary (Sümeghy 1944), and the lowland behind the alluvial fans was dissected by countless rivers and streams in the subsidences on the surface. The Solt-Baja alluvial plain, the study area, is the lowland between the Danube and the Tisza that is made up of two Late Quaternary neotectonic catchment sub-basins (Jaskó / Krolopp 1991; Scheuer et al. 1992). In terms of evolution, the interfluve, the western part of the Great Hungarian Plain, is one of the most intriguing regions in Hungary, where relief conditions and the river network underwent a dramatic transformation during the Upper Pleistocene. The watercourses arriving from the northern Carpathians and the Alps all played a role in the evolution of this alluvial fan plain. During the first phase of the Quaternary, the Danube and its tributaries flowed across the alluvial fan of the Solt-Baja Plain. During the Weichselian glaciation, the intensity of the subsidence process increased substantially and, as a result, an entirely new network of watercourses developed, which, in the course of their erosion and deposition, transformed the subsiding area into a floodplain. This subsidence was, for a time, counterbalanced by the aggradational work of the river. Thus, rivers often changed their course on this plain (Sümeghy 1944; Pécsi 1959).

The first study site is located on the eastern edge of the Sárköz region, near the village of Hajós, and is a former basin of the Danube, a classic oxbow lake bed in the eastern part of the Danubian alluvial plain, as is the second study site, a former river bed at Császártöltés *(Figs 3–4)*. The development of the Danube alluvium was modelled by geological mapping and core profiles created on high river banks (Sümeghy 1944; 1953; 1955; Miháltz 1953; Molnár 2015; *Fig. 5*).

On the basis of the geological record, about 35 000–40 000 years ago the Danube flowing across the Danube-Tisza interfluve shifted westwards as a result of neotectonic movement and incised itself into its own alluvium (Sümeghy 1944; 1953; 1955; Miháltz 1953; Molnár 2015; Sümegi et al. 2015a), thereby creating a deeper-lying and broader alluvium. Its eastern edge, covered by loess and sand, became a dry, higher river bank. The former river beds at Hajós and Császártöltés lie in the transition zone between two regions, characterised by different environmental conditions. These former river beds in the Danubian alluvial fan are located in an environment characterised by a high groundwater level, while few metres farther from the river bed we find a dry surface with a groundwater level lying deeper than 5–10 m. Hydromorphic soils can be found in the vicinity of river beds (IUSS Working Group 1998; 2006: fluvisols), while the cultivated dry surfaces led to the formation of black earth soils (Stefanovits et al. 1999: chernozems, andosols).

The vegetation of the high bluff reflects strong human impacts and the same holds true of the alluvial fan, although disturbed hardwood and softwood gallery forest could be identified too. While the two cores indicated a highly similar environment, the geomorphological characteristics differ. The Hajós location is an oxbow lake that evolved from a river meander; the former river bed at Császártöltés is a several kilometres long oxbow lake. The two sites have a differing sediment accumulation, and their biological development differed since their water supply and their relationship with the active river bed diverged. Diverse flows developed in the two types of oxbow lakes that determined pollen accumulation.

A classic, horseshoe-shaped oxbow lake evolved at Hajós that only became connected to the living aquatic system during major floods and functioned as a lake during periods between floods. The spring issuing at the foot of the high bluff on the lakeshore played a very important role in water level stabilisation between floods. At Hajós, a 4–6 m high river bank rose towards the oxbow lake, and thus the local environmental and vegetation elements of the high bluff differ from the immediate vicinity of the oxbow lake, an important factor regarding pollen accumulation.

In contrast, the oxbow lake at Császártöltés was cut off due to neotectonic movements (Jaskó / Krolopp 1991) as the Danube shifted its channel westward and became a several kilometres long transitional channel (Butzer 1971; Rosgen 1994; Vandenberghe 2002; Schumm 2005; Church 2006). This north to south oriented, few hundred metres wide channel still had contact with living water through the groundwater system, even if for a very short period only. North to south continuous flows evolved in the long former river bed and, as a result, its pollen composition was homogenised. There is also a high bluff along the oxbow lake of Császártöltés, although not in the immediate vicinity

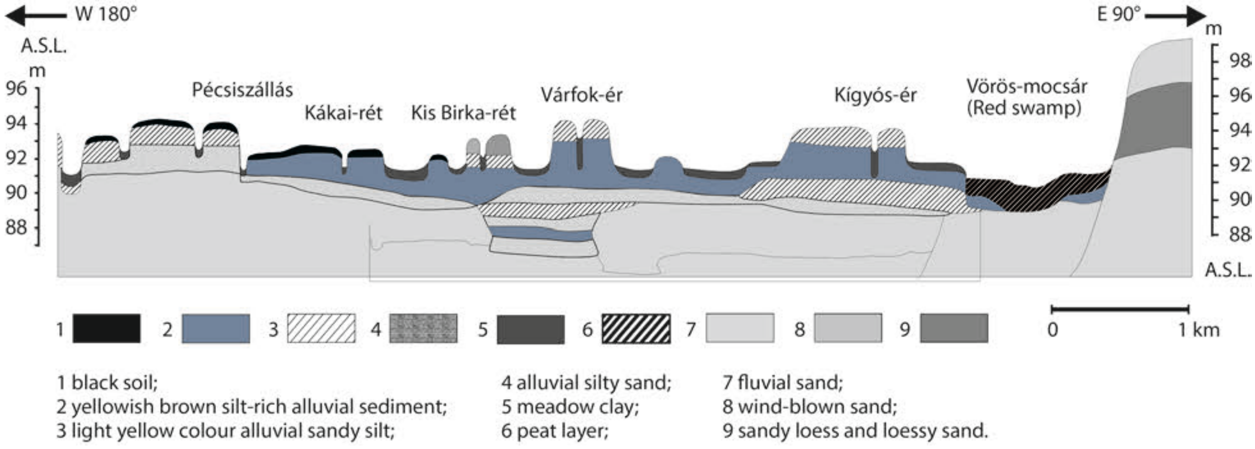

Fig. 5. East-West cross-section of the Danube alluvial plain between Vörös-mocsár (Red Marsh) and Transdanubia (Pécsiszállás village).

as there is a 100 m wide zone between them, where the high bluff did not act as a sharp environmental border as at the Hajós site.

The Danube-Tisza interfluve lies in the warm temperate zone. It is characterised by January mean temperatures higher than -2 ºC and the duration of the winter is only three months. The region's climate is semiarid and dominated by a sub-Mediterranean rather than a cool continental climate influence. The region is poor in precipitation. The total annual precipitation over most of the region varies between 500 and 600 mm (Borhidi 1961; 1993).

The natural vegetation of the sand dunes and loess-covered high bluff was *Junipero-Populetum* scrub and sandy grasslands, made up of *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, the area's greater part is a cultural landscape with ploughlands and vineyards, and only some patches of natural vegetation. Somewhat north of the Sárköz region, the Solt Plain was an extensive peatland with patches of *Fraxino pannonicae-Alnetum* forests (Tóth 1979; 1996; Pócs 1991; Borhidi 2003; Rakonczay 2001).

Methods

Field sampling

Four undisturbed peat cores were retrieved using a 5 cm diameter Russian corer (Aaby / Diegerfeld 1986) at the Hajós–Kaszálók site *(Fig. 6)*. The boreholes were placed along a geological transect. The Hajós–Kaszálók I core was extracted from the deepest part of the basin and was used for pollen, plant macrofossil, malacological, and radiocarbon analyses. Two cores were retrieved at the Császártöltés location and we present the most complete profile *(Fig. 7)*. The detailed sedimentological description of the peat cores follows the system elaborated by Troels-Smith (1955), while the colours of sediment layers are specified according to the Munsell Soil Color Charts (Munsell Colour 1990).

Radiocarbon dating

AMS and mass bulk ^{14}C dating was performed in the Light Isotope Laboratory of the Nuclear Research Center of the Hungarian Academy of Sciences in Debrecen and in the Radiocarbon Lab at Gliwicze (Poland) on 16 samples from plants and one mussel shell from the Hajós–Kaszálók I and Császártöltés–Vörös-mocsár cores (*Figs 8–11*; cf. *Tabs 3–4* below). The preparation of the samples and the actual procedure of the measurement followed Hertelendi et al. (1989; 1992).

Sedimentology and geochemistry

The sediment analyses revealed considerable quantities of layered organic matter, carbonate concretions, and small ferrous concretions (*Figs 8–9*; cf. *Tabs 1–2* below). The organic content of the core samples was estimated by loss-on-ignition at 550 °C for five hours and the carbonate content by the further loss-on-ignition at 900 °C for five hours (Dean 1974). Based on Dean (1974), organic content change indicates the ancient trophic state of the oxbow lake.

A new, so-called sequential extraction method (Dániel 2004) with a long-established history in the analysis of the geochemical composition of lacustrine

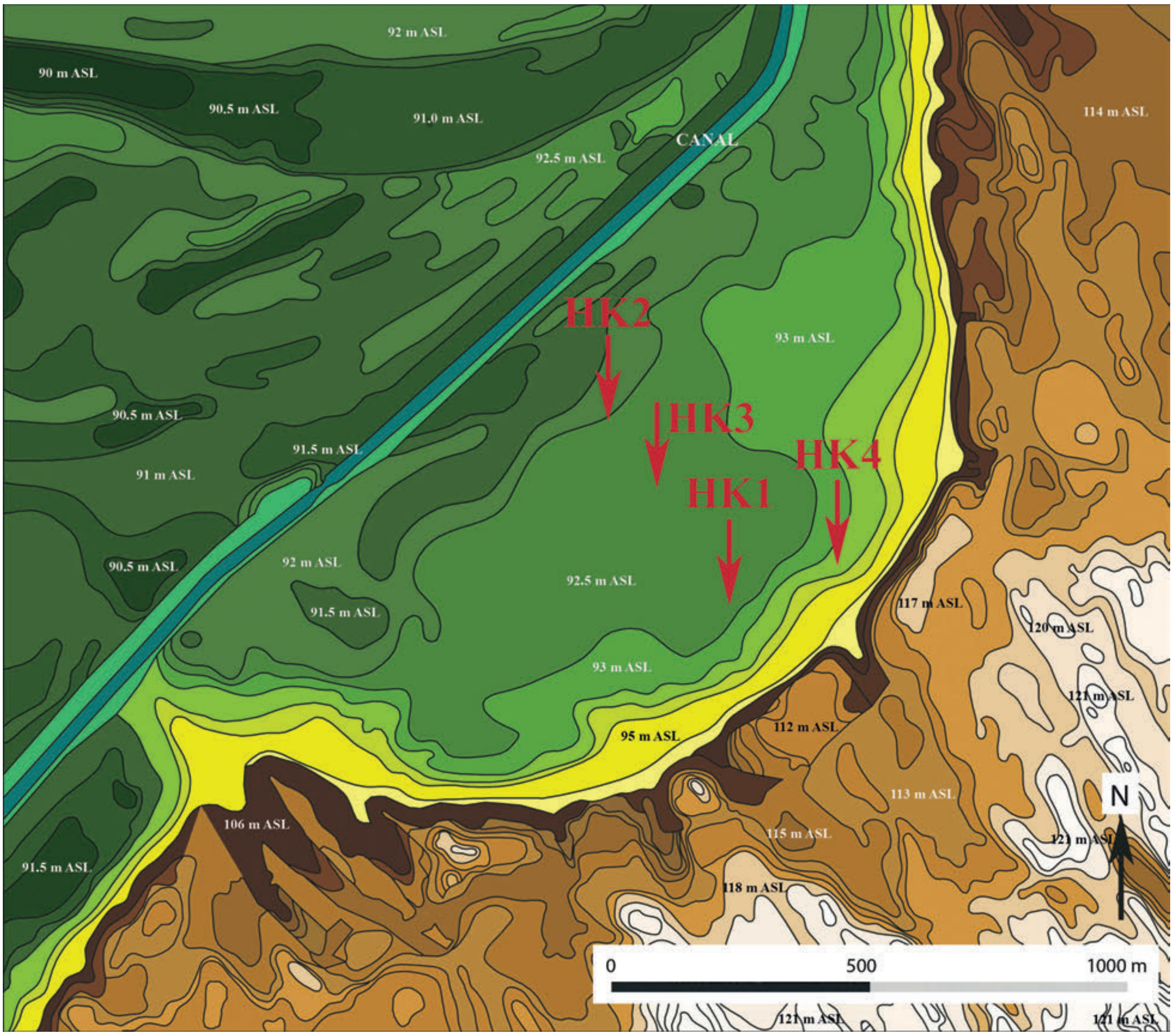

Fig. 6. Location of the undisturbed core points on the Kaszálók Mire at Hajós (DTM).

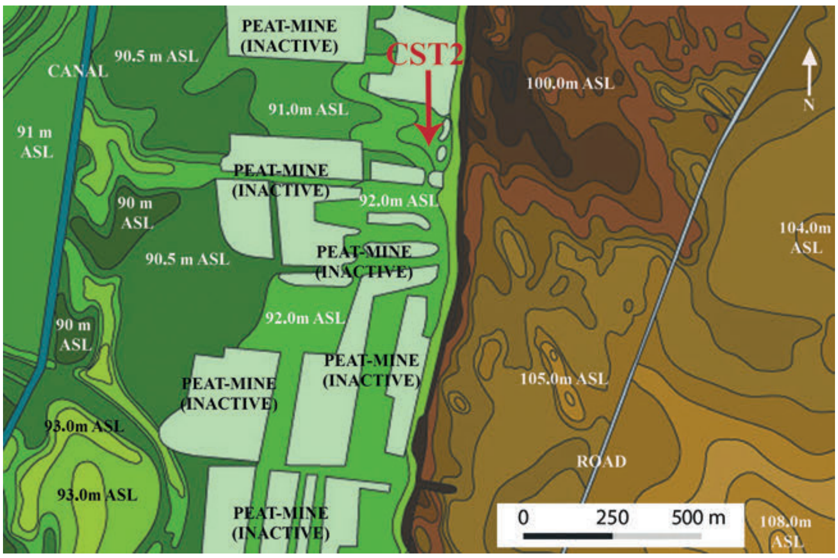

Fig. 7. Location of the undisturbed core point on the Vörös-mocsár (Red Marsh) at Császártöltés.

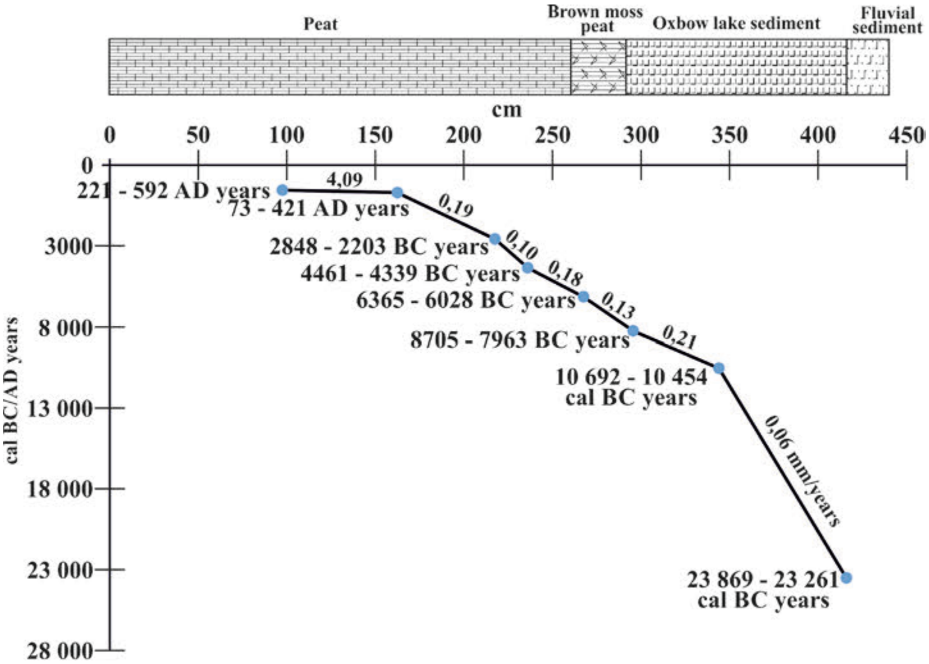

Fig. 8. The sedimentation rate changes based on calibrated radiocarbon ages from the undisturbed core sequence at Hajós *(Fig. 6)*.

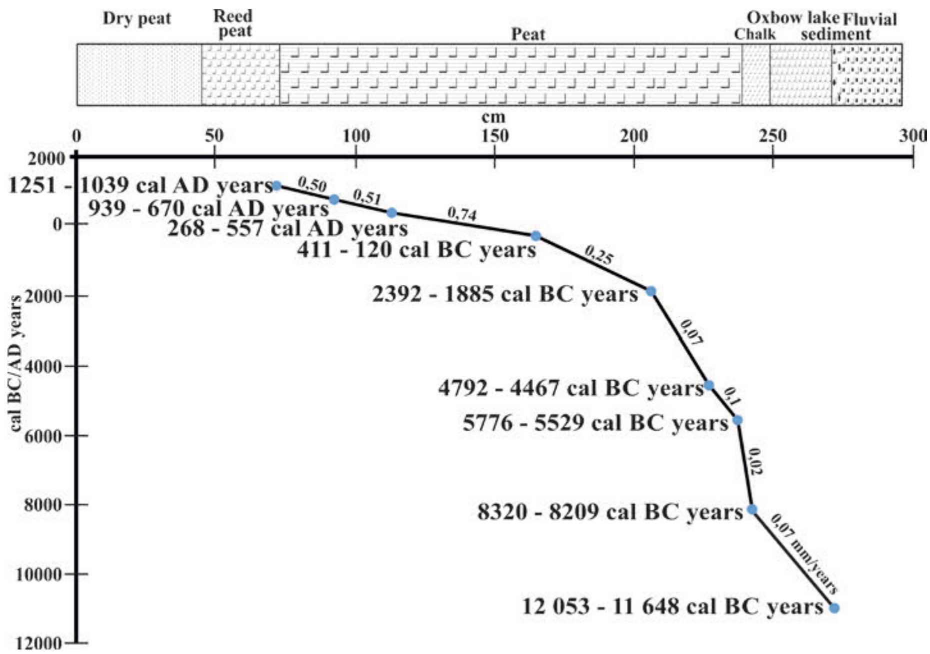

Fig. 9. The sedimentation rate changes based on calibrated radiocarbon ages from the undisturbed core sequence at Császártöltés *(Fig. 7)*.

sediments was adopted in this study. Earlier experience indicated that of the full procedure, the water extraction phase for unseparated samples was sufficient for our analytical needs (Dániel 2004; Sümegi et al. 2013a), since the most important palaeohydrological and palaeoecological data are yielded by water extraction samples.

The geochemical results from water extraction samples will follow the widely used and accepted methods. The results of the geochemical analyses are plotted against depth. Distilled water was purified using a Millipore 5 Plus Water Purification System for water extraction samples. 100 ml distilled and purified water was added to a 1.0 g sample and was shaken for one hour and then the water extract elements of Na, K, Ca, Mg, Fe were analysed using a Perkin-Elmer AAS spectrometer (Dániel 2004). Statistical procedures were used to zone the data. Principal component analyses computed on correlation matrices were performed after the logarithmic transformation of the geochemical data (Rollinson 1993). The sedimentological and geochemical zones were identified by cluster analysis of principal components with the squared Euclidean distance and Ward aggregation method (Dowdeswell 1982).

Pollen

The retrieved cores were also subsampled at 1–2–4 cm intervals for pollen analysis. A volumetric sampler was used to obtain 2 cm^3 samples, which were then processed for pollen recovery (Berglund / Ralska-Jasiewiczowa 1986). We used double and quadruple sediment volumes in the case of samples where a low number of pollen was found previously for the statistical analysis, and thus obtained statistically evaluable pollen material (Jakab et al. 2004a; 2004b).

Lycopodium spore tablets of known volume were added to each sample to determine pollen concentrations. A known quantity of exotic pollen was added to each sample in order to determine the concentration of the identified pollen grains (Stockmarr 1971).

A minimum count of 500 grains per sample (excluding exotics) was made in order to ensure a statistically significant sample size (Punt et al. 1976–1995; Fægri / Iversen 1989; Moore et al. 1991). Micro-charcoal (fly ash) abundances were determined using the point count method (Clark 1982). Tablets with a known *Lycopodium* spore content (supplied by Lund University, Sweden) were added to each sample to enable the calculation of pollen concentrations and accumulation rates. The pollen types were identified and modified according to Moore et al. (1991), Beug (2004) and Punt et al. (2007), Kozáková / Pokorny (2007), supplemented by the examination of photographs in Reille (1992; 1995; 1998) and the reference material in the Hungarian Geological Institute in Budapest.

Percentages of terrestrial pollen taxa, excluding Cyperaceae, were calculated using the sum of all those taxa. Percentages of Cyperaceae, aquatics, and pteridophyte spores were calculated relative to the main sum plus the relevant sum for each taxon or taxon group. Calculations, numerical analyses, and graphing of pollen diagrams were performed using the Psimpoll 4.26 software package (Bennett 2005). Local pollen assemblage zones (LPAZs) were defined using the optimal splitting of information content (Birks / Gordon 1985), while zonation was performed using the terrestrial pollen taxa that reached at least 5 % in at least one sample.

Various models and empirical studies (Sugita 1994; Soepboer et al. 2007) indicate that in the case of an oxbow lake with a diameter of 50–200 m, the correlation between pollen abundances and vegetation composition is not improved by considering vegetation lying farther than 400–600 m from the lake. The regionally "uniform" background pollen component, representing vegetation between 600 m and tens of kilometres from the lake, accounts for c. 45 % of the total pollen (Soepboer et al. 2007). The pollen data from the oxbow lakes at Hajós and Császártöltés thus provide an integrated palaeovegetation record for the landscape around the lake and the surrounding region, with a dominance of pollen from extra-local and regional sources (Jacobson / Bradshaw 1981).

Nevertheless, in the light of pollen taphonomical studies on sedimentary sequences of North American oxbow lakes (Fall 1987; Hall 1989), it must be borne in mind that catchment basins found on floodplains experiencing recurrent floods receive large quantities of so-called "intrusive" pollen originating from distant areas on the watershed, which largely distorts the final pollen spectrum. Consequently, these palaeochannels are far from ideal pollen traps. The degree of this type of "contamination" is largely dependent on the height of the floodwaters and the expansion and vegetation of the watershed, biasing any reconstruction of local and regional vegetations. This holds true for all the alluvial areas of the Great Hungarian Plain as well, and thus all earlier pollen analyses (e. g. Sümegi / Bodor 2000; Magyari et al. 2010a; 2010b; 2012; Nádor et al. 2011) that were based on various oxbow lake profiles of alluvia must be treated with caution in view of these pollen taphonomical, accumulation, and preservation problems.

The biomisation procedure translates pollen and plant macrofossil spectra into biome assignments. It is an objective method based on assigning taxa to one or more plant functional types (PFTs). The concept and the different steps of this method are fully described in Prentice et al. (1996) and Prentice / Webb (1998).

The palaeovegetation was reconstructed using the works of Sugita (1994), Soepboer et al. (2007), Jacobson / Bradshaw (1981), Prentice (1985), and Magyari et al. (2010a; 2010b). The different vegetation types, indicator elements, and weed types were separated according to Allen et al. (2000), Behre (1981; 1986), Tarasov et al. (1998; 2000), Magyari et al. (2010a; 2010b), Prentice et al. (1996), and Prentice / Webb (1998). We distinguished the species of the warm steppe, cold steppe, cold-mixed forest steppe, cold mixed forest, temperate deciduous forest, and deciduous forest steppe. Based on the works of Beug (2004), Kozáková /

Pokorný (2007), Magyari et al. (2010a), Prentice et al. (1996), Prentice / Webb (1998), Allen et al. (2000), we identified the following steppe indicator pollen taxa in the core sequence of the analysed palaeochannels: *Ajuga*, *Allium*, *Artemisia*, Aster type, *Astragalus*, Caryophyllaceae undiff., Chenopodiaceae (including *Atriplex*, *Kochia*), Compositae, subfamily Cichorioideae, Dianthus type, *Euphorbia*, Gramineae, *Helianthemum*, *Inula*, Matricaria pollen type (including *Achillea*, *Anthemis*, *Matricaria*), *Plantago lanceolata*, *Plantago major / P. media*, *Thalictrum*, *Trifolium pratense* type, *Trifolium repens* type, and *Verbascum*.

We followed Behre (1981; 1988) regarding human impact since these works also take into account the appearance of weeds that spread as a result of human activities (Jones 1992). Papers covering Hungarian vegetation and weed analysis (Újvárosi 1957; Fekete et al. 1987; Magyari et al. 2012) did not adopt archaeobotanical analysis from different archaeological excavations (Holzner 1978; Behre 1981; 1986; 1988; 1993; 1999; Küster 1984; Behre / Jacomet 1991; Kreuz / Schäfer 2011; Gyulai 2010). However, any reconstruction without consideration of the human impact is essentially meaningless.

Pollen data reflecting the plant cultivation practices of different prehistoric population groups should be considered as prior hypothetic data. Archaeobotanical data from archaeological sites constitute the main body of evidence regarding plant cultivation and farming activities (Behre 2007; 2008). The possible contradictions between pollen and archaeobotanical data (Willis 2007; Bogaard et al. 2007; Behre 2008) can only be resolved by the archaeobotanical analysis of archaeological sites (Jacomet 2013). Although major advances have been made in the identification of pollen, especially of cultivated plants and weeds, since the work of Firbas (1937), the identification of cultivated plants in the pollen record still poses some difficulties (Beug 1961; 2004; Andersen 1979; Dickson 1988) compared to botanical remains, especially those of seeds and fruit.

The difficulties of identification hold true for weed pollen as well (Magyari 2011), causing serious headaches in interpretation. Namely, some weeds (such as *Plantago lanceolata*) that spread due to human impact are native to Central Europe and the Carpathian Basin, and thus the presence of these weed species is not necessarily an indication of human impact (Behre 1988; 2007; 2008). A further problem is represented by long-distance transport (Gregory 1978; Hjelmroos 1991; Behre 2007; 2008) that often affects oxbow lake systems, especially in alluvia bordered by high bluffs. In addition to wind-transported pollen material, the accumulation of river-transported pollen grains from the river catchment area is also significant (Fall 1987; Sümegi et al. 1999; Sümegi / Bodor 2000). Therefore, previously deposited, washed out, and redeposited pollen material in Holocene layers needs also to be taken into account (Sümegi / Bodor 2000). Consequently, oxbow lakes located in active alluvial regions are not ideal sites for pollen analysis (Birks / Birks 1980; Fall 1987). From an archaeological point of view, a reconstruction of vegetation history with a consideration of human impacts involves several difficulties (Sümegi / Bodor 2000).

The above caveats have not been highlighted in recent studies on vegetation history and human impact on the Great Hungarian Plain (Magyari et al. 2008; 2010a; 2010b; 2012; Magyari 2011), even though the problematic nature of the sampling locations was pointed out in earlier studies (Sümegi et al. 1999; 2005; 2006; 2012a; 2013a; Sümegi / Bodor 2000; Jakab et al. 2004a; 2004b; Bodor et al. 2008; Salisbury et al. 2013). Given that mostly oxbow lakes and lakes that evolved between dunes on alluvial fans are available for pollen studies on the Great Hungarian Plain (Willis et al. 1995; Sümegi et al. 2011b; 2011c; 2015a; 2015b), the above caveats must be considered when assuming possible local human impacts in the interpretation of pollen samples taken from the oxbow lakes at Császártöltés and Hajós in the Sárköz region.

Macrobotanical analyses

For the description of macrofossils, we used a modified version of the QLCMA technique (Barber et al. 1994; Jakab et al. 2004a; 2004b; Jakab / Sümegi 2004; 2011). Organic remains from peat and lacustrine sediments can be divided into two major groups. Some remains can be identified with lower ranking taxa (specific peat components), while others cannot be identified using this approach (non-specific peat components). The most important non-specific peat components are the following:

- unidentified organic material (UOM): irregularly shaped tissue fragments, often moderately decomposed;
- undifferentiated monocotyledon remains (Monocot. undiff.): opaque or slightly pigmented rhizomes and epidermal tissue fragments, with elongated or short cells;
- unidentified bryophyte fragments (UBF): only the tubular, brown pigmented "stem" survives in decomposed peat with the stub of the "leaf veins";
- unidentifiable leaf fragments (ULF): moderately humified deciduous tree leaf fragments that are easily recognisable by the remains of web-like veins;
- charcoal: 1–3 mm large charcoal fragments (macro-charcoal), probably of allochthonous origin;

– wood: lignified plant tissues can be easily recognised from their compact, thick-walled wood fibres.

The most important specific peat components are seeds, fruit remains, sporogons, mosses, rhizomes and epidermis remains (e. g. *Carex* species), leaf epidermis, other tissues and organs (hairs, tracheids, etc.), insect remains, and Ostracoda shells. The identification of non-arboreal plant tissues was based on the procedure described by Jakab / Sümegi (2004; 2011). The amount of peat components was defined at the 1 cm^3 level and the amount of seeds at the 3 cm^3 level. The samples were washed through a sieve with a 300 µm mesh size. Concentration levels were determined by adding a known amount of indicator grains (0.5 g poppy seed, c. 960 pieces) and by counting the poppy seeds and the remains using a stereo microscope in ten 10 mm by 10 mm quadrates in a Petri dish. Similarly to mosses, rhizomes can only be identified under a light microscope. A hundred monocotyledon remains were removed and mounted in water on microscopic slides to determine the percentages of individual taxa and of undifferentiated monocotyledon. The values for different moss species and UBF were determined using a similar procedure. The concentration can be described with the following equation: macrofossil concentration = counted macrofossil (average) x 960 (total poppy seeds / counted poppy seeds (average) x sample volume (cm^3)

The Psimpoll programme was used to plot the analytical results of the macrobotanical analyses (Bennett 1992; Podani 1993).

Malacological analyses

Mollusc shells were collected from 2 to 4 cm thick sub-samples taken at regular intervals throughout the core. The aquatic malacofauna was divided into three groups following the palaeoecological classifications of Boycott (1934), Sparks (1961), Ložek (1964), and Krolopp / Sümegi (1995):

– moving-water habitat preferring species (rheophilous species);
– species demanding steady water inundation (ditch group);
– species tolerant to periodic water supply (slum group).

The terrestrial fauna was grouped as follows: water bank (hygrophilous), mesophilous, xerophilous, cold-resistant, intermediate, thermophilous, open habitat preferring, ecotone habitat preferring, and woodland habitat preferring species (Sümegi / Krolopp 2002; Sümegi 2005a).

The malacological record was also classified according to the recent geographical distribution of the species (Soós 1943; Evans 1972; Krolopp 1983; Kerney et al. 1983; Horsák et al. 2013; Alexandrowicz 2004; Welter-Schultes 2012) and on the basis of palaeoclimatological indicator roles (Sümegi / Krolopp 2002; Sümegi 2005a; Sümegi et al. 2013a).

Statistical methods were used for the zonation of the data. Principal components analysis computed on correlation matrices was performed following the arcsine transformation (Zar 1990) of the malacological data. Correspondence analysis was used for mollusc-based palaeoecological reconstructions.

The dominance values of certain mollusc species and those of the given palaeoecological groups are of crucial importance regarding the reconstruction of the dominant environmental factors. Dominance values are based on the calculation of percentages from the specimen numbers of species collected from the sample (Sparks 1961; Ložek 1964; Krolopp 1973; 1983).

Results

Core analysis

Hajós–Kaszálók

We extracted four undisturbed cores along a geological section and processed the longest core that was taken at the deepest point beneath the high bluff (cf. *Figs 4–6*). The cores indicated that lacustrine sediment had accumulated to a substantial thickness in the middle of the oxbow lake, while it narrowed and peat layers developed due to biogene infilling at its edge. In classic oxbow lakes the location of coring determines the environmental and palaeoecological results. Thus, in the case of horseshoe-shaped oxbow lakes, a coring technique along a transect is necessary. If a morphological and sedimentological analysis is lacking, the nature of the pollen trap of oxbow lakes is not interpretable (Sümegi et al. 1999; 2006; 2013a) owing to alluvial pollen accumulation (Fall 1987).

Császártöltés–Vörös-mocsár

As a result of peat mining in the area for over a hundred years (Molnár 2015), there are few locations with undisturbed peat layers. We found two locations where we could explore the bedrock of the river basin and the accumulated undisturbed sediment sequence, including peat layers. The undisturbed cores (cf. *Figs 4–5; 7*) were extracted along a several kilometres long transitional channel.

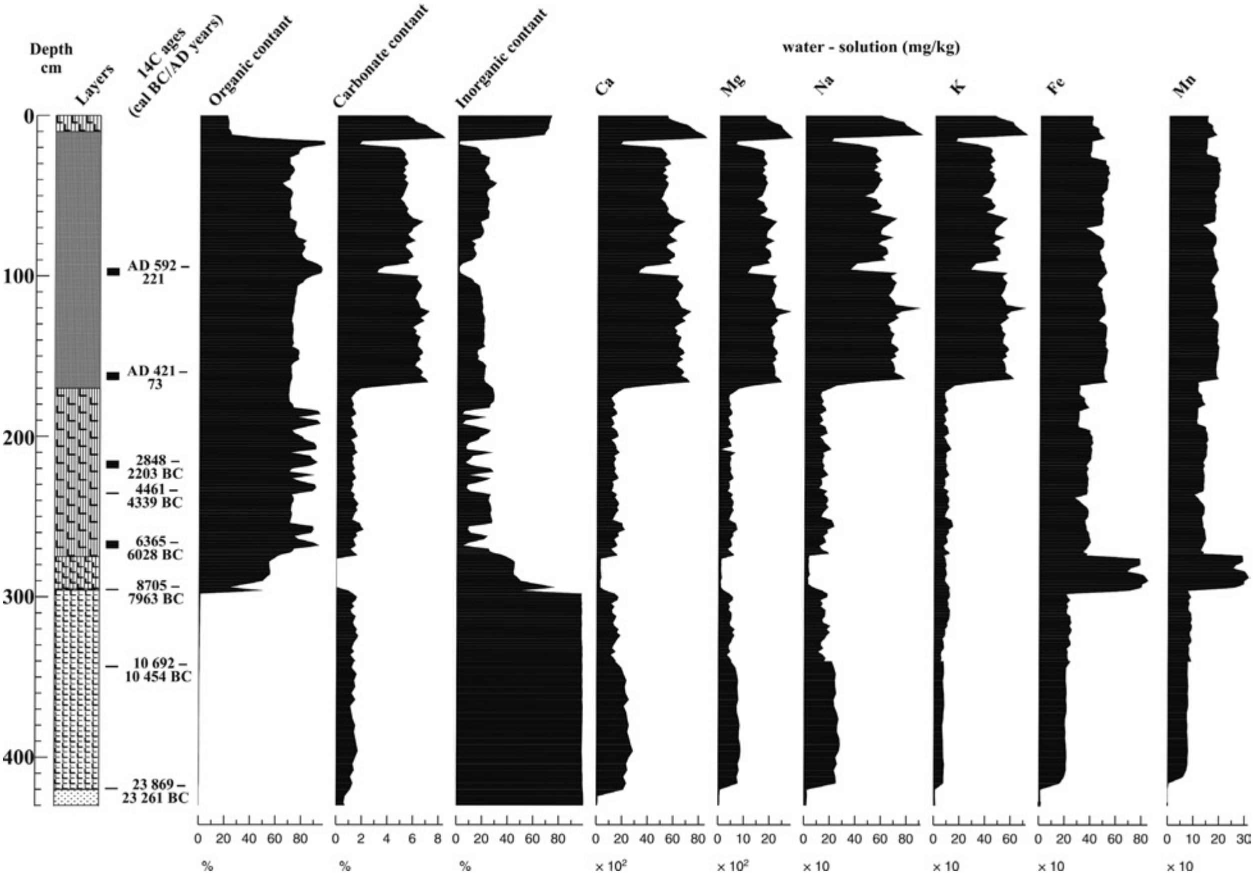

Fig. 10. Sediment and lithological changes in the undisturbed core sequence from Kaszálók Mire at Hajós.

Depth (cm)	Troels-Smith code	Sediment type	Sediment genetic	Stratigraphy	Archaeological period
0–10	Th2As2	hydromorphic soil	soil process	Sub-Boreal	Modern Age
10–170	Th4	sedge peat	peatland	Sub-Boreal	Late Roman, Early Middle Ages High Middle Ages
170–275	Th3As1	reed peat	peatland	Atlantic / Sub-Boreal	Neolithic to Late Roman
275–295	Th2As2	brown moss peat	brown moss	Pre-Boreal / Boreal	Mesolithic
295–296	Th1As3	brown moss peat	brown moss	Pre-Boreal	Early Mesolithic
296–420	Ag2As2	lake sediment	oxbow lake	MIS2 and Lake Glacial	Upper Palaeolithic
420–430	Ga4	fluvial sand	river bed	MIS3 / MIS2 transition	Upper Palaeolithic

Tab. 1. Sediment types, ages, and stratigraphy from the undisturbed core sequence of Hajós–Kaszálók.

Lithological and sedimentological analysis

Hajós–Kaszálók

430–420 cm

Whitish-grey (10 YR 7/1) cross-bedded riverine fine sandy layers with very fine sand, shells, and snails (Ga4). Pollen and macrobotanical material were lacking. The riverine sand grains are carbonates, dolomite, and unweathered silicates *(Tab. 1)*.

420–296 cm

Greenish-grey (10 YR 5/3) slightly laminated coarse silty fine silt (Ag2As2) with dispersible organic material and poor macrobotanical remains. Lacustrine (oxbow lake) sediment without riverine sandy layers. The sediment is well sorted and slightly calcareous *(Fig. 10)*. Pollen grains occurred in this level of the profile.

Depth (cm)	Troels-Smith code	Sediment type	Sediment genetic	Stratigraphy	Archaeological period
0–80	Sh3As1	hydromorphic soil	decomposed sedge peat	Sub-Boreal	Medieval to Modern
80–240	Th4	reed peat	peatland	Atlantic / Sub-Boreal	Neolithic to Medieval
250–240	Lc2As2	clayey chalk	mesotrophic oxbow lake	Pre-Boreal / Atlantic	Late Mesolithic – Early Neolithic
270–250	Lc1As3	lake sediment	oligotrophic oxbow lake	Allerød / Pre-Boreal	Epipalaeolithic and Mesolithic
295–270	Ga4	fluvial sand	river bed	Late Glacial	Upper Palaeolithic

Tab. 2. Sediment types, ages, and stratigraphy from the undisturbed core sequence of Császártöltés–Vörös-mocsár.

296–275 cm
Reddish-yellowish brown (10 YR 4/3) carbonate-free organic material-rich peat layer with plant remains and pollen grains (296–295 cm: Th1As3; 295–275 cm: Th2As2). In this level of the profile, the oxbow lake became marshy, and biogene infilling became dominant. The pollen trap changed and mainly local-extralocal pollen grains accumulated. The water-soluble Na, K, Fe, and Mn content is highest in this section of the profile.

275–170 cm
Dark, blackish brown (10 YR 3/1) organic material, macrobotanical remains, pollen-rich peat layer (Th3As1). The organic material content increased compared to the previous zone. The macroscopic evolution of the peat layer changed. The water-soluble content (K, Na, Fe, Mn) of the section is significant.

170–10 cm
Yellow-brown (10 YR 6/4) layer with minimal organic material (Th4) and significant carbonate content. The water-soluble K and Na content is significant, the Ca, Mg, and Fe content is about average.

The upper 10 cm section of the peat layer reflected a transformation generated by a pedogenesis process. Its inorganic material (Ca and Mg) content increased, resulting in the development of a dark brown (10 YR 3/3) soil horizon (Th2Aa2). The formation of the hydromorphic soil occurred during the past 150 years after the hydroregulation and the decrease of the groundwater level.

Császártöltés–Vörös-mocsár

295–270 cm
Whitish-grey (10 YR 7/1) very fine sandy fine sand (Ga4) with significant numbers of snail and shell fragments on the bedrock of the profile. Besides mollusc shells, dispersed plant remains were found without pollen grains. Unweathered silicates (quartz, feldspar, muscovite, biotite) mixed with small calcareous fragments make up the layer. The organic material content of this level is minimal *(Tab. 2)*.

270–250 cm
Brownish-grey (10 YR 4/2) silty lacustrine sediment (Lc1As3) with sedge remains. Rich in mixed organic material. The water-soluble Ca, Mg, K, Fe, and Mn content is significant. Mollusc shells, macrobotanical remains, and pollen grains occur.

250–240 cm
Whitish grey (10 YR 8/1) clayey chalk (Lc2As2). Significant amount of *Chara* remains, snail, and shell fragments. Significant carbonate and water-soluble Ca and Mg content.

240–80 cm
Blackish-brown (10 YR 2/3) organic material, Fe, Mn, Ca, Mg, K, Na-rich peat layer with carbonate content (Th4). Significant amount of macrobotanical remains, mollusc shells, and pollen material were found.

The upper 80 cm of the profile is yellowish-brown (10 YR 4/3) decomposed peat. This level is probably the pedogenesited version of the peat layer beneath this level. Its Fe, Mn, and K content is significant. High amount of mollusc shells and decayed plant remains occurred without pollen material in this horizon. This decomposed peat layer could have developed as a result of a decrease in groundwater level after peat mining ceased in 1972.

Radiocarbon dating

Hajós–Kaszálók

We have eight radiocarbon dates for the Hajós–Kaszálók profile, five of which were published earlier (Jakab

Laboratory number	Depth (cm)	Material	uncal BP (years)	±	cal BP (years)	±	cal BC / AD (years), 2-sigma
deb-9329*	95 – 100	peat	1650	80	1544	186	221 – 592 AD
deb-9326*	160 – 165	peat	1770	80	1703	174	73 – 421 AD
deb-9328*	215 – 220	peat	3960	80	4575	423	2848 – 2203 BC
ETH-41278	236	Typha	5560	40	6349	61	4461 – 4339 BC
deb-9325*	265 – 270	peat	7310	80	8145	168	6365 – 6028 BC
deb-9327*	295 – 296	peat	9130	130	10 258	346	8705 – 7963 BC
ETH-41275	344	peat	10540	45	12 522	122	10 692 – 10 454 BC
GdA-554	420	shell	21190	140	25 509	299	23 869 – 23 261 BC

Tab. 3. Radiocarbon dates for the Hajós–Kaszálók undisturbed core profile.

et al. 2004a; 2004b). Together with the new radiocarbon dates, we now focus on the bedrock of the profile, on the early Holocene phase, including the Neolithic, in order to gain a finer dating of the peat layer *(Tab. 3)*.

The riverine phase of the oxbow lake ended at the close of the Pleistocene, in the second part of the Marine Isotope Stage 3 (MIS3) (Aitken / Stokes 1997; Voelker 2002; Van Meerbeeck et al. 2011; Pettitt / White 2012), around 23 000–24 000 cal BC. Lacustrine sedimentation started during MIS2 (Suggate / Almond 2005; Mackintosh et al. 2006; Rasmussen et al. 2008), during the coldest stages of the Upper Pleistocene (Rind / Peteet 1985; Sümegi / Krolopp 1995; 2002; Shin et al. 2003; Sümegi 2005a). The sedimentation rate was 0.06–0.7 mm / yr (cf. *Fig. 6*) during MIS2 in the oxbow lake environment.

At the end of the Pleistocene, between 10 600 and 10 400 cal BC, during the Younger Dryas (Fairbanks 1990; Cuffey / Clow 1997; Alley 2000; Lotter et al. 2000; Stuiver / Grootes 2000), biogene infilling began in a cold interval (Marchal et al. 1999; Alley 2000; Lotter et al. 2000) and lacustrine sediment accumulated with increasing organic material content. As a result of the vegetation cover, the sedimentation rate increased to 0.2–0.3 mm / yr (cf. *Fig. 8*). The accumulation of macrobotanical remains and the trap of pollen grains changed, leading to a dominance of local-extralocal pollen. Thus, during the last 12 600 years, from the Epipalaeolithic of the Carpathian Basin (Vértes 1962; 1965; Sümegi 2010; Sümegi et al. 2012a; 2012b), the accumulation of plant residues originated from the immediate vicinity of the Hajós–Kaszálók site.

From the onset of the Holocene (Pre-Boreal phase; Mangerud et al. 1974; de Beaulieu et al. 1994; Magny 1995; Tantau et al. 2006), a closed peatbog developed. The sedimentation rate was constant at 0.1–0.2 mm / yr between 8700 cal BC to 300 cal AD (cf. *Fig. 8*), accumulating in the same sedimentary environment. We could study the profile at the 1–2–4 cm sampling intervals at a decade-scale, spanning the period from the Mesolithic (Sümegi 2010; Sümegi et al. 2012a) to the end of the Late Roman period (Vaday 2003).

At the end of the Late Roman period, at the turn of the 4th–5th centuries AD, the nature and macroscopic plant remains of the peat layer underwent a change at the Hajós site. Compared to the previous reed dominance, sedge became dominant.

Our previous studies revealed that a dike was constructed at the end of the Late Roman period in the northern part of Hajós–Kaszálók (Sümegi 2005b). The closed sedge-dominated vegetation cover could have evolved over the last 1500 years as a result of human disturbance. The sedimentation rate increased to 4 mm / yr. This sedimentation rate remained unchanged during the Migration period (early Medieval period). Although the speed of sedimentation decreased in the Middle Ages, we could analyse these horizons by our 2 cm sampling intervals.

The chemical composition of the peat also changed, and high water-soluble K content was dominant (cf. *Fig. 10*). Simultaneously, the peat's organic material content decreased, while its inorganic content grew. As a result of pedogenesis in the upper part of the profile, the environmental reconstruction of the last 200–300 years was not possible. At the same time, this profile is highly important as it is one of the best decade-scaled profiles in the Danube-Tisza interfluve. Its significance is comparable to the profiles from Bátorliget (Willis et al. 1995), Ecsegfalva (Willis 2007), Maroslele (Sümegi et al. 2011a), Izsák (Sümegi et al. 2011b; Törőcsik et al. 2014), and Polgár (Sümegi et al. 2002; Magyari et al. 2010a; 2010b; 2012) east of the Tisza, on the Great Hungarian Plain.

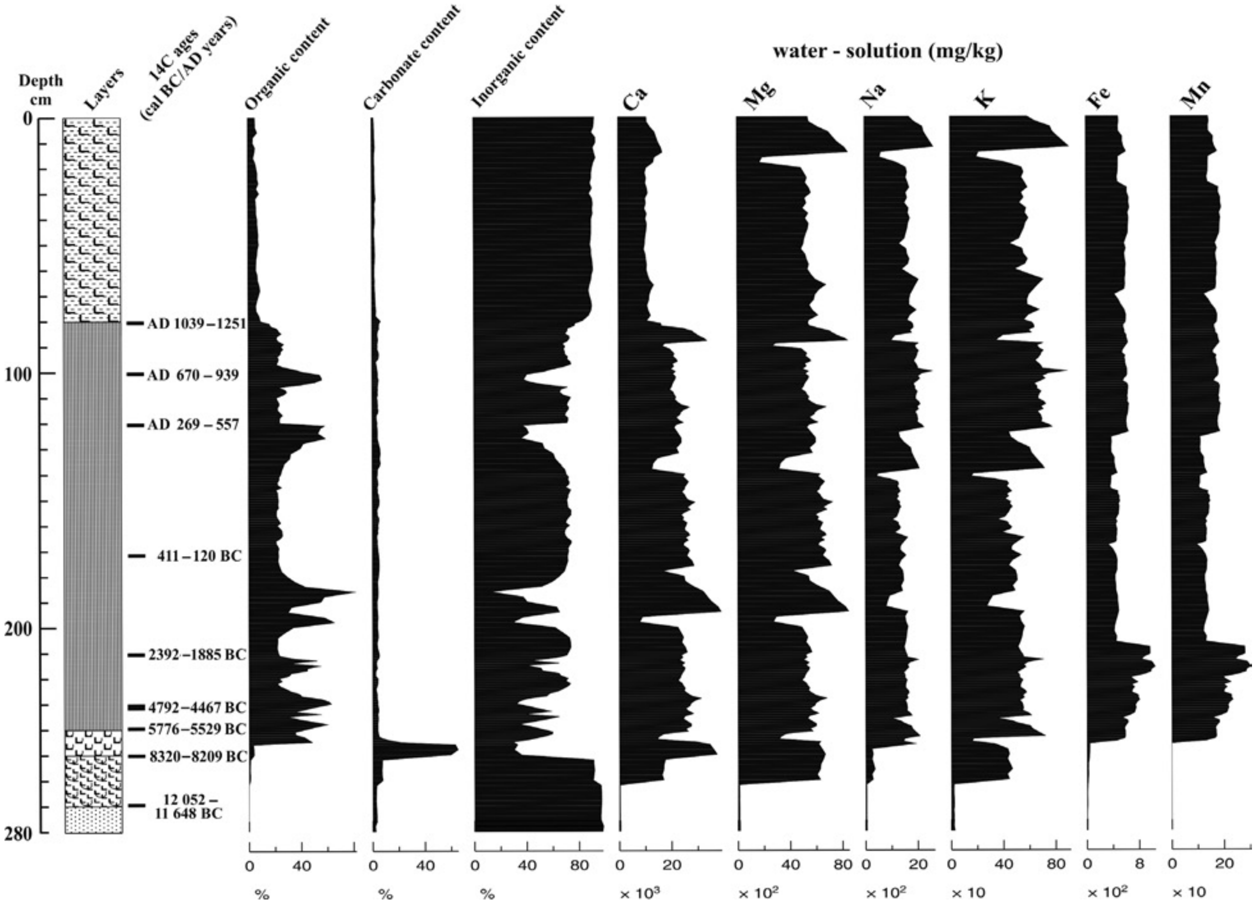

Fig. 11. Sediment and lithological changes in the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés.

Császártöltés–Vörös-mocsár

We submitted nine samples for radiocarbon dating, eight of which are published here for the first time *(Tab. 4)*. The end of the riverine phase occurred at the end of the Pleistocene, in MIS2 (Suggate / Almond 2005; Macintosh et al. 2006; Rasmussen et al. 2008) in the Allerød climatic phase (Iversen 1953; Mercer 1969; Mangerud et al. 1974; Johnsen et al. 1992; Preece 1994; Limondin 1995; Rundgren 1995; Preece / Bridgland 1999; Lohne et al. 2004; Magny et al. 2006; Bondevik et al. 2006). This time horizon corresponds to the Upper Palaeolithic and Epipalaeolithic or the Magdalenian culture and the Federmesser group in Central European archaeostratigraphy (Vértes 1962; 1965; Schmider 1982; 1990; Street et al. 1994; Baales / Street 1996; Eriksen 2002; Sümegi 2010; Sümegi et al. 2012b; Debout et al. 2012).

Following the end of the riverine stage in the Allerød phase, an oligotrophic lacustrine environment developed that lasted until the Pre-Boreal (8320–8209 cal BC; cf. *Tab. 4*). Thus, an oxbow lake developed with unweathered minerals, silt-rich sediments at the end of the Late Glacial *(Fig. 11)*.

In the Pre-Boreal, the nature of sedimentation changed. The carbonate content increased significantly, and a mesotrophic environment developed, where chalk accumulated in the oxbow lake. The sedimentation rate was 0.02–0.04 mm / yr, similarly to the Hajós site. This oligotrophic and mesotrophic environment corresponds to the Early Mesolithic in the Carpathian Basin.

In the Boreal phase between 6000–7000 cal BC, peat formation began, and the lake became a reed swamp system. Peat accumulation began from the Late Mesolithic onward (Sümegi 2010; Sümegi et al. 2012b) that lasted until the last 200 years, until the hydroregulation (Molnár 2015). As a result of biogene infilling and peat formation, the sedimentation rate increased to 0.2–0.8 mm / yr (cf. *Fig. 9*) between the Mesolithic and the Modern Age. Sedimentation did not change during the last 9000 years, meaning that this did not affect the accumulation of plant residues. On the basis of the sedimentation rate and the radiocarbon dates, our 1–2 cm sampling intervals enabled a decade-scaled vegetation and environment reconstruction for the Császártöltés–Vörös-mocsár site.

Laboratory number	Depth (cm)	Material	uncal BP (years)	±	cal BP (years)	±	cal BC / AD (years), 2-sigma
deb-11310	80	peat	875	45	745	56	1039 – 1251 AD
deb-11309	100	peat	1228	53	1146	135	670 – 939 AD
deb-11306	120	peat	1619	49	1537	144	269 – 557 AD
deb-11308	170	peat	2253	62	2215	146	411 – 120 BC
ETH-41276	210	peat	3695	75	3834	224	2392 – 1885 BC
deb-11334	230	peat	5785	74	6577	164	4792 – 4467 BC
deb-3926	240	peat	6756	72	7602	124	5776 – 5529 BC
ETH-41277	245	Typha	9045	45	10 213	55	8320 – 8209 BC
GdA-555	260	shell	11 960	60	13 799	202	12 052 – 11 648 BC

Tab. 4. Radiocarbon dates for the Császártöltés–Vörös-mocsár undisturbed core profile.

Pollen analyses *(Figs 12–13)*

Hajós–Kaszálók

Of the 195 samples, 193 contained evaluable pollen samples. We reached the minimum 500 terrestrial pollen grains per sample, although the pollen density of the upper 416 cm varied. Based on the statistical analysis (cluster and PCA), we distinguished eight local pollen zones and five additional subzones in the profile *(Tab. 5)*.

Hajós–Kaszálók Local Pollen Zone 1 (HK LPZ 1)

416–330 cm (24 000–11 600 cal BC; MIS2 and Late Glacial; *Pinus* subgenus *Diploxylon* pollen type dominance level)

This level of the profile was dominated by pine species and saw the appearance of narrow-leaved deciduous trees *(Betula*, *Populus*, *Alnus) (Fig. 12)*. *Larix*, *Picea*, *Abies*, and *Juniperus* appeared among pine types and *Pinus* subgenus *Diploxylon* pollen type dominated *(Pinus sylvestris*, *P. mugo)*. Nevertheless, pollen grains of the *Pinus* subgenus *Haploxylon* pollen type *(Pinus cembra)* were found as well. Besides a large number of pine pollen grains, some tundra vegetation elements appeared in this level *(Betula nana*, *Hyppophaë rhamnoides*, *Selaginella selaginoides)*. The small number of non-arboreal pollen grains (particularly *Artemisia* and Chenopodiaceae) is an unusual phenomenon in this section, corresponding to MIS2. The pollen concentration in this zone is extremely low, suggesting selective fossilisation, and it probably indicates extensive barren surfaces with patches of tundra vegetation *(Betula nana–Pinus mugo–Hyppophaë rhamnoides)*.

The oxbow lake and the west-southwest oriented loess-covered high bluff were probably covered by a mixed pine forest. Simultaneously, a Boreal forest steppe with scattered tundra patches evolved on the top of the high bluff. This would support the models on the regional and local mosaic patterning of the environment in the Danube-Tisza interfluve: a patchwork of Boreal forests, cold steppe, tundra vegetation, and saline areas (Sümegi / Krolopp 1995; 2002; Sümegi et al. 1999; 2004). Nevertheless, the eurytherm (Prentice et al. 1996) *Pinus* pollen dominance of 80 % during MIS2 is unusual and might reflect special pollen taphonomical processes (Fall 1987).

The local pollen zone can be divided into two subzones. Tundra elements disappear and cold loving elements *(Larix*, *Pinus mugo*, *Betula nana*, *Pinus cembra)* become more intensive from 360 cm of the profile (approximately from 11 000 cal BC).

Hajós–Kaszálók Local Pollen Zone 2 (HK LPZ 2)

330–310 cm (9600–8400 cal BC; *Pinus* subgenus *Diploxylon* pollen type dominance level and appearance of broad-leaved trees horizon)

Beginning with 9600 cal BC, *Pinus* subgenus *Diploxylon* pollen type, *Pinus sylvestris* dominated. Deciduous trees and shrubs such as *Betula, Corylus*, *Quercus*, *Tilia, Fraxinus*, and *Ulmus* appeared and their ratio started to increase (cf. *Fig. 12*). Surprisingly, the values of non-arboreal taxa (Poaceae, *Artemisia,* Chenopodiaceae) increased as well. The pollen data indicate two different vegetation environments in the vicinity of the oxbow lake at the onset of the Holocene. It would appear that a temperate steppe-forest steppe extended over the dry high bluff (cf. *Fig. 12*) in addition to the Boreal mixed taiga forest enclosing the lake (Sümegi 1995; 1996; Sümegi et al. 2011a; 2012a), indicating that the mixed taiga and steppe-forest steppe developed simultaneously between the Late Glacial and the Early Holocene. These changes occurred in several phases, starting at approximately 10 500 BC and ending at 6500 BP. The continuous change was stimulated by climatic changes at the end of the Pleistocene and beginning of the Holocene.

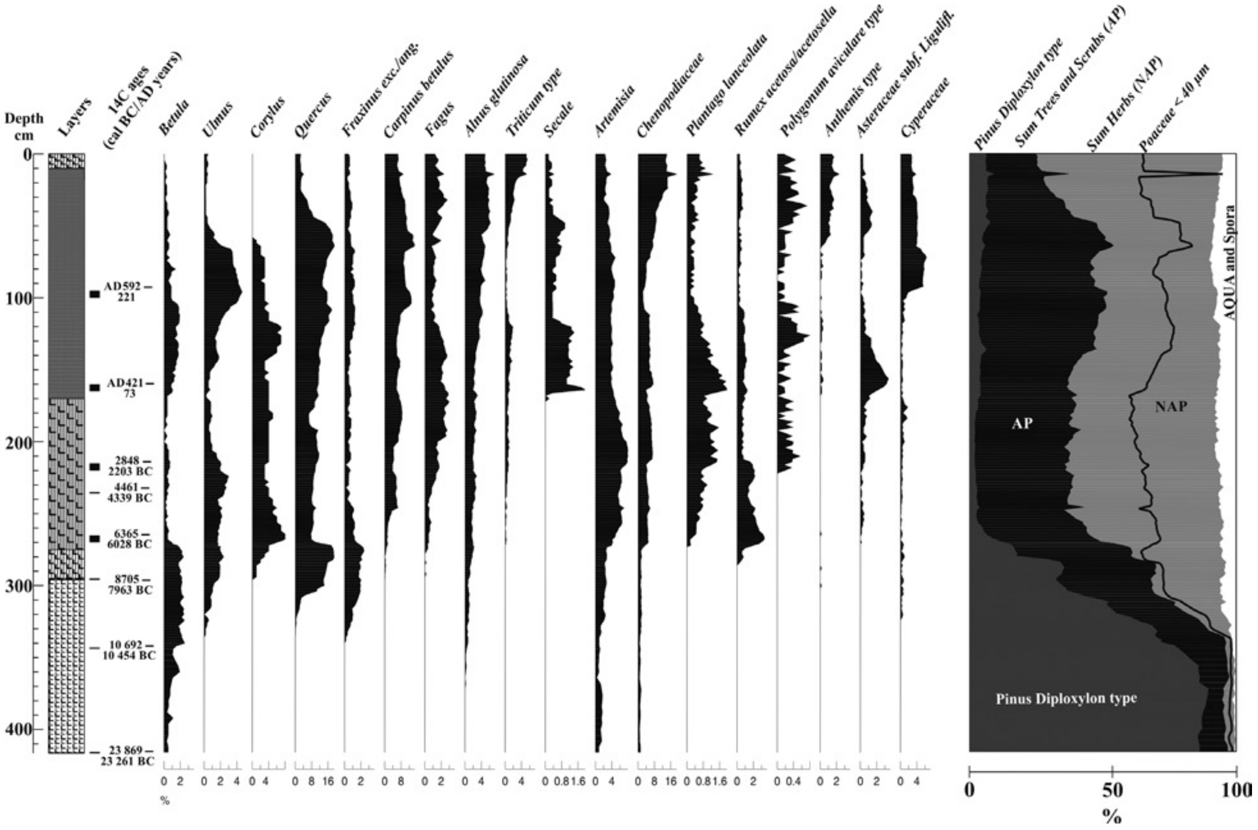

Fig. 12. Pollen (selective taxa) content changes in the undisturbed core sequence from Kaszálók Mire at Hajós.

Hajós–Kaszálók Local Pollen Zone 3 (HK LPZ 3)

310–272 cm (8400–6000 cal BC; *Quercus-Ulmus-Fraxinus-Corylus* horizon)

This level corresponds to the development of hardwood gallery forests. However, the presence of *Fraxinus* and *Ulmus* was more prominent compared to the present-day hardwood gallery forests on the Great Hungarian Plain (Borhidi et al. 2012; Molnár et al. 2012; Fekete et al. 2014). The arboreal pollen ratio was between 55–72 %, indicating a forest steppe vegetation (Allen et al. 2000). At the same time, the forest steppe vegetation was not made up of scattered stands of trees and non-arboreal plants, but rather seems to have been mosaic-like patches of hardwood gallery forests (Danubian alluvium) alternating with steppe-forest steppe (loess- and sand-covered high bluff).

One archaeologically important element is the *Corylus* peak (cf. *Fig. 12*) between 280 and 272 cm that corresponds to the Late Mesolithic. Comparable Late Mesolithic *Corylus* peaks were noted on several other sites in the Carpathian Basin (Sümegi 1998; 1999; 2004a; 2007a; 2013a). Following Smith (1970), who modelled human-environment interactions on Mesolithic sites in Great Britain, we consider this *Corylus* peak as an indication of human impact during the Late Mesolithic (Sümegi 1999; 2004a; 2007a; 2013a; Magyari et al. 2001; Sümegi et al. 2011a;). The dominance peak of *Betula* and *Tilia* in this level can probably also be interpreted as a reflection of Late Mesolithic human impact (Willis et al. 1998; Sümegi 1998). The pollen record thus suggests that the human transformation of the original forest vegetation began in the Late Mesolithic, indicating the presence of Mesolithic groups between 6500–6000 cal BC.

Hajós–Kaszálók Local Pollen Zone 4 (HK LPZ 4)

271–216 cm (6000–2000 cal BC; *Quercus-Ulmus-Fraxinus-Corylus* and anthropogenic weeds-cereal horizon)

Although the ratio of *Quercus*, *Fraxinus*, and *Corylus* remained significant, their values decreased. Parallel to the dominance of non-arboreal pollen accounting for 50 %, and especially of weed species such as *Plantago lanceolata* and *Plantago media/major* expanding due to human impact, *Rumex* and Asteraceae also spread (Behre 1981; 1988; 1990; Behre/Jacomet 1991; Kreuz/Schäfer 2011). Cereal pollen grains appeared sporadically from the Early Neolithic. The settlements of the Körös culture known in the vicinity of the study site (Knipl/Sümegi 2012) attest to the presence of the first farming communities in the region, and we can thus compare our results with the already published pollen data from other Körös sites (Sümegi 2004a; Willis 2007; Sümegi et al. 2011a).

Depth (cm)	Local pollen zone	cal BC / AD (years)	Pollen zone description
upper 10	HK LPZ 9	last 300 years	Humus (?)
10 – 50	HK LPZ 8	1000 – 1700 AD	A strong anthropogenic signal and extensive forest steppe area was detected in this zone. Traces of mosaic-like agricultural activity; the forest steppe expanded sporadically, but the wooded area expanded and human impact declined at the end of the pollen zone.
50 – 100	HK LPZ 7	500 – 1000 AD	The principal tree species in this zone are *Quercus, Carpinus betulus*, and *Alnus* cf. *glutinosa*. Total arboreal pollen reaches 35 – 40 %. Mixed oak and oak-hornbeam forests were typical. A strong anthropogenic signal and an extensive forest steppe area was detected in this zone. Cyperaceae pollen grains are frequent.
100 – 170	HK LPZ 6	200 – 500 AD	Strong transformation of the vegetation due to anthropogenic impact. In addition to *Triticum* pollen, *Secale* pollen appeared and became dominant. Asteraceae pollen dominated among weeds.
170 – 216	HK LPZ 5	2000 BC – 200 AD	The principal tree species in this zone were *Quercus*, *Carpinus betulus*, *Fagus*, and *Alnus*. Total arboreal pollen accounts for 35 – 40 %. Mixed oak and oak-hornbeam forests are typical. A strong anthropogenic signal and an extensive forest steppe area was detected in this zone. Poaceae, *Artemisia*, Chenopodiaceae pollen dominance reached the maximum level.
216 – 272	HK LPZ 4	6000 – 2000 BC	The principal tree species of the mixed forest steppe dominated this zone: *Quercus*, *Ulmus*, *Corylus avellana* and *Tilia*, later with *Carpinus* and *Fagus*. The most dominant non-arboreal pollen are represented by *Artemisia, Aster* type, Poaceae and Umbelliferae. Other important non-arboreal species are *Plantago lanceolata*, *Filipendula vulgaris* and *Rumex*. The first anthropogenic signal, cereal pollen grains, were detected at 271 cm.
272 – 310	HK LPZ 3	8400 – 6000 BC	The principal tree species of the mixed forest steppe dominated this zone: *Quercus*, *Ulmus*, *Corylus*, *Fraxinus*, *Tilia platyphyllos*, and *Tilia cordata*. *Pinus sylvestris* as well as *Salix* and *Betula* were an important species of the terrestrial vegetation up to 282 cm. The dominance of arboreal pollen is 60 – 70 %, suggesting the presence of a typical forest steppe. Between 6500 – 6000 cal BC, a short dominance peak of *Corylus*, *Tilia*, and *Betula* could be detected.
310 – 330	HK LPZ 2	9600 – 8400 BC	*Pinus* subgenus *Diploxylon* pollen type dominated, primarily *Pinus sylvestris*. Broad-leaved elements such as *Fraxinus*, *Quercus*, *Ulmus,* and *Corylus* pollen appeared. The proportion of *Betula*, *Artemisia*, Poaceae, and Cheno podiaceae increased.
330 – 420	HK LPZ 1	22 000 – 9600 BC	The principal tree species in this zone was *Pinus* subgenus *Diploxylon* pollen type, primarily *Pinus sylvestris*. Small quantities of *Pinus cembra*, *Pinus mugo*, *Larix decidua*, *Betula nana*, *Hyppophaë rhamnoides*, *Alnus,* and *Selaginella selaginoide*. *Artemisia* and Chenopodiaceae were also found. Tundra, Boreal taiga, cold steppe mosaic spots.
420 – 430	–	> 22 000 BC	There are no pollen remains.

Tab. 5. Local pollen zones in the Hajós–Kaszálók undisturbed core profile.

This pollen horizon spans the entire Neolithic and Copper Age up to the beginning of the Bronze Age. The ratio of *Carpinus* and *Fagus* pollen appearing in the Mesolithic (cf. *Fig. 12*) increased continuously and these species became the dominant taxa in the forest from the later half of the Neolithic. A subzone was distinguished on the basis of the expansion of *Carpinus* and *Fagus* between 232–210 cm, corresponding approximately to 2300–1900 cal BC. This subzone can be correlated with the Early Bronze Age and indicates a vegetation shift when beech and hornbeam became dominant among arboreal species. This reflects a colder, more humid phase, and a balanced precipitation (cf. *Fig. 12*). The ratio of arboreal and non-arboreal pollen was similar to the Early Holocene level, but cereal and weed pollen grains, indicating plant cultivation (Zohary et al. 2012), distinguish it from the Early Holocene horizon. From the second part of the Neolithic, the weed vegetation changed and remained stable until the second part of the Copper Age (Burga 1988; Rösch 1998; Lososová et al. 2004; Pyšek et al. 2005; Kreuz / Schäfer 2011), and the growing ratio of the *Polygonum aviculare* indicator plant characterised the new weed vegetation. The weed vegetation composition changed again at the end of the Early Bronze Age (Vaday 2003) and a second organic weed vegetation level developed (Sümegi et al. 2011a).

Hajós–Kaszálók Local Pollen Zone 5 (HK LPZ 5)

216–170 cm (2000 cal BC–200 cal AD; *Quercus-Carpinus-Artemisia*-Chenopodiaceae-Poaceae and anthropogenic weeds-cereal horizon)
Strong human impacts could be observed from the Middle Bronze Age to the later half of the Late Roman period. The ratio of non-arboreal pollen is the highest in this level of the profile. The vegetation of the high bluff was probably affected by strong human impacts and changed accordingly. Similar observations regarding human-environmental interactions were made elsewhere too (Sümegi 1998; 2003a; 2003b; Sümegi / Bodor 2000): the tell cultures of the Middle Bronze Age transformed the environment of the Great Hungarian Plain and created similar eco-spatial structures (Sümegi 2009; 2013a).

Hajós–Kaszálók Local Pollen Zone 6 (HK LPZ 6)

170–100 cm (200–500 cal AD; *Quercus-Carpinus-Artemisia*-Chenopodiaceae-Poaceae and anthropogenic weeds-cereal horizon)
In the later half of the Late Roman period, the pollen values of the weed vegetation and cultivated plants increased significantly, and the third organic weed vegetation level developed (spanning the period from the Late Iron Age to the end of the Roman period). The dominant weed species were Asteraceae taxa, and *Secale* appeared among cereals at the end of the Roman period. Its ratio was high in the 4th–5th centuries; these high values probably reflect a cooler climate (increasing precipitation along with a colder period).

Hajós–Kaszálók Local Pollen Zone 7 (HK LPZ 7)

100–50 cm (500–1000 cal AD; forest regeneration stage)
This pollen horizon spans the Migration period and lasted until the Hungarian Conquest period (9th century). The ratio of arboreal pollen increased from 30–40 % to 45–50 %. The anthropogenic steppe-forest steppe reverted to the natural forest steppe that had once thrived at the onset of the Holocene, which challenges models of the transformation of the Great Hungarian Plain into a cultural steppe during the past 3000 years (Chapman et al. 2009; Magyari et al. 2010a; 2010b). Alluvial, mixed oak, softwood, and hardwood gallery forests are capable of regeneration when land use and agricultural activity change and / or the population decreases.

Hajós–Kaszálók Local Pollen Zone 8 (HK LPZ 8)

50–20 cm (1000–1700 cal AD; Middle Ages agricultural horizon)
Following the Hungarian Conquest period, anthropogenic impact increased again and the forest composition changed: the previous *Carpinus-Quercus*-dominated woodland was transformed into an *Ulmus-Quercus-Carpinus*-dominated forest. The pollen composition indicates the mosaic patterning of the medieval environment with natural steppe, forest steppe, *Ulmus-Quercus-Carpinus*-dominated forests, ploughed lands, grazing fields, and meadows.

Hajós–Kaszálók Local Pollen Zone 9 (HK LPZ 9)

20–0 cm (last 300 years; Ottoman Turkish Occupation period and Modern Age).
Forest regeneration can be observed to some extent in the vicinity of the study site during the last 300 years. This horizon can be correlated with the Ottoman Turkish occupation of Hungary, the destruction of the medieval village network, and a drastic population decline.

One very important feature is that the dominance of *Fagus*, *Carpinus*, and *Alnus* increased in the flood basin, while the ratio of *Corylus* and *Ulmus* decreased. It seems likely that besides the climatic change (a colder climate) in the 16th–17th centuries, military administration played an important role in the increase of *Fagus* and *Carpinus*. These species supply the highest amount of charcoal, meaning that they played a prominent role in metallurgy, arms production, and smithing.

Császártöltés–Vörös-mocsár

Evaluable pollen material occurred between 270 and 80 cm in the profile. Of the 155 samples, 147 contained statistically evaluable pollen grains. On the basis of statistical analyses, we distinguished ten local pollen zones in the Császártöltés profile *(Tab. 6)*.

Császártöltés–Vörös-mocsár Local Pollen Zone 1 (CST VM LPZ 1)

270–252 cm (12 000–10 000 cal BC; Late Glacial Allerød phase; *Pinus* subgenus *Diploxylon* pollen type, and Poaceae dominance level)
The ratio of arboreal pollen is between 65–72 % in this pollen zone, with a dominance of *Pinus sylvestris*, *Betula*, *Picea*, and Poaceae. On the testimony of the AP : NAP ratio, a Boreal forest steppe-mixed taiga forest enclosed the area during the Upper Pleistocene in the Allerød phase. A closed mixed taiga surrounded the close vicinity of the

Depth (cm)	Local pollen zone	cal BC / AD (years)	Pollen zone description
80 – 110	CST VM LPZ 10	900 – 1300 AD	Increase of farming activities and plant cultivation. Despite human impacts, forestation increased, with a mosaic of forests, grazing fields, meadows, and ploughland.
110 – 120	CST VM LPZ 9	500 – 900 AD	Forest regeneration level
120 – 170	CST VM LPZ 8	400 BC – 500 AD	*Triticum* type-*Secale* and weed pollen dominance level
170 – 210	CST VM LPZ 7	2000 – 400 BC	Sedge peat, early phase, with strong human impact
210 – 230	CST VM LPZ 6	4400 – 2000 BC	*Ulmus*, *Corylus* decline and *Fagus-Carpinus-Quercus* dominance level
230 – 239	CST VM LPZ 5	5900 – 4400 BC	Appearance of cereals and weed dominance level. Neolithic occupation and food-producing subsistence.
239 – 242	CST VM LPZ 4	6500 – 5900 BC	*Corylus-Ulmus* dominance level; pre-Neolithic human impacts
242 – 248	CST VM LPZ 3	9600 – 6500 BC	*Ulmus-Fraxinus-Quercus-Corylus* dominance level; broad-leaved forest level
248 – 252	CST VM LPZ 2	10 000 – 9600 BC	Poaceae and *Pinus* subgenus *Diploxylon* pollen type dominance level; open Boreal parkland level
252 – 270	CST VM LPZ 1	12 000 – 10 000 BC	*Pinus* subgenus *Diploxylon* pollen type and Poaceae dominance level with Betula-mixed taiga level

Tab. 6. Local pollen zones in the Császártöltés–Vörös-mocsár undisturbed core profile.

site, while a Boreal steppe-forest steppe extended over the 5–6 m high loess-covered high bluff *(Fig. 13)*.

Császártöltés–Vörös-mocsár Local Pollen Zone 2 (CST VM LPZ 2)

252–248 cm (10 000–9600 cal BC; Late Glacial Dryas III phase; Poaceae and *Pinus* subgenus *Diploxylon* pollen type dominance level)
The ratio of Poaceae increased to over 40 %, while the dominance values of *Pinus sylvestris* dropped to below 50 % and the number of *Betula* pollen too declined (cf. *Fig. 13*), suggesting a drier climatic phase that can be correlated with the Late Glacial Dryas III phase on the testimony of the radiocarbon dates and the sedimentation rate.

Császártöltés–Vörös-mocsár Local Pollen Zone 3 (CST VM LPZ 3)

248–242 cm (9600–6500 cal BC; Pre-Boreal / Boreal phase; *Ulmus-Fraxinus-Quercus-Corylus* dominance level)
The ratio of deciduous trees reached 45 % while values of *Pinus sylvestris* drop to below 30 % (cf. *Fig. 13*). Hardwood gallery forests thrived on floodplains, the extent of the steppe-forest steppe vegetation decreased. On the basis of AP values (Allen et al. 2000), the ratio of trees was on the boundary of the forest / forest steppe zones. However, the steppe-forest vegetation reconstructed from the AP : NAP ratio (Allen et al. 2000) is based on the zonal vegetation of the Eastern European Plain. The vegetation and pollen analyses of the Carpathian Basin indicate a mosaic landscape on the macro, meso, and micro level alike. Thus, the vegetation and pollen model proposed for the Eastern European Plain (Allen et al. 2000) is not fully valid in the Carpathian Basin (Sümegi 1995; 1996).

Császártöltés–Vörös-mocsár Local Pollen Zone 4 (CST VM LPZ 4)

242–239 cm (6500–5900 cal BC; Boreal phase; *Corylus-Ulmus* dominance level)
The dominance of deciduous trees declined to below 40 %, *Pinus sylvestris* dropped to below 20 %, while *Betula* to under 2 % (cf. *Fig. 13*). At the same time, the ratio of *Corylus* increased again. The pollen record thus indicates a hardwood gallery forest on the floodplain at the beginning of Holocene. The expansion of the steppe-forest steppe halted. Similarly to the Hajós profile, a steppe-forest steppe vegetation can be reconstructed for the dry sand- and aeolian loess-covered high bluff (Molnár 2015), while a closed deciduous forest evolved on the alluvium. The open forest dominated by *Ulmus*

Fig. 13. Pollen (selective taxa) content changes in the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés.

and *Corylus* probably reflects the impact of hunter-forager communities who encouraged the spread of hazel (Clark 1934; Smith 1970; Simmons / Innes 1985; Smith et al. 1989; Zvelebil 1994; McComb 2009). Hazel boughs were also utilised (McQuade / O'Donnell 2007; Holst 2010). It would appear, then, that intensive foraging may have been practiced during the Late Mesolithic in the Carpathian Basin, before the onset of the Neolithic (Sümegi 1999; 2004a; 2008).

Császártöltés–Vörös-mocsár Local Pollen Zone 5 (CST VM LPZ 5)

239–230 cm (5900–4400 cal BC; Atlantic phase; the appearance of cereals, weed dominance level, impact of Neolithic subsistence)

Cereals, especially cultivated wheat, appeared in this level coupled with the spread of weeds as a result of plant cultivation and grazing *(Plantago major/media*, *Plantago lanceolata*, *Anthemis*, *Asteraceae*, *Rumex)* (cf. *Fig. 13*). The ratio of *Quercus* and *Fraxinus* decreased, while *Ulmus* and *Corylus* increased. The arboreal pollen ratio dropped to below 40 %. On the basis of the pollen composition on the alluvium and on the high bluff, a strong human impact could be noted in this level, beginning with 3900 ± 100 cal BC.

The proportion of weeds and non-arboreal pollen increased continuously during the Neolithic; by the end of the Neolithic, the weed composition changed, and the ratio of *Polygonum aviculare* increased, as did the proportion of other taxa such as *Artemisia* and Chenopodiaceae. Among arboreal pollen, *Fagus* and *Carpinus* expanded and by the end of Neolithic, these taxa became significant in the forest canopy. These changes were already visible at the time of the earliest farming groups in the Carpathian Basin, such as the Körös culture (Sümegi et al. 2004; 2011b; Willis 2007), and a similar change has been noted in other sedimentary basins on the Great Hungarian Plain that lie near Middle and Late Neolithic sites (Willis et al. 1995; Sümegi 1998; 1999; Sümegi et al. 2002; 2008a; 2008b; 2009b; 2011a; 2011b).

Császártöltés–Vörös-mocsár Local Pollen Zone 6 (CST VM LPZ 6)

230–210 cm (4400–2000 cal BC; Atlantic / Sub-Atlantic phase; *Ulmus*, *Corylus* decline, and *Fagus-Carpinus-Quercus* dominance level)

Traces of human impact are significant throughout the Copper Age and Early Bronze Age. The *Ulmus* pollen decline occurred at 3000 cal BC (Girling / Greig 1985; Peglar 1993; Parker et al. 2002). A *Quercus-Carpinus* forest with *Fagus* dominated on the alluvium, while the high river bluff was covered with weeds and steppe-forest steppe. A colder climatic phase can be reconstructed for this level on the basis of the change in the pollen composition.

Császártöltés–Vörös-mocsár Local Pollen Zone 7 (CST VM LPZ 7)

210–170 cm (2000–400 cal BC; Sub-Atlantic / Sub-Boreal phase; sedge peat, early phase, with a strong human impact)
This level indicates a humid, balanced climate (or perhaps significant floods in the catchment area). Sedge peat occurs at this level. The infilling of the basin accelerated and *Carex* taxa spread in the previously reed-dominated basin. A closed sedge peat developed at the end of the Bronze Age.

Continuous and significant human impact characterises the later half of the Bronze Age and the onset of the Iron Age as well as a pollen maximum of *Fagus* and *Carpinus*. The arboreal pollen ratio was between 48 % and 51 %. Despite the human impact, the development of the sedge peat and the significant weed vegetation indicate a slight reforestation on the floodplain. A more humid climatic phase can be reconstructed for the second part of the Bronze Age and the beginning of the Iron Age.

Császártöltés–Vörös-mocsár Local Pollen Zone 8 (CST VM LPZ 8)

170–120 cm (400 cal BC–500 cal AD; Sub-Boreal phase; *Triticum* type-*Secale*, and weed pollen dominance level)
From the Late Iron Age to the end of the Roman period, the pollen record indicates increasing human impact, a weed vegetation dominance including *Rumex, Plantago lanceolata* and *Polygonum aviculare*, and cereals (*Triticum* type and *Secale*). The arboreal pollen ratio was below 40 %. One of the most intensive human impacts can be reconstructed for this level: plant cultivation and animal husbandry were intensive in the vicinity of the study site.

The presence of *Vitis* pollen may indicate viticulture; however, these pollen grains could equally well originate from the wild form of grape *(Vitis sylvestris)*, as this species abounds in the forests of the Danube alluvium even today.

Based on the pollen data, local / regional cereal, walnut and fruit cultivation can be reconstructed, and intense land use with major human disturbances characterised the site during the Late Roman period.

The high coniferous pollen ratio reflects a Europe-wide phenomenon (Willis 1994) and does not indicate a local pollen accumulation and local pollen content. The cultural landscape (ploughed lands, roads, and settlement network) emerging during the Late Roman period cut through the European deciduous forest zones. Thus, patches of forested areas and cultivated lands characterised the landscape (Willis 1994), meaning that the pollen material of the less disturbed coniferous (taiga zone) and mountainous pine forests dominated the atmosphere. As a result, sedimentary deposits are relatively rich in pine pollen across most of the European continent during the Late Roman period, forming a palaeoenvironmental marker level.

Császártöltés–Vörös-mocsár Local Pollen Zone 9 (CST VM LPZ 9)

120–110 cm (500–900 cal AD; Sub-Boreal phase; forest regeneration level)
The pollen composition changed at the end of the Late Roman period (at the turn of the 4th–5th centuries). *Triticum* and *Secale* pollen still occurred, but their ratio dropped, as did the weed ratio (cf. *Fig. 13*). *Salix*, *Alnus*, *Carpinus*, *Quercus*, *Ulmus*, and *Fagus* increased significantly. *Prunus*, *Vitis*, and *Sambucus* disappeared from this level. The arboreal pollen ratio reached 45 %, indicating reforestation and the decrease of human impact and cultivated plants. Poaceae, *Artemisia*, and Chenopodiaceae declined drastically and the ratio of aquatic plants increased. On the basis of the pollen composition, animal husbandry dominated during the Migration period.

Császártöltés–Vörös-mocsár Local Pollen Zone 10 (CST VM LPZ 10)

110–80 cm (900–1300 cal AD; Sub-Boreal phase; sedge peat with strong human impact).
The pollen composition changed again from the later 10th century. Arboreal pollen dropped below 40 %, indicating strong human impact and agricultural activity between the 10th and 13th centuries. *Triticum* type and *Secale* cereals dominated and the ratio of weeds also increased. Following the Hungarian Conquest period, farming activities changed as a result of a more sedentary lifeway and expansive plant cultivation. The pollen composition reflects a mosaic-like environment of ploughed land and grazing fields alternating with forest patches during the Middle Ages, a landscape that evolved after the arrival of the ancients Hungarians.

Despite the increasing human impact and agricultural activity, the forested area (especially hardwood) increased on the alluvial plain, perhaps an indication of planned forest management and forest protection after the settlement of the ancient Hungarians.

The upper part of the profile was disturbed by groundwater management in the 20th century as a result of peat mining.

Depth (cm)	Local macrobotanical zone	cal BC / AD (years)	Macrobotanical zone description
0 – 20	–	last 400 years	There are no macrobotanical remains.
20 – 115	**HK LMBZ 6**	600 – 1600 AD	*Caricetum elatae*
115 – 140	**HK LMBZ 5**	350 – 600 AD	*Caricetum elatae*, *Calamagrostio-Salicetum cinereae*
140 – 215	**HK LMBZ 4**	2000 BC – 350 AD	*Caricetum elatae*, *Cypero-Juncetum bufonii*, *Nymphaeetum alboluteae* – tussock-hollow formation
215 – 275	**HK LMBZ 3**	6500 – 2000 BC	*Thelypteridi-Phragmitetum*, *Thelypteridi-Typhetum* communities – reed swamp peatland
275 – 300	**HK LMBZ 2**	8250 – 6500 BC	*Menyanthetum*, *Sparganio minimi-Utricularietum* communities – brown moss carpet
300 – 420	**HK LMBZ 1**	22 000 – 8250 BC	*Equisetetum fluitantis*, *Phragmitetum communis* communities
420 – 430	–	> 22 000 BC	There are no macrobotanical remains.

Tab. 7. Local macrobotanical zones in the Hajós–Kaszálók undisturbed core profile.

Macrobotanical analyses *(Figs* 14–15*)*

Hajós–Kaszálók

On the basis of macrobotanical analysis (Jakab et al. 2004a; 2004b), we distinguished six local macrobotanical zones *(Tab. 7)*.

Hajós–Kaszálók Local Macrobotanical Zone 1 (HK LMBZ 1)

420–300 cm (22 000–8250 cal BC;*Equisetetum fluitantis Phragmitetum communis* communities zone)

On the basis of the macrobotanical analysis, one vegetation horizon can be detected from the onset of MIS2 to the beginning of the Holocene. The macrofossil concentration is very low in this zone. *Phragmites* and *Equisetum* cf. *fluitans* is the main peat component. On the basis of the sediment composition, there was an open aquatic environment during this period. The presence of *Phragmites communis* is low, but its continuous presence is very important from a palaeobotanical perspective in MIS2 and during the Late Glacial. It has been attested in other profiles too in the Danube-Tisza interfluve (Sümegi et al. 2011a) and indicates different environmental and climatic conditions in the southern and south-western than in the northern part of the Great Hungarian Plain *(Fig. 14)*.

Hajós–Kaszálók Local Macrobotanical Zone 2 (HK LMBZ 2)

300–275 cm (8250–6500 cal BC; *Menyanthetum*, *Sparganio minimi-Utricularietum* communities zone)

The macrofossil concentration is higher and peat formation began. *Carex elata* appeared in this zone, corresponding to the pollen record in which sedge pollen appeared from this zone. Higher UOM indicates humification. The presence of *Menyanthes trifoliata* is characteristic of this zone (Jakab et al. 2004a; 2004b). Peat formation started 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 mosses. 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” that is frequently reported from Pleistocene sediments in Hungary (Boros 1952), but has not been attested in the Early Holocene until now (Jakab et al. 2004a; 2004b). This brown moss community is very similar to the Upper Pleistocene moss assemblage of the Nagy-Mohos peat bog in north-eastern Hungary (Magyari et al. 1999; 2000; Juhász 2002) and the Late Glacial moss assemblages of Balatonederics in the central part of the Carpathian Basin (Jakab et al. 2005; Sümegi et al. 2008c).

Hajós–Kaszálók Local Macrobotanical Zone 3 (HK LMBZ 3)

275–215 cm (6500–2000 cal BC; *Thelypteridi-Phragmitetum*, *Thelypteridi-Typhetum* communities zone)

The vegetation of the channel became uniform. Reed swamp covered the entire basin and reed-dominated peat

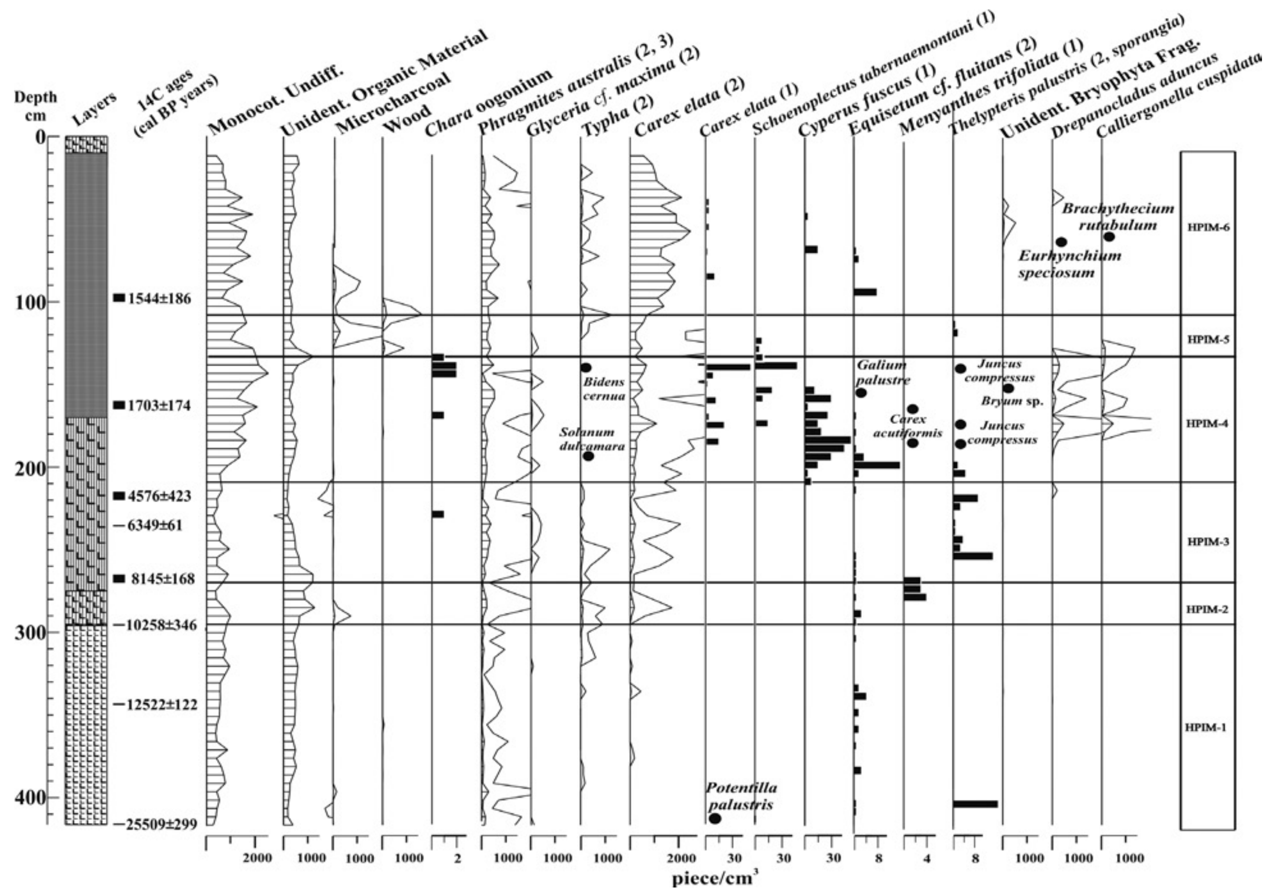

Fig. 14. Macrobotanical content changes in the undisturbed core sequence from Kaszálók Mire at Hajós (redrawn after Jakab / Sümegi 2011 within new radiocarbon data and J. Troels-Smith symbols).

began forming in the analysed catchment basin. The occurrence of *Thelypteris palustris* remains suggests the presence of floating reed swamps *(Thelypteridi-Phragmitetum*, *Thelypteridi-Typhetum)* in the deeper parts of the basin. This fossil plant context is very poor in species. The macrofossil record does not suggest submerged vegetation in this phase (cf. *Fig. 14*).

Hajós–Kaszálók Local Macrobotanical Zone 4 (HK LMBZ 4)

215–140 cm (2000 cal BC–350 cal AD; *Caricetum elatae*, *Cypero-Juncetum bufonii*, *Nymphaeetum albo-luteae* zone)

After 4000 BP, the climate became much more favourable. The groundwater table became higher and a diverse mire vegetation developed in the Hajós–Kaszálók channel. The tussock-hollow formation became the dominant vegetation type. Large tussocks of *Carex elata* standing in shallow, fluctuating water is a typical wetland vegetation type (*Caricetum elatae* plant association) of the Danube Tisza interfluve. 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 suggests high, but fluctuating water levels. The water table was probably high in spring and early summer, but low water levels and bare muddy surfaces likely prevailed in late summer (cf. *Fig. 14*).

Hajós–Kaszálók Local Macrobotanical Zone 5 (HK LMBZ 5)

140–115 cm (350–600 cal AD; *Caricetum elatae*, *Calamagrostio-Salicetum cinereae* zone)

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 (cf. *Fig. 14*). A willow swamp *(Calamagrostio-Salicetum cinereae)* emerged in the deeper part of the channel. This complex hydroseral vegetation succession (Phillips 1934; Van Hulst 1979; Gittins 1981; Strack et al. 2006) is common in recent mires affected by human activities (water regulation). The hummock-hollow complex became denser and the bare mud surfaces disappeared (Szodfridt / Tallós 1968).

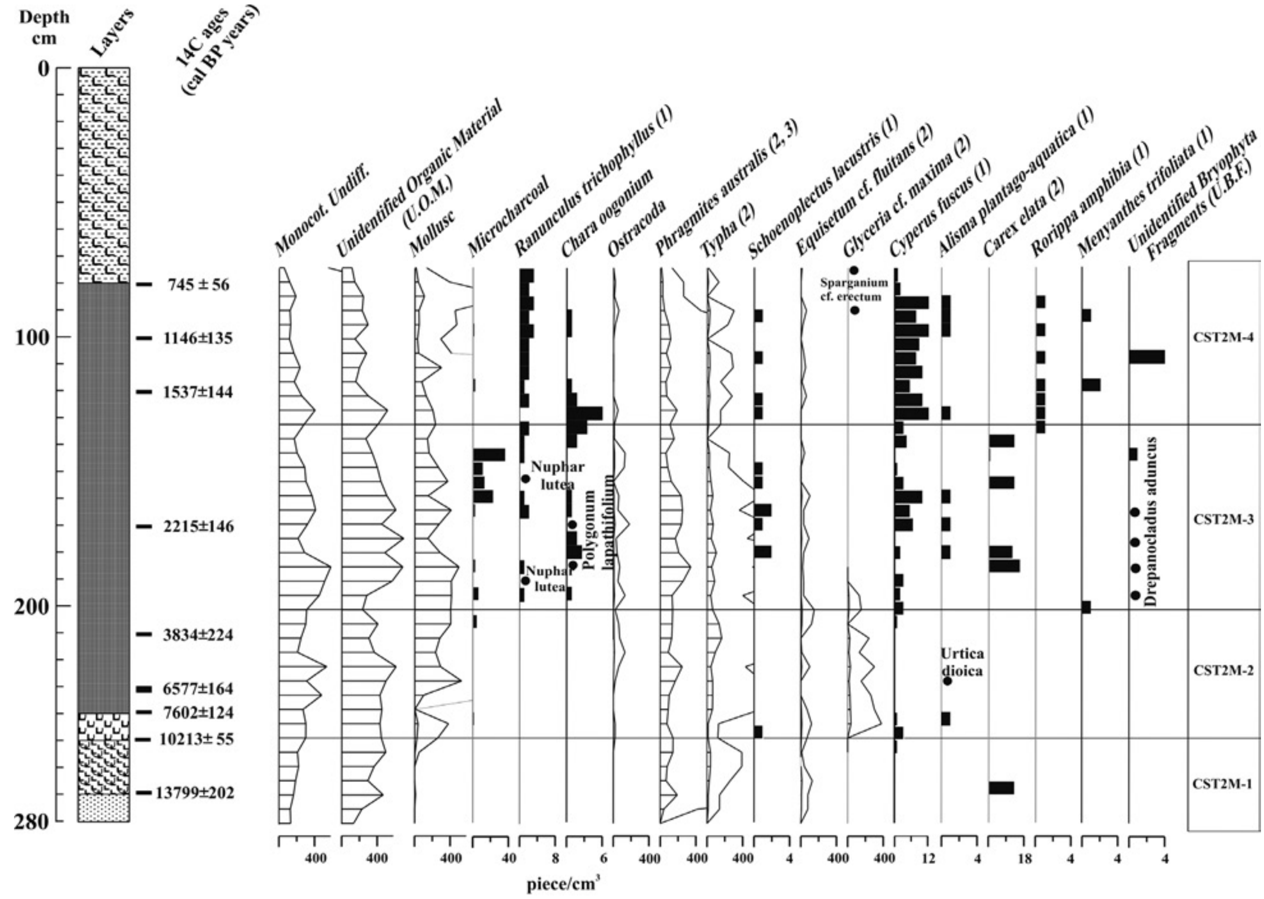

Fig. 15. Macrobotanical content changes in the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés (redrawn after Jakab / Sümegi 2011 within new radiocarbon data and J. Troels-Smith symbols).

Hajós–Kaszálók Local Macrobotanical Zone 6 (HK LMBZ 6)

115–20 cm (600–1600 cal BC; *Caricetum elatae* zone)
Carex elata is the most important peat component and *Phragmites australis* is present as well. The water level was probably higher than in the previous macrobotanical zone.

There was not macrobotanical material in the upper 20 cm.

Császártöltés–Vörös-mocsár

A macrobotanical analysis was carried out at Császártöltés–Vörös-mocsár as well (Jakab et al. 2004a; 2004b). Macrobotanical material occurred between 270 and 80 cm in the profile, on the basis of which five local macrobotanical zones were distinguished *(Tab. 8)*.

Császártöltés–Vörös-mocsár Local Macrobotanical Zone 1 (CSVM LMBZ 1)

270–245 cm (12 000–9500 cal BC)
The macrofossil concentration is low in this zone. *Typha*, *Phragmites*, and *Equisetum* are the major macrobotanical components. Sediment and macrobotanical material accumulated in a moving water environment *(Fig. 15; Tab. 8)*.

Császártöltés–Vörös-mocsár Local Macrobotanical Zone 2 (CSVM LMBZ 2)

240–200 cm (9500–6000 cal BC; stagnant water, oligotrophic-mesotrophic lake phase)
The macrofossil concentration is higher. *Typha* and *Phragmites* are the major peat components, with a combination of *Glyceria* remains. Mollusca and Ostracoda remains became frequent. An oligotrophic-mesotrophic lake of the stagnant water phase was formed in the catchment basin *(Fig. 15)*.

Császártöltés–Vörös-mocsár Local Macrobotanical Zone 3 (CSVM LMBZ 3)

200–135 cm (6000–0 cal BC; reed and reed-sedge peat phase)
Typha and *Phragmites* are the major peat components, alongside *Carex elata* remains. Reed peat, and later, reed and sedge peat were formed. The remains of water-lily and pioneer mud communities were detect-

Depth (cm)	Local macrobotanical zone	cal BC / AD (years)	Macrobotanical zone description
0 – 80	CSVM LMBZ 5	last 700 years	There are no macrobotanical remains.
80 – 135	CSVM LMBZ 4	0 – 1300 AD	*Phragmitetum - Ranunculetum aquatilis - Cypero-Juncetum bufonii* communities
240 – 135	CSVM LMBZ 3	6000 – 0 BC	*Phragmitetum - Nymphaeetum albo-luteae - Cypero-Juncetum bufonii* communities
240 – 250	CSVM LMBZ 2	9500 – 6000 BC	*Glycerietum - Phragmitetum communis* communities: stagnant water and peatland
250 – 270	CSVM LMBZ 1	12 000 – 9500 BC	*Equisetum fluitantis*: living water community

Tab. 8. Local macrobotanical zones in the Császártöltés–Vörös-mocsár undisturbed core profile.

ed in this zone. The water table is higher. The mixed peat formation remained until the Late Roman period, c. 100 cal BC (cf. *Fig. 15*).

Császártöltés–Vörös-mocsár Local Macrobotanical Zone 4 (CSVM LMBZ 4)

135–80 cm (0–1300 cal AD; sedge peat phase)
The macrofossil concentration is lower. Sedge taxons such as *Typha* and *Phragmites* are the major peat components. Pioneer mud vegetation and water-crowfoot communities are important in this zone. The water table is somewhat lower and fluctuating. Peat formation continued, in which sedge peat formation dominated and the ratio of reed peat decreased (cf. *Fig. 15*).

Császártöltés–Vörös-mocsár Local Macrobotanical Zone 5 (CSVM LMBZ 5)

Upper 80 cm (last 700 years; hydromorphic soil phase)
There was no evaluable macrobotanical material from the last 700 years due to groundwater regulation (cf. *Fig. 15*).

Malacological analyses *(Figs* 16–17*)*

Hajós–Kaszálók

The living water lacked macrophytes and was well oxigenised and relatively rich in nutrients as indicated by the number of rheophilous molluscs *(Valvata piscinalis*, *Valvata naticina*, *Lymnaea stagnalis*, *Planorbis* cf. *carinatus*, *Unio* cf. *crassus*, *Pisidium amnicum)* from the base sand-rich layer between 430–420 cm. There are no mollusc remains from other parts of the undisturbed core sequence of Hajós–Kaszálók.

Császártöltés–Vörös-mocsár

The profile yielded 12 632 individuals (10 727 freshwater and 1905 terrestrial) representing 52 mollusc species (29 freshwater snails, three mussel taxons, and 23 terrestrial species), identified in the 71 samples taken at 4 cm intervals. All samples contained statistically evaluable malacological material.

We distinguished eight local malacological zones *(Tab. 9)*. Aquatic snails dominated throughout of the profile, except for the upper 40–50 cm where the dominance value of terrestrial species reached 40–45 % *(Figs 16–17)*.

Császártöltés–Vörös-mocsár Local Malacological Zone 1 (CST VM LMZ 1)

280–270 cm (13 000–12 000 cal BC; *Lithoglyphus naticoides-Valvata pulchella* local malacological zone)
The riverine sand that forms the bedrock of the profile accumulated during the Late Glacial. This level of the profile was dominated by rheophilous mollusc elements (30–40 %), species that prefer a streaming water environment. *Viviparus acerosus*, *Lithoglyphus naticoides*, *Valvata piscinalis*, and *Valvata naticina* dominated among snails, while *Pisidium amnicum* and *Unio crassus* among mussels. At the same time, slum species that tolerate periodically significant quantities of water, stagnant water preferring species (called catholic group after Sparks 1961), and terrestrial species also occurred, indicating that the malacofauna originated from different habitats and that it mixed and accumulated in the sedimentary basin. The fauna composition reflects the joint presence of cold-loving elements such as *Valvata pulchella* that spread in Northern Europe and were present in the Carpathian Basin during the Pleistocene, and of warmth-loving species such as *Lithoglyphus naticoides* that prefer mild climate during this time horizon. These

Depth (cm)	Local malacological zone	cal BC/AD (years)	Malacological zone description
0–44	CST VM LMZ 8	1600–1900 AD	*Anisus spirorbis – Succinea oblonga*
44–80	CST VM LMZ 7	1200–1600 AD	*Valvata cristata – Anisus spirorbis*
80–120	CST VM LMZ 6	500–1200 AD	*Stagnicola palustris – Bithynia tentaculata*
120–200	CST VM LMZ 5	1400 BC–500 AD	*Valvata cristata - Planorbarius corneus – Stagnicola palustris*
200–240	CST VM LMZ 4	6000–1400 BC	*Valvata cristata – Bithynia leachi*
240–250	CST VM LMZ 3	9500–6000 BC	*Physa fontinalis – Gyraulus albus*
250–270	CST VM LMZ 2	12 000–9500 BC	*Bithynia leachi – Bithynia tentaculata*
270–280	CST VM LMZ 1	13 000–12 000 BC	*Lithoglyphus naticoides – Valvata pulchella*

Tab. 9. Local malacological zones from Császártöltés–Vörös-mocsár undisturbed core profile.

species occurred together in the Carpathian Basin during the Late Glacial and the Early Holocene (Sümegi 1996; 2003d), an indication that the fauna development of the Carpathian Basin differed from other regions of Europe, which can be attributed to the double refuge effect (Sümegi 1995; 2004a; Sümegi / Krolopp 1995; 2002; Willis et al. 1995). The double refuge effect emerged as a result of the mosaic patterning of the palaeoenvironmental conditions in the Carpathian Basin: this multiple mosaic environment, a result of climatic, orographical, geological, and hydrological conditions, was a typical feature in the Carpathian Basin, reflected by the simultaneous presence and survival of floral and faunal elements with contrasting ecological needs. This mosaic patterning contributed to the long-term sustainment of a woodland-grassland ecotone during the climate fluctuations of the Ice Age (Sümegi 1996). Furthermore, the presence of multiple ecological habitats also ensured the survival of cold-resistant taxa during the warmer periods and of warmth-loving taxa during the cooler periods in specially sheltered habitats.

Császártöltés–Vörös-mocsár Local Malacological Zone 2 (CST VM LMZ 2)

270–250 cm (12 000–9500 cal BC; *Bithynia leachi-Bithynia tentaculata* local malacological zone)

Stagnant water elements dominated in this level *(Fig. 16)*, indicating a lacustrine environment. At the same time, species preferring moving water such as *Valvata piscinalis* also thrived. Based on these, an oxygen-rich, light, organic material-poor oligotrophic lake can be reconstructed in the last phase of the Late Glacial. Cold-loving and mild climate preferring species such as *Bithynia leachi* and *Bithynia tentaculata* occurred in similar proportion, indicating the double refuge effect (cf. *Figs 16–17*).

Császártöltés–Vörös-mocsár Local Malacological Zone 3 (CST VM LMZ 3)

250–240 cm (9500–6000 BP; *Physa fontinalis-Gyraulus albus* local malacological zone)

The malacofauna changed at the onset of the Holocene. The lake became mesotrophic, and a *Chara*-rich lacustrine environment developed (*Chara* lake: van den Berg et al. 1999; Apolinarska 2009). This carbonate-rich, mesotrophic condition spanned the entire Mesolithic. Cold-loving, cold-resistant species *(Bithynia leachi)* appear in this level as well, although with smaller values (cf. *Figs 16–17*).

Császártöltés–Vörös-mocsár Local Malacological Zone 4 (CST VM LMZ 4)

240–200 cm (8000–3400 BP; *Valvata cristata-Bithynia leachi* local malacological zone)

The lacustrine environment became eutrophic at the beginning of the Neolithic, and a significant vegetation cover developed. As a result, the malacofauna was transformed and species preferring a eutrophic environment such as *Valvata cristata* dominated. This species expanded after the formation of the marshy lacustrine environment. The ecological analysis suggests that the

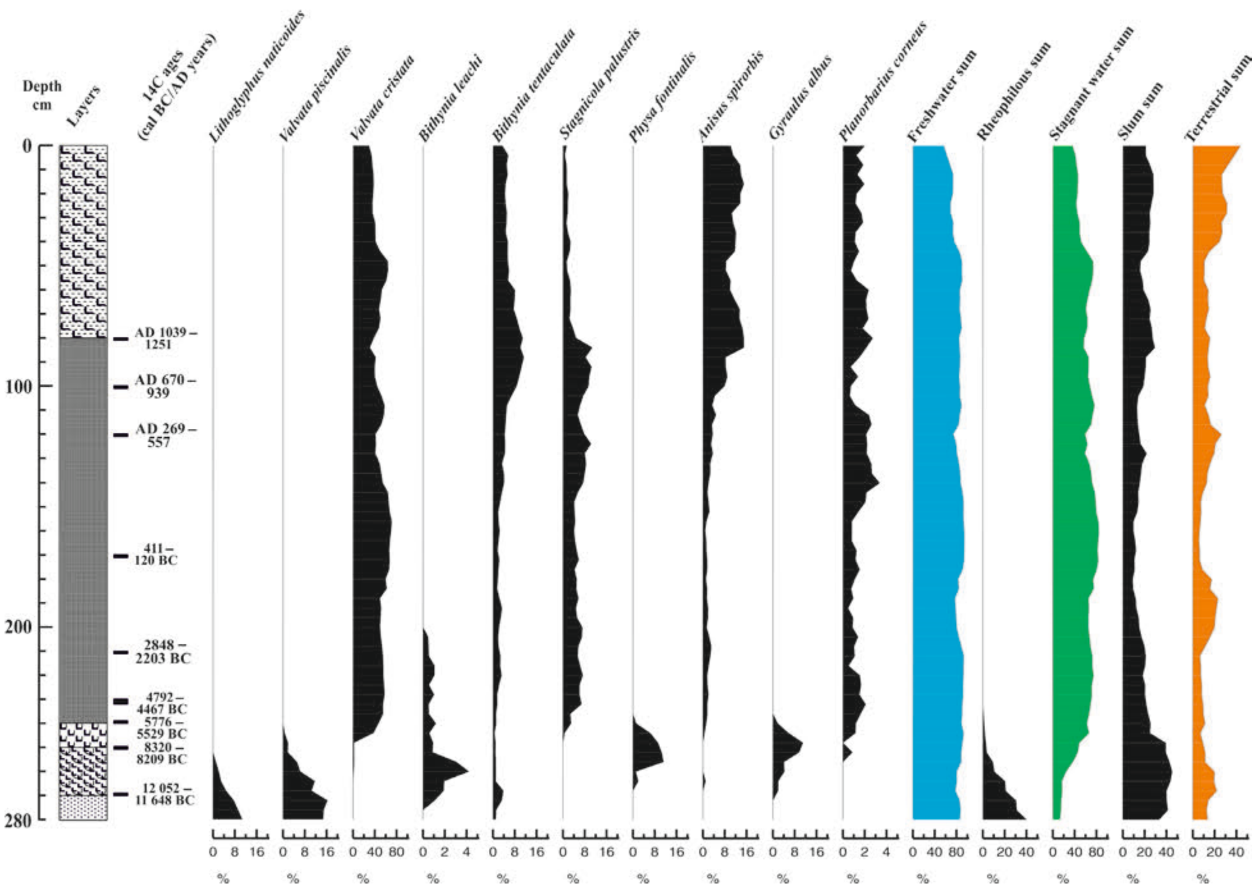

Fig. 16. Malacological changes in the undisturbed core sequence Császártöltés 1 from Vörös-mocsár (Red Marsh).

increase of phosphorus could cause the lapse of the carbonate-rich *Chara* environment because the higher phosphorus content was conducive to the spread of Tracheophyta (vascular) plants at the expense of *Chara* taxa. The increasing number of Tracheophyta (vascular) plant taxa resulted in a lacustrine environment, rich in organic material, which led to eutrophisation. As a consequence, the formation of a silt rich in organic material, and an increasing amount of phytomass peat started.

After the development of the marshy lacustrine environment, peat formation began that characterised the study site during the past 8000 years (cf. *Figs 16–17*).

At present, it is indeterminable whether the peat formation was a consequence of human activity. However, our data from other Körös sites east of the Tisza such as Tiszapüspöki, Nagykörű, Ecsegfalva, and Maroslele (Sümegi 2003c; 2004b; 2004c; Sümegi / Molnár 2007; Sümegi et al. 2011a) indicate that oxbow lakes in the vicinity of Körös sites started to eutrophicate at around 5700–6000 cal BC, similarly to the Császártöltés site. It would appear, then, that the change in the fauna composition and peat formation, the eutrophication of the lacustrine environment can be correlated with the arrival of Körös groups to the Danube alluvial region. However, the main reason for these changes remains unknown.

This malacological zone spans the entire Neolithic, the Copper Age, and the Bronze Age, with only slight changes in the dominance variation of temperature-sensitive species, presumably due to smaller climatic fluctuations. The marshy lake environment remained until the close of the Bronze Age (cf. *Figs 16–17*).

Császártöltés–Vörös-mocsár Local Malacological Zone 5 (CST VM LMZ 5)

200–120 cm (1400 cal BC–500 cal AD; *Valvata cristata-Planorbarius corneus-Stagnicola palustris* local malacological zone)

Although the mollusc fauna changed during the second part of the Bronze Age, *Valvata cristata* remained dominant, indicating a peat formation environment. At the same time, Eurosiberian *Planorbarius corneus* and Holarctic *Stagnicola palustris* dominated secondarily, indicating a shallow and colder aquatic environment. Peat formation and the vegetation cover increased on the testimony of the malacofauna. Similar changes occurred in other sedimentary basins as well in Transdanubia, in the Little Balaton region, and in the Benta Valley in the later

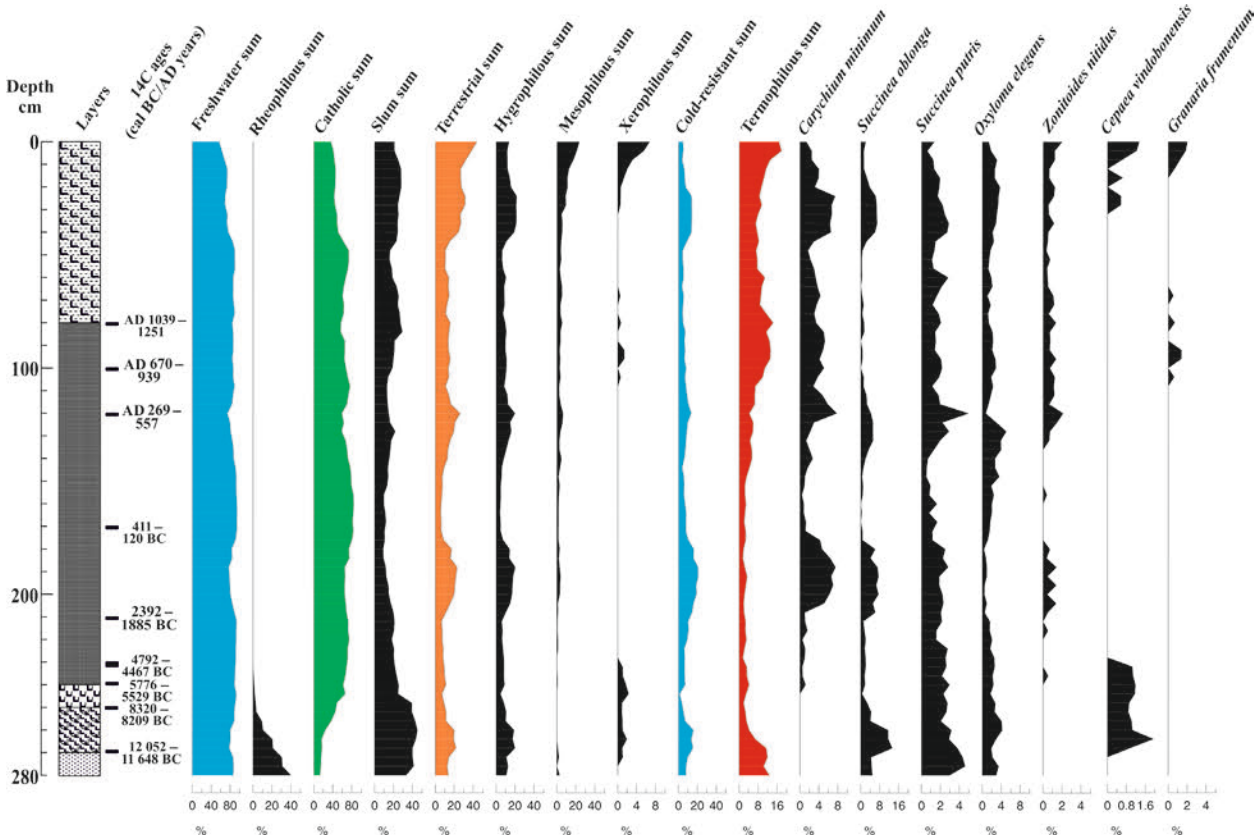

Fig. 17. Malacological changes in the undisturbed core sequence Császártöltés 2 from Vörös-mocsár (Red Marsh).

half of the Bronze Age (Sümegi / Bodor 2005; Sümegi et al. 2008a; 2008b; 2008c; 2009b; 2011b; 2011c). Terrestrial (waterside) species indicate an environmental change. A colder and more humid climate as well as increasing human impacts resulted in the accelerated infilling of the basin, and thus the vegetation cover changed, as did the malacofauna. The malacofauna correlates with the spread of sedge and the development of sedge peat (cf. *Figs 16–17*).

Császártöltés–Vörös-mocsár Local Malacological Zone 6 (CST VM LMZ 6)

120–80 cm (500–1200 cal AD; *Stagnicola palustris-Bithynia tentaculata* local malacological zone)
This local malacological zone indicates the decrease of the vegetation cover. The open water surface increased and species preferring a eutrophic lacustrine environment spread. The malacofauna indicates a milder climate at the end of the Migration period and the beginning of the Middle Ages.

The decrease of the vegetation cover may have been caused by human impact, as sedge leaves were used to cover houses and insulate roofs. Human disturbance increased in the vicinity of the basin.

Császártöltés–Vörös-mocsár Local Malacological Zone 7 (CST VM LMZ 7)

80–40 cm (1200–1600 cal AD; *Valvata cristata-Anisus spirorbis* local malacological zone)
The malacofauna (terrestrial species, especially waterside taxa) indicates that the lake periodically dried up and smaller lakes covered by vegetation made up the basin. Infilling accelerated in the second part of the Medieval period when the basin, or a part of it, periodically dried up. Terrestrial vegetation spread in the basin and the vegetation cover reached its maximum. Human impact declined in the second part of the Medieval period on the floodplain, probably as the human settlement and along with this, land use was shifted to the high bluff.

Császártöltés–Vörös-mocsár Local Malacological Zone 8 (CST VM LMZ 8)

40–0 cm (last 400 years; *Anisus spirorbis-Succinea oblonga* local malacological zone)
The end phase of infilling, with the bog periodically drying up. The climate became colder and cooler and Eurosiberian malacofauna, which is typical on watersides, humid meadows, and in willow bogs, became dominant. The temperature of the growing season decreased during

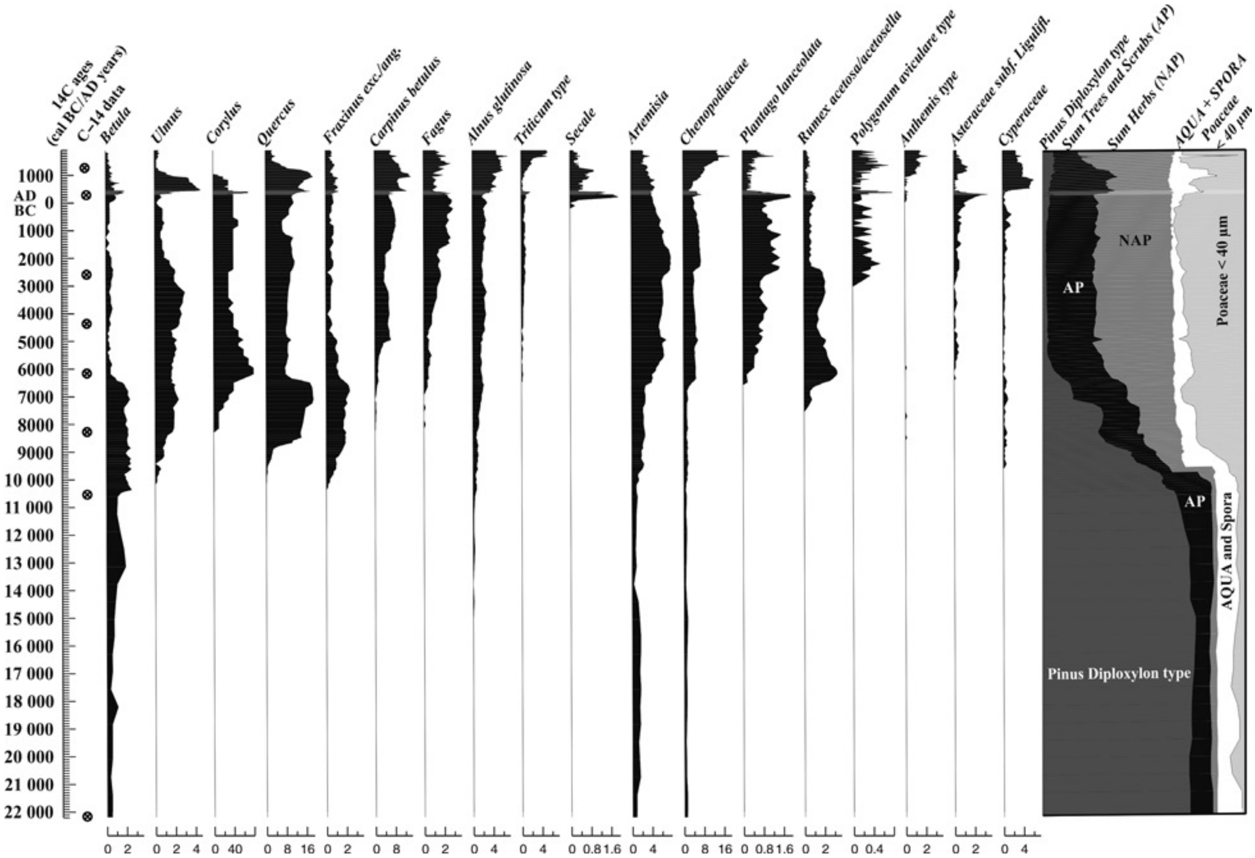

Fig. 18. Pollen percentage diagram for the undisturbed core sequence from Kaszálók Mire at Hajós. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

this phase and peat decay, and pedogenesis started at the end of the Middle Ages, continuing during the Ottoman occupation of Hungary. This natural process accelerated in the 20th century as a result of peat mining and groundwater level management.

Discussion

On the basis of the radiocarbon, sedimentological, geochemical, macrobotanical, pollen analytical, and malacological data, the evolution of the two study sites correlates well with each other, although there are some differences too, which can be attributed to the biogenic nature of infilling at the Hajós site, a basin that is much older than the oxbow lake at Császártöltés. The environmental and vegetation development of the two study sites are presented together *(Figs 18–23)*.

MIS3 level (24 000–22 000 cal BC)

The oxbow lake at Hajós was formed at the end of the Pleistocene, during MIS3 (Dansgaard et al. 1982; 1993), a warming period called the Dansgaard-Oeschger 3 event (Johnsen et al. 1992; Grootes / Stuiver 1997; van Kreveld et al. 2000), approximately between 26 000–27 000 BP (Fairbanks et al. 2005). During the riverine phase a decayed silicate-rich sand accumulated with *Valvata naticina* species indicating a mild climatic phase. Oxbow lake sediments accumulated from MIS3 / MIS2. The MIS3 level corresponds to the Upper Gravettian (Krolopp / Sümegi 1990; 1991; 1992; 1995; Sümegi / Krolopp 1995; 2002; Sümegi 1996; 2005a; 2014). Settlements dating from this period can be found in the Sub-Carpathian region where an open spruce parkland vegetation developed (Sümegi 1995; 1996; 2005a; 2011; 2014; Sümegi et al. 2000; Sümegi / Rudner 2001; Rudner / Sümegi 2001; 2002). On the basis of recently available data, the environments evolving in the southern and northern part of the Carpathian Basin differed during the earliest Gravettian (Sümegi 1995; 1996; 2005a). These environmental habitats may have influenced the distribution of Upper Palaeolithic populations (Gábori 1980; 1981; 1984).

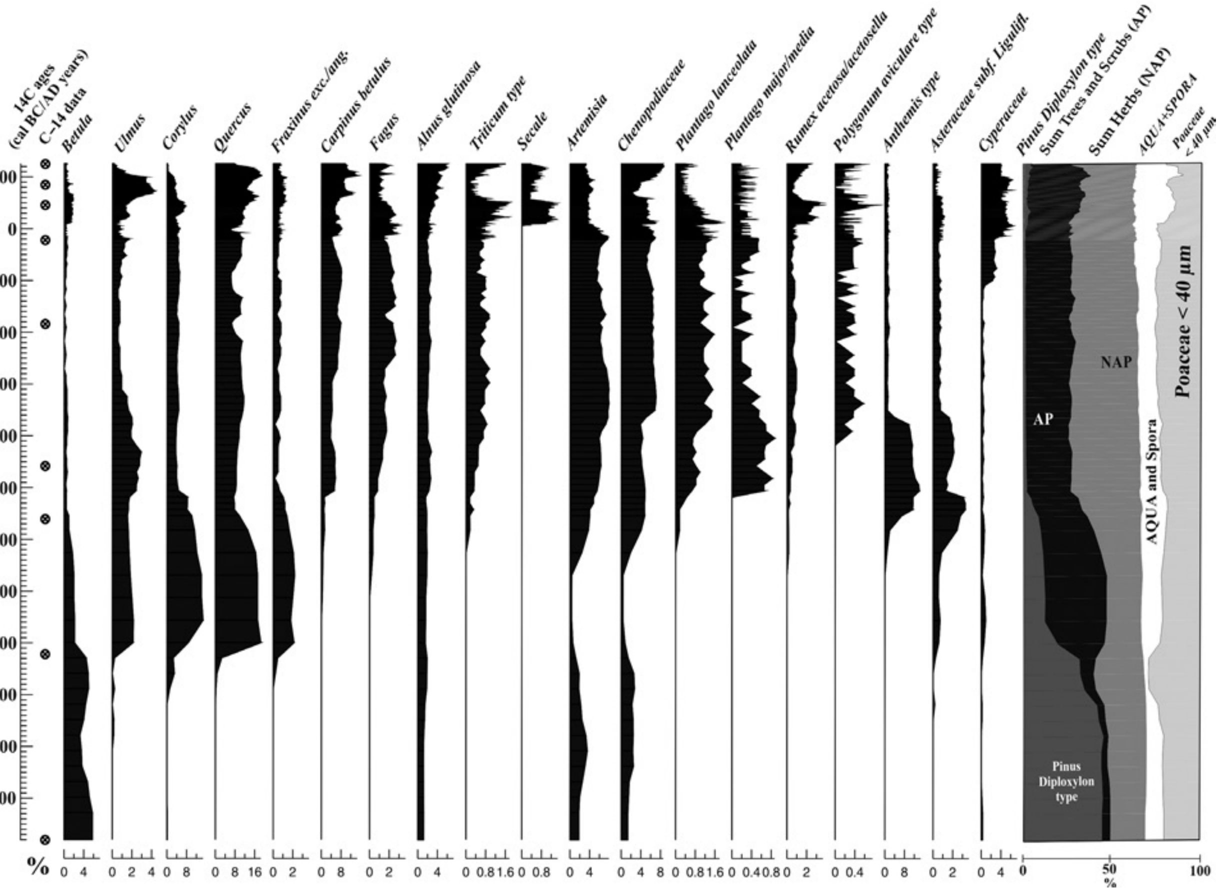

Fig. 19. Pollen percentage diagram for the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

MIS2 level (23 000–14 000 cal BC)

From 23 000 cal BC, lacustrine sediments composed mainly of silt and containing decayed silicate grains accumulated *(Fig. 22)*. The macrobotanical analysis indicates the development of *Equisetum fluviatile* associations on the edge of the organic material-rich and vegetation-poor oligotrophic lake. Sporadic *Phragmites communis* preferring a milder climate appeared as well. This indicates the Dansgaard-Oeschger 2 climate event in the MIS2 phase and that vegetation development in the southern Great Hungarian Plain differed from the general environmental model for Central Europe (Sümegi / Krolopp 1995; 2002; Sümegi 2005a). Accordingly, the study area in the Danubian alluvial region had more favourable temperature conditions on a local and regional level than other sites in the European loess belt at the end of the Pleistocene (Sümegi / Krolopp 1995; 2002; Sümegi 2005a; Sümegi et al. 2013a). The low, but sporadic presence of reed during MIS2 can probably be explained by this mild climate (Jakab et al. 2004a; 2004b). At the same time, the pollen composition is very specific in MIS2 and very similar to the Kardoskút-Fehér-tó profile east of the Tisza (Sümegi et al. 1999; 2013a).

The absolute and continuous dominance of pines characterises the level. This contradicts every palaeoecological finding of the Upper Pleistocene in the study area and can possibly be explained by the oxbow lake beneath the high bluff, which may have represented a specific pollen trap. A mixed taiga forest with *Alnus*, *Betula*, *Larix*, *Pinus silvestris*, and *Pinus cembra* thrived in the immediate vicinity of the oxbow lake and the high bluff. At the same time, on the basis of the low pollen concentration and the presence of *Pinus mugo*, *Betula nana*, *Hyppophaë rhamnoides*, *Selaginella selaginoides*, *Artemisia*, and Chenopodiaceae, there were also Boreal steppe, forest steppe, and tundra patches in the mixed taiga forest. Thus, a mosaic of tundra, Boreal taiga, and cold steppe developed at the study site during MIS2.

This vegetation profile differs from the homogeneous tundra-cold steppe vegetation model and from the German vegetation model (Járainé-Komlódi 1966a; 1966b; 1966c; 1968; 1969; 2000; 2003; 2006) that was incorrectly generalised for the entire territory of Hungary and is still used for characterising the vegetation of

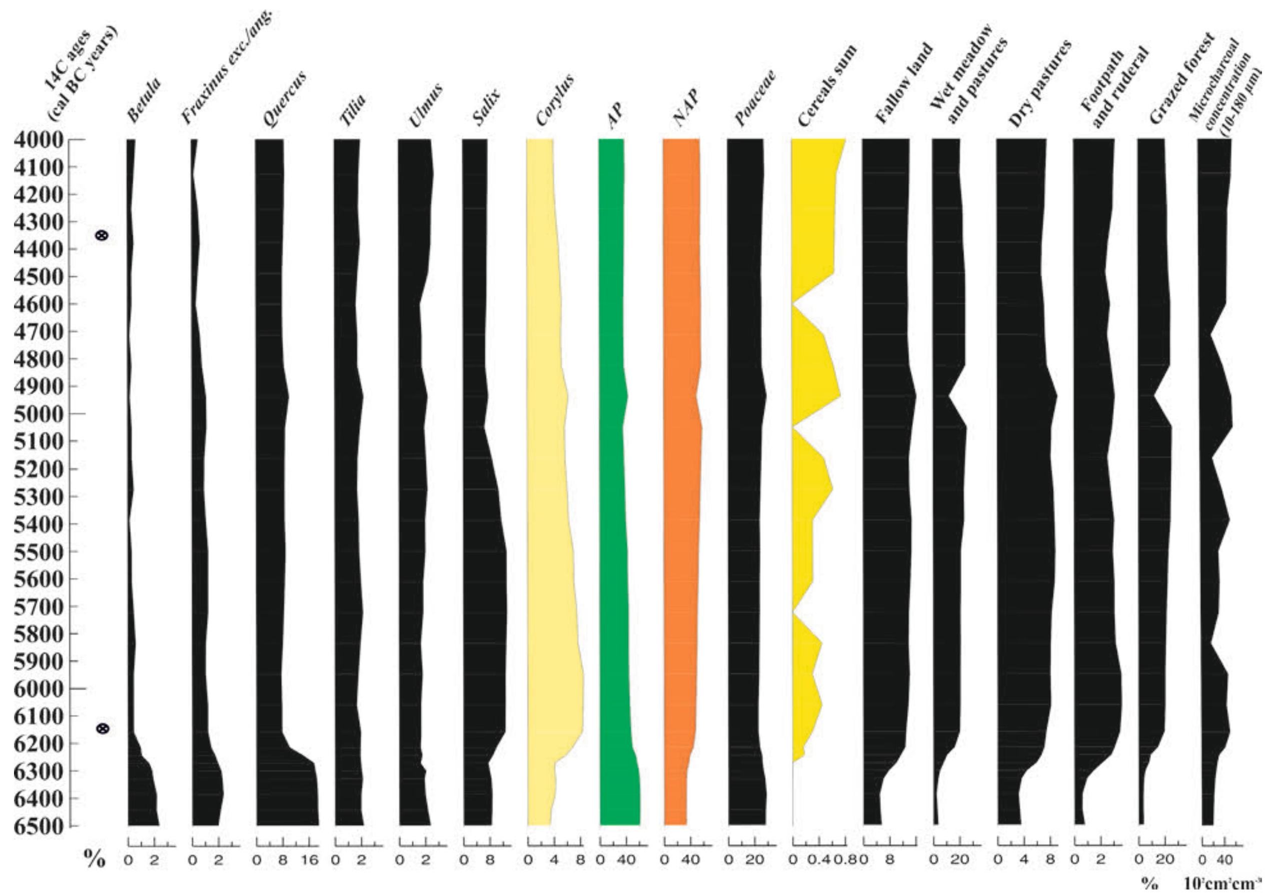

Fig. 20. Pollen percentage diagram and microcharcoal content change for undisturbed core sequence between Late Mesolithic and Middle Copper Ages from Kaszálók Mire at Hajós. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

Hungary during the Upper Pleistocene (Gábris 1995; 1998; Gábris et al. 2002; Kiss et al. 2015). As has been shown by József Stieber, a Hungarian palaeobotanist active in the mid-20th century (Stieber 1956; 1967; 1968; 1969), and also by our own studies (Sümegi 1996; 2005a; Sümegi et al. 1999; Jakab / Sümegi 2011; Törőcsik et al. 2015), these models are untenable and incorrect, and should no longer be used for vegetation reconstruction in Hungary.

The vegetation and fauna development of the Great Hungarian Plain also differs from that of the Western, Northern, and Eastern Europe (Sümegi 1996; 2005a; Sümegi / Krolopp 2002) due to the basin effect (Sümegi 1995), the significant distance from the ice sheet during the Pleistocene (Sümegi et al. 2012a; 2012b), and the refuge areas in the basin (Sümegi 1995; 1996; 2005a; Willis et al. 1995; 2000). Models that try to homogenise the environment and vegetation evolution of the Carpathian Basin during MIS2 on the basis of a single pollen profile or on the evidence of a single site may lead to questionable results (Gábris 1995; 1998; Járainé-Komlódi 2000; 2003; 2006; Magyari et al. 2010a; 2010b; 2012; Kiss et al. 2015). Since we want to avoid this mistake, we emphasise that our vegetation and environment reconstructions are on the local-regional scale and are valid for the Danube alluvial region in the Danube-Tisza interfluve, and that they can hardly be extrapolated for the entire Great Hungarian Plain.

Regarding floral and faunal development, two important points can be made: first, that the high bluff was drier, and second, that the south-western and western part towards the alluvial plain was more humid, with a significant forest cover even during glaciations or arid periods. Moreover, the Danubian alluvium had a colder, but more humid micro-climate. This hydroseries in surface humidity and temperature enabled the development of a diverse vegetation from the high bluff to the alluvial plain, which constituted the forest steppe vegetation. The malacological and phytolith analyses of loess profiles support the vegetation picture of forest steppes (Sümegi / Krolopp 1995; Sümegi 1995; 1996; 2005a; Willis et al. 2000; Rudner / Sümegi 2001; Sümegi / Rudner 2001; Persaits / Sümegi 2011; Páll et al. 2013), as does the independent plant biomarker analysis (Zech et al. 2009).

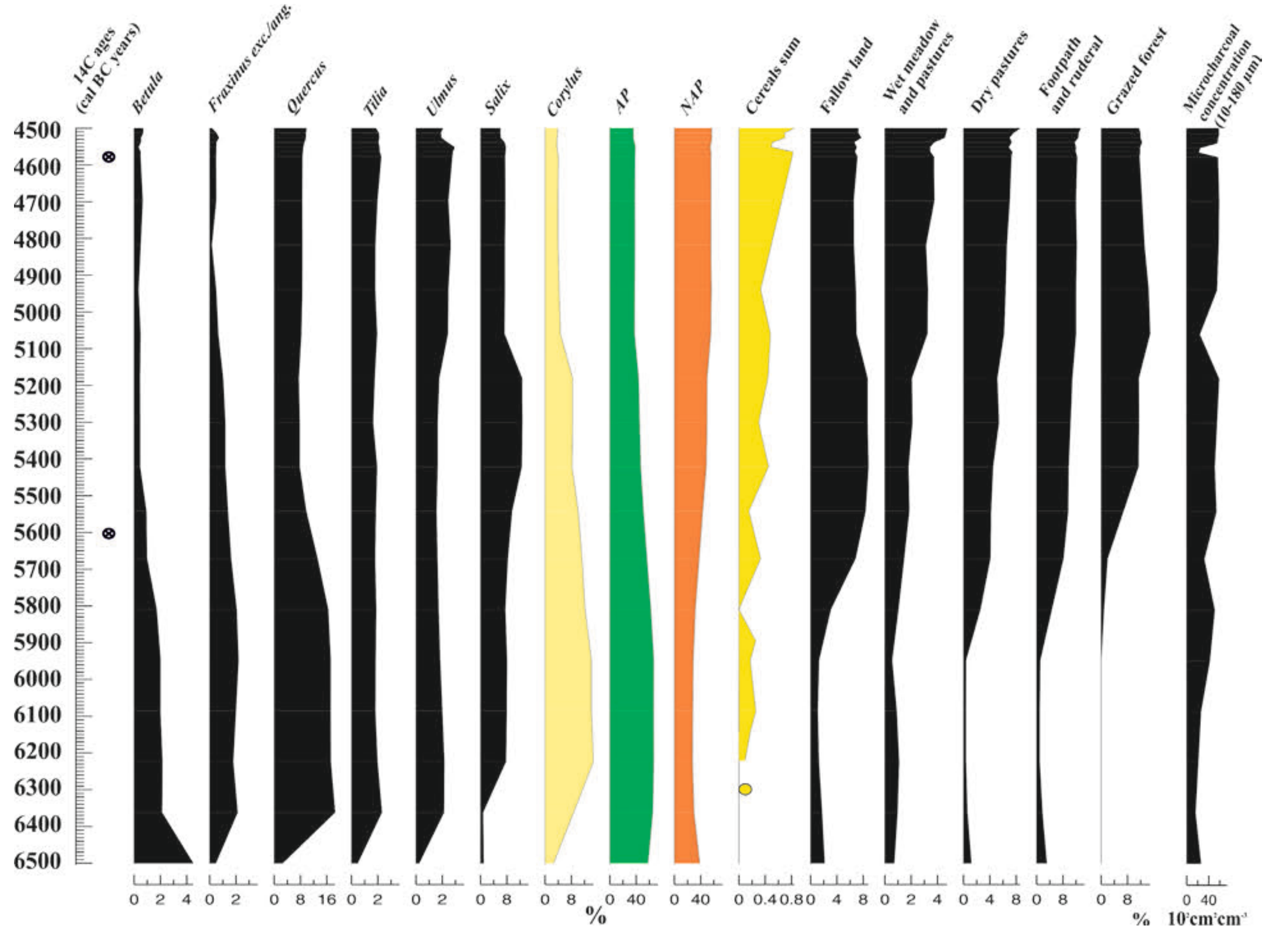

Fig. 21. Pollen percentage diagram and microcharcoal content change for undisturbed core sequence between Late Mesolithic and Middle Copper Ages from Vörös-mocsár (Red Marsh) at Császártöltés. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

During MIS2, Upper Gravettian hunters appeared on the Great Hungarian Plain (Banner 1936; Dobosi 1967; 2000), who followed their prey that lived in taiga habitats (Sümegi 1996; 2005a; 2011; 2014). The environmental historian Sturdy (1975) assumed that herbivores moved from the mountainous zone of the Alps and the Carpathians to the heartland of the Carpathian Basin and to the southern taiga patches at the beginning of the Gravettian.

The migration of caribous is related to the alternation of the seasons, as they tended to dwell in the tundra during the summertime and retreated to the taiga belt during the winter (Jarman et al. 1982). Their migration between the two belts or zones occurred during spring and autumn. Palaeolithic hunters specialising in the hunting of these animals, which served as a basis of their subsistence, generally pursued the herds throughout their migration (Sturdy 1975; Jarman et al. 1982). Caribous probably migrated between the taiga areas of the Carpathian Basin and the tundra regions enclosing it from the north and west between 16 000–18 000 BP (Sturdy 1975); because according to a more recent analysis of vertebrate remains, the caribous were hunted during the winter in the Carpathian Basin (Vörös 1982), during the period when the caribous dwelt in the taiga zone. The migration of the caribous to the winter taiga zone is an annual process triggered by the lack of food resources and unfavourable conditions of the tundra in wintertime and the presence of lichens as a food source in relation to the coniferous vegetation in the taiga. Thus, it is not surprising that the southern margin of the taiga zone coincides with the southern limit of the migration of caribous. Consequently, during the Late Würmian, Transdanubia or, on a broader scale, the southern margins of the Carpathian Basin marked the southern boundary of the distribution of caribous (Vörös 1982; 1987; 2000).

Our findings indicate that a pine *(Pinus silvestris)*-dominated taiga patch existed in the transition zone between the high bluff at Hajós and the Danubian alluvial plain. It is therefore hardly surprising that a campsite of Upper Gravettian hunters was excavated at the Madaras loess profile (Dobosi 1967), a site lying close to Hajós, and that prey bones and stone tools were found in the Katymár loess profile (Sümegi 1996; 2005a; 2011; 2014).

Late Glacial level (14 000–9600 cal BC)

At the beginning of the Late Glacial, the oxbow lake at Császártöltés evolved *(Figs 22–23)*. Lake reed, sedge, and *Equisetum fluitantis* expanded in the waterfront area and in the oxbow. During the Late Glacial, the number of steppe elements increased, while cold-preferring species such as *Betula nana*, *Pinus cembra*, *Pinus mugo*, and *Larix* disappeared. Diverse, mild climate preferring elements *(Corylus*, *Ulmus*, *Quercus*, *Fraxinus)* thrived in the Boreal forest steppe in the study areas.

On the basis of the vegetation changes in the southern Great Hungarian Plain, which also marked the southern boundary of the Eurasian Loess Belt (Sümegi 2005a), a significant vegetation cover evolved during colder climatic phases as a result of the more humid local environment, while a steppe-forest steppe environment existed during warmer phases (Sümegi et al. 2012a; 2012b; 2013a).

The Hajós and Császártöltés profiles indicate the development of a mosaic-like forest steppe environment between 16 000 and 14 000 cal BC in MIS2. This environment persisted during the Late Glacial as well; however, the open vegetation patches expanded and thermophilous trees and shrubs replaced cold-loving elements. It would appear that the vegetation structure that dominated the Great Hungarian Plain throughout the Holocene developed at the end of the Pleistocene, during the Late Glacial. Differences can be attributed to the species composition in the forest steppe. These observations support the models according to which the entire Great Hungarian Plain had not been reforested at the beginning of the Holocene. At the same time, it is obvious that the forest steppe appearing at the end of the Pleistocene adapted to the climatic conditions of the Holocene and that the species composition changed (Sümegi 1986; 1989; 1995; 1996; 2005a; 2011; Sümegi et al. 1999; 2005; 2006; 2011a; 2011b; 2011c; 2012a; 2012b; 2013a; 2013b), and also that there was no cold steppe / warm steppe transition at the Pleistocene / Holocene boundary as had been modelled earlier. Our data prove that the pollen profiles from the Tisza alluvial plain in the northern Great Hungarian Plain (Chapman et al. 2009; 2010; Magyari et al. 2010a; 2010b; 2012; Magyari 2011) cannot be extrapolated for the entire Great Hungarian Plain because it is not a homogeneous landscape (Sümegi 1989; 1995; 1996; Willis et al. 1995; Willis 2007).

One of the perhaps most significant palaeoecological findings of the Hajós and Császártöltés profiles is that they provide additional confirmation for earlier models regarding the existence of a mixed, transitional flora and fauna in the Carpathian Basin during the Late Glacial (Sümegi 1986; 1989; 1995; 1996; Sümegi et al. 1999; Sümegi / Krolopp 1995; 2002; Willis et al. 1995). The fact, that cold resistant and cold preferring flora and fauna elements of the Pleistocene and vegetation elements preferring a milder climate – that exist today in the Holocene – occur together in these profiles, implies that they existed simultaneously during the Upper Pleistocene (Sümegi 1986; 1989; 1995; 1996; 2005a; Sümegi / Krolopp 1995; 2002; Sümegi et al. 1999). This double refuge effect is best seen in the malacofauna composition of the Carpathian Basin in the Upper Pleistocene (Willis et al. 1995; Sümegi 1995; 1996; 2003b; 2003d; 2005a).

The forest-covered areas may have expanded on the Danubian alluvial plain during the Late Glacial, but the micro-environment of the high bluff became drier due to climatic warming when the steppe environment spread. The Late Glacial stratigraphic horizon is the most problematic in the Carpathian Basin since we hardly have any data from between 14 000/13 000 and 9700 BP. The few assemblages from this period come from caves in the Sub-Carpathian region (Jánossy 1962; Vértes 1965), but these are not radiocarbon dated (Sümegi 1996; 2007b; 2010; Sümegi et al. 2012b; Sümegi / Náfrádi 2015). Based on our own studies (Sümegi 2007a; 2010; Sümegi et al. 2012b; Sümegi / Náfrádi 2015), we can cite traces of human impact during the Epipalaeolithic, the Early Mesolithic, and the Late Mesolithic that could indicate the adaption of some population groups to the environmental changes (Vértes 1965; Tortosa et al. 2002; Sümegi 1996; 2004a; 2010; Sümegi et al. 2012b; Sümegi / Náfrádi 2015). The environmental change led to the transformation of the composition of vegetation and prey and, as a result, led to changes in the lifestyle and habitat of the different hunter-forager groups living in these landscapes (Sümegi 2004a; 2010). This is supported by global archaeological and palaeoenvironmental data from the Late Glacial (Baied / Wheeler 1993; Goring-Morris / Belfer-Cohen 1997; Tchernov 1997; Heinz / Barbaza 1998; Bar-Yosef 2002).

We can reconstruct similar processes in our study areas, where the oligotrophic lacustrine environment was transformed into a brown moss bog and a mesotrophic environment as a result of vegetation change and organic material accumulation in the Late Glacial. Our data support the earlier findings on a Boreal forest steppe dominance mixed with temperate elements in the region (Sümegi 1986; 1989; 1996; 2005a; 2005b; 2005c; Sümegi et al. 2012a; 2012b). This diverse landscape offered different options for hunting and foraging during the Upper Palaeolithic and the Epipalaeolithic. Still, it

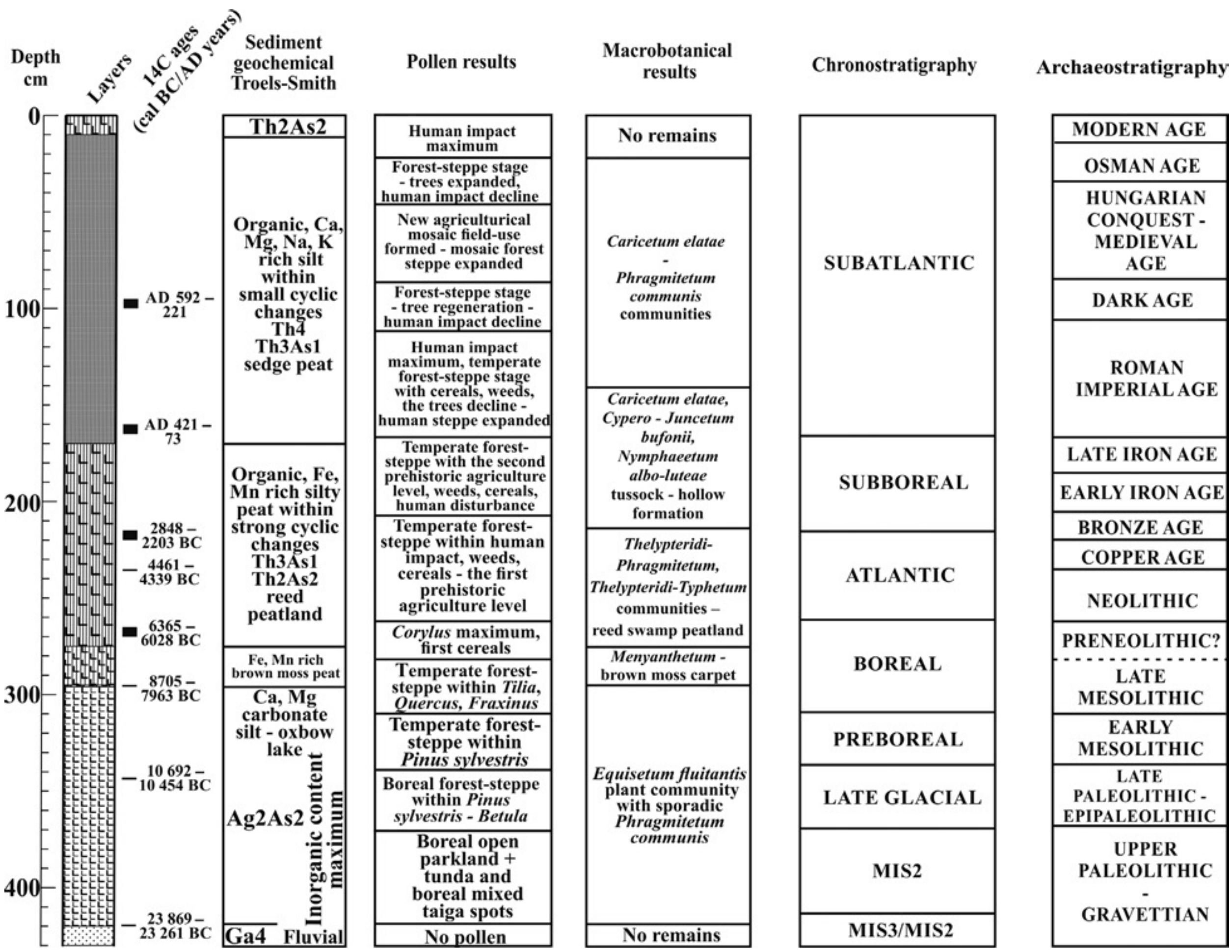

Fig. 22. Description of litostratigraphic, sedimentological, geochemical, pollenanalytical, macrobotanical, chronostratigraphic, and archaeostratigraphic zones for the undisturbed core sequence from Kaszálók Mire at Hajós.

must be borne in mind that the archaeological sites of these periods are barely known in the Carpathian Basin (Vértes 1962; 1965; Sümegi 2004a; 2005a). These settlements were possibly sited in greater number along the dendritic river system in the Danube Valley. The discovery and excavation of such a site would be highly important for the identification of Epipalaeolithic cultural formations in the Carpathian Basin.

Early Holocene / Pre-Boreal level (9600–8200 cal BC)

This chronological level was earlier interpreted as the expansion phase of birch-pine and mixed taiga forests across the entire Carpathian Basin (Zólyomi 1952; Járainé-Komlódi 1966c; 1987; Zólyomi / Fekete 1994; Gábris 1995; 1998; 2006; Gábris et al. 2002). However, the evidence from Hajós and Császártöltés as well as from profiles farther north in the Danube-Tisza interfluve, in the Jászság, and east of the Tisza, from the Hortobágy and Hajdúság palaeoecological sites rather indicate that a forest steppe vegetation dominated during this period (Sümegi 1986; 1989; 1996; 2005a; 2007a; 2007b; Sümegi et al. 2005; 2006; 2008a; 2008b; 2012a). This view is supported by recent biological observations as well as by biogeographical and historical models (Molnár 1996; Molnár / Borhidi 2003; Fekete et al. 2002; 2012; 2014; Chapman et al. 2010; Magyari et al. 2010a; 2010b; 2012; 2014; Molnár et al. 2012).

The Danubian alluvial plain was covered with mixed *Betula-* and *Pinus sylvestris*-dominated forest with thermophilous trees and shrubs *(Ulmus*, *Tilia*, *Quercus*, *Fraxinus*, *Corylus)*, while a temperate steppe-forest steppe dominated by Gramineae, *Artemisia*, and Chenopodiaceae developed on the high bluff. The regional vegetation is forest steppe, as shown by the pollen ratio of trees and shrubs that was around 60 %.

The macrobotanical record reflects a brown moss bog at the Hajós site at the beginning of the Holocene, while at the Császártöltés site, the oligotrophic lake sys-

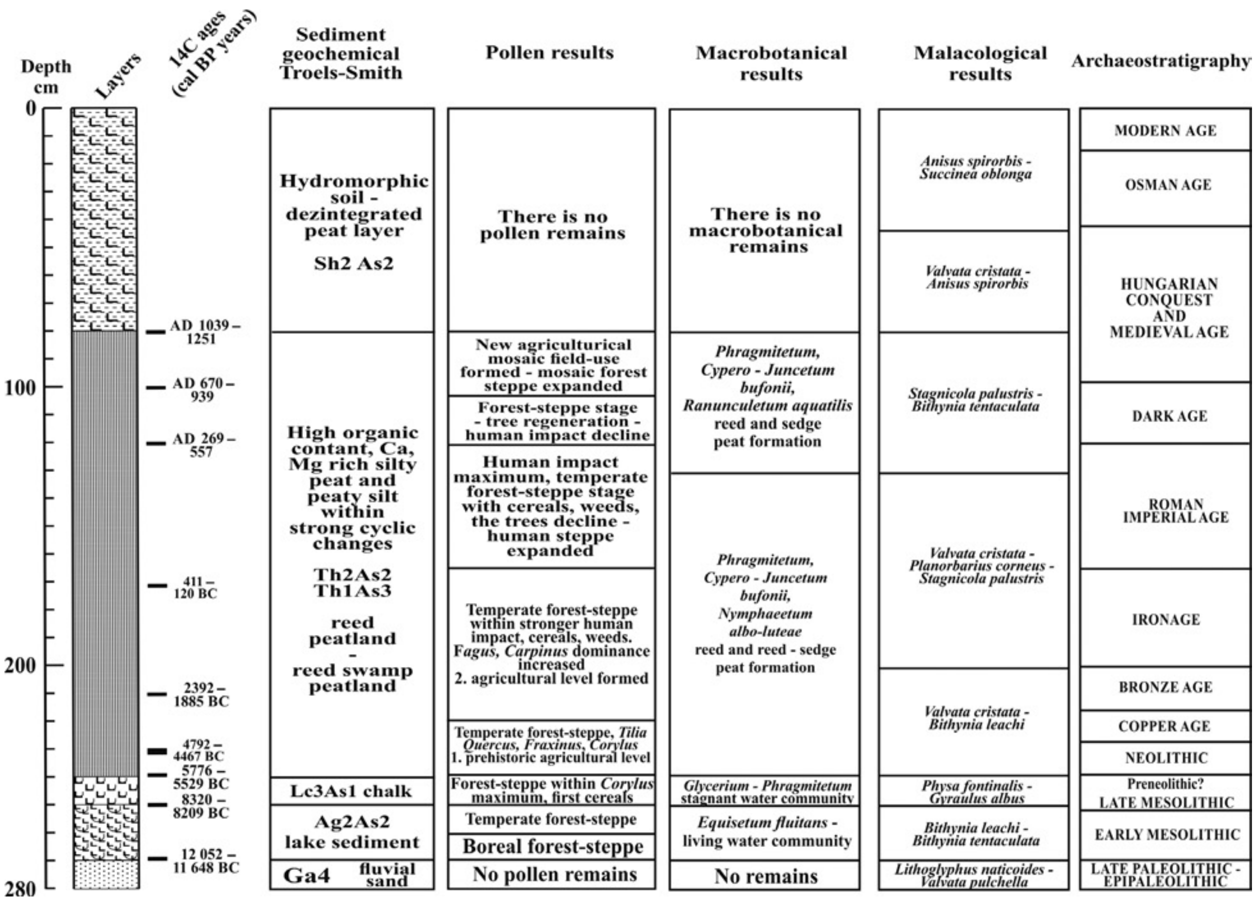

Fig. 23. Description of litostratigraphic, sedimentological, geochemical, pollenanalytical, macrobotanical, chronostratigraphic, and archaeostratigraphic zones for the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés.

tem, was transformed into a mesotrophic *Chara* lake. The basins showed diverse chemical characteristics due to different processes of infilling and element accumulation of plants. As a result, a calcium-, potassium-, and magnesium-rich *Chara* lake poor in phosphorus and phosphate evolved at Császártöltés. Clean chalk accumulated in an alkaline environment in this lacustrine environment, while at Hajós, an acidic character evolved due to the brown moss bog environment.

A mosaic local environment developed as a result of different biogene infilling on the Danubian alluvial plain in the Early Holocene. Thus, although a broadly similar Early Holocene flora and fauna development can be reconstructed regionally, there were sometimes also significant differences between sites lying close to each other (Sümegi 2004a), again underscoring that models suggesting a homogeneous environment on the Great Hungarian Plain cannot be accepted (Zólyomi 1952; Járainé-Komlódi 1966c; 1987; Zólyomi / Fekete 1994; Gábris 1995; 1998; 2006; Gábris et al. 2002).

The macrobotanical (Watts 1967; 1978; 1980; Jakab / Magyari 1999), pollen analytical (Stieber 1967; Cushing 1967), and malacological data (Sümegi 1989; 1996; 2005a; 2007b) reflect local environmental changes. We can reconstruct the flora and fauna of the regional units through the comparison of the local data (Birks / Birks 1980).

The pollen profiles from various sites farther north in the Danube-Tisza interfluve, in the Jászság (Sümegi 2004b; 2004c), east of the Danube, on the Great Hungarian Plain, at Izsák (Sümegi et al. 2011a), Hortobágy (Sümegi et al. 2005; 2006; 2013a), Maroslele (Sümegi et al. 2011b), Polgár (Sümegi et al. 2002; Magyari et al. 2010a; 2014), and Mezőföld (Willis 1997) yielded similar results regarding the Early Holocene. The ratio of trees and shrubs varied, but was always invariably between 50 % and 70 %, corresponding to a forest steppe vegetation (Magyari et al. 2010a; 2010b; 2014). In contrast, the ratio of trees exceeded 70 %, indicating a closed forest, especially a mixed taiga forest, during the Pre-Boreal phase in the profiles from the Sub-Carpathian region (Stieber 1967; Willis et al. 1997; 1998; Gardner / Willis 1999; Gardner 1999; 2002; 2005; Sümegi et al. 2009b; Sümegi 2010), the Alpine foreland (Sümegi et al. 2011c), Lake Balaton (Sümegi et al. 2008c; 2009b), and the fringes of the

Great Hungarian Plain (Willis et al. 1995). At the same time, a *Tilia*-dominated forest persisted along the rivers and streams of the Partium region in north-western Romania (Willis et al. 1995).

Early Holocene / Boreal level (8200–6000 cal BC)

The brown moss bog still existed at Hajós, while the *Chara* lake phase dominated at Császártöltés. This phase can be described by an alkaline environment preferring malacofauna. The oxbow lakes were enclosed by a temperate forest steppe environment, while a temperate hardwood gallery forest developed, mainly with *Quercus*, *Ulmus*, *Fraxinus*, *Tilia*, and *Corylus* on the Danubian alluvium. The dominance values of *Pinus sylvestris* and *Betula* decreased. On the high bluff, the ratio of non-arboreal taxa increased and the temperate steppe-forest steppe vegetation became stable. The Boreal phase was characterised by a similar vegetation structure as in the Pre-Boreal phase, although with a higher proportion of temperate trees and shrubs. Thus, a loess- and sand-covered dry steppe and a temperate hardwood gallery forest can be reconstructed for the second half of the Mesolithic (Sümegi 2010; Sümegi et al. 2012b). In other words, a Boreal forest steppe evolved during the Early Mesolithic and a temperate forest steppe in the Late Mesolithic. This change in the vegetation can be noted at other sites to the east, on the Great Hungarian Plain as well, for example at Kiskunság, Hortobágy, and the Lower Tisza region, as well to the west, in the Transdanubian Mezőföld region (Willis 1997; 2007; Sümegi 2003d; 2007b; 2007c; Sümegi et al. 2005; 2006; 2011b; 2012a). The mixed taiga and lime forests in the forested zone of the Great Hungarian Plain were transformed into closed oak forests (Stieber 1967; Willis et al. 1995; 1997; 1998; 2000; Sümegi et al. 2008a; 2009a; 2009b; 2011a; 2011b).

The most important vegetation change was the *Corylus* peak that can be observed during the Late Mesolithic. This peak appears in profiles from other sites as well, both in Transdanubia, near Balatontördemic and at Zalavár in the Balaton region, in the Alpine foreland, and at other sites in western Hungary (Sümegi 1997; 1998; 1999; 2003c; 2004b; 2010; Sümegi et al. 2008b), and in eastern Hungary, as at Mohos and in the Tiszahát region (Willis et al. 1998; Magyari et al. 2000; 2001; 2008). These *Corylus* peaks may be linked to the activity of Mesolithic population groups: the spread of this bush can probably be linked to deliberate action such as clearing heavily forested areas to create hunting paths (Sümegi 1998; 1999). Besides the spread of *Corylus*, a growing proportion of *Hedera* pollen can perhaps also be linked to Mesolithic activity (Magyari et al. 2001; Sümegi 2004a; 2004b; 2013; Sümegi et al. 2011b).

The *Corylus* pollen peak in the Late Mesolithic corresponds to 6500–6000 cal BC at Hajós and Császártöltés (cf. *Figs 18–21*). This provides important information from the southern Danubian area regarding the prelude to the Neolithic (Bánffy et al. 2007b). Additionally, horizons of the same period from other radiocarbon-dated profiles have been investigated in detail from other regions in the Carpathian Basin such as the Bátorliget I (Willis et al. 1995) and Bátorliget II profiles (Sümegi 2004a) in the Partium region, the Kelemér-Kis-Mohos (Willis et al. 1997; 1998; Sümegi et al. 2008a; 2008b), Kelemér–Nagy-Mohos (Magyari et al. 2000; 2001; Sümegi et al. 2008a; 2008b), Nagybárkány-Nádas-tó (Sümegi et al. 2009a) and Sirok profiles (Gardner 2002; 2005; Jakab / Sümegi 2010; 2011; Náfrádi et al. 2012) in northern Hungary, the Kolon-tó (Sümegi et al. 2011a), Ecsegfalva-Kiri-tó (Willis 2007; Sümegi / Molnár 2007), Polgár-Selypes-ér (Sümegi et al. 2002), Tiszagyulaháza-Sarlóhát (Gábris et al. 2001a; 2001b, 2004; Magyari 2011; Magyari et al. 2010a; 2010b; 2012; Chapman et al. 2010; Fekete et al. 2012; 2014), Csaroda-Nyíres-tó (Sümegi 1999), Csaroda–Báb-tava (Magyari et al. 2008), Maroslele-Pana (Sümegi et al. 2011c) and Ócsa–Selyemrét profiles (Veres et al. 2011) on the Great Hungarian Plain, the Sárrét-Nádasdladány (Willis 1997; Sümegi 2003a; 2007a; 2007b), Sárrét-Sárkeszi (Sümegi 2007a; 2007b), Balatonederics (Sümegi et al. 2008c) and Fenékpuszta profiles (Sümegi et al. 2009b; 2011b) in Transdanubia, and the Szombathely-Zanat profile (Sümegi et al. 2011c) in the Alpine foreland.

From the second half of the Mesolithic, *Pinus sylvestris*, *Betula*, and *Tilia* declined significantly in the Carpathian Basin, accompanied by the arrival of *Quercus*. According to the palynological record, a closed oak woodland and oak-dominated forest steppe developed in the Carpathian Basin under more balanced, milder, and wetter climatic conditions (Sümegi et al. 2012a; 2012b). According to our data, the hunter-forager Mesolithic communities probably settled in the closed oak forested regions in the north-easterly areas of the Great Hungarian Plain and the foothills of the Carpathians, where they had sufficient water supply. The palynological and radiocarbon analysis of the deposits of an oxbow lake lying near Mesolithic archaeological sites in the Jászberény area likewise indicated the development of closed oak hardwood gallery forests during the second part of the Mesolithic (Kertész et al. 1994; Sümegi 2002; 2005c).

This palaeoenvironmental transformation at the Pleistocene / Holocene boundary and in the Early Holocene reflected in different profiles from the Great

Hungarian Plain can perhaps be correlated with the evidence for the environmental transformation during the Mesolithic from Franchthi Cave on the Greek coast, where this was reflected in the changes of the composition of the malacofauna piles. The presence of *Cyclope neritea*, a species preferring a significant water cover, most likely marked the flooding of the coastal areas (Shackleton / van Andel 1980; van Andel et al. 1980) and the development of a maximum water level in the Eastern Mediterranean (Williams et al. 1978). These changes were apparently triggered by the more intensive melting of the gradually retreating continental ice sheets and glaciers during this period, yielding an increased freshwater supply for the seas. This process resulted in the rise of global sea levels and the flooding of shelves and river estuaries (Adamson et al. 1980).

The palaeoenvironmental data (Sümegi et al. 2002) and the transformations observable in the Mesolithic industries of the Carpathian Basin around 9000 cal BC (Kertész et al. 1994; Kertész 1996) marked an important point in the subsequent development of the Mesolithic groups of the Great Hungarian Plain as well: this period saw the appearance of new technocultural components in lithic tool kits, which are generally typical for the second half of the Mesolithic (Kertész 1996). On the other hand, no technical innovations (such as trapezoid blades) appeared that were related to the latest Mesolithic horizon. The analysis of samples from the Jászberény I Mesolithic site lacking trapezoidal blades yielded radiocarbon dates of 7537–6451 cal BC (based on calib 700), and thus the appearance of these tools occurred later, during 7000–6500 cal BC.

An important palaeoenvironmental fact regarding the archaeology and history of the Mesolithic communities of the Carpathian Basin is that the hinterland of the Mesolithic settlements in the closed oak forests of the alluvial plains and sand hummocks in the northern Great Hungarian Plain was characterised by a closed pine-birch mixed taiga vegetation in the mid-mountain zone (Sub-Carpathian, Sub-Alpine) even around 9000 BC (Willis et al. 1995; 1997; 1998; Sümegi 1998, 2004a; 2004b; 2009; Magyari et al. 2001; Gardner 2002; 2005). Several Mesolithic sites characterised by a different raw material usage, but nonetheless closely linked to the Mesolithic industries of the northern Great Hungarian Plain (Kertész 1996), have been excavated in these background areas, for example at Smolín, Kamegg, Sered I, and Barca I (Prošek 1959; Bárta 1980; 1981). According to the archaeological evidence, the Mesolithic sites of the northern Great Hungarian Plain, the Sub-Carpathian, and Sub-Alpine regions are located north of the Balkanic Tardigravettian distribution and represent regional variants of the local industries following Epigravettian traditions, in which western stone production techniques and the Sauveterrian and Beuronian cultural components are of primary importance (Kertész 1996). The Mesolithic sites on the alluvial fans of the northern Great Hungarian Plain fit into this northern zone (Kertész 1994), while those of the Sub-Carpathian region fit into the Mesolithic of the Tisza Valley (Bárta 1981).

The latter groups were interpreted as special local subgroups of the Epigravettian, derived from the Gravettian and characterised by a mixed culture employing western stone production techniques as well. In contrast to Kertész's (1996) opinion, these groups did not occupy the continental forest steppe regions, but rather the closed woodlands of different composition (oak and pines alternatively) during the 9th–8th millennia cal BC. Thus, the flora, fauna, and the soils occurring in the distribution areas of the two groups with differing raw material structures correlates with this fundamental difference (Willis et al. 1995; 1997; 1998; Sümegi 1998; 1999; 2003b; 2003c; 2003d; 2004a; 2004b; 2007a; 2007b; 2007c; 2013a; 2013b; Sümegi et al. 2002; 2011a; 2011b; 2011c; Magyari et al. 2001; 2008; 2010a; 2012; Gardner 2002; 2005; Feurdean et al. 2007; 2014; Náfrádi et al. 2013), suggesting that the differing natural environment possibly played a role in the emergence of cultural differences during the Mesolithic.

At the close of the 8th millennium cal BC and the beginning of the 7th millennium cal BC, the vegetation differences between the northern Great Hungarian Plain, the Sub-Carpathian, and the Sub-Alpine regions disappeared, resulting in the emergence of a relatively uniform vegetation of closed deciduous woodlands, rich in species and characterised by a dominance of oak and hazel, up to an elevation of 600 m a.s.l. The zone between 600 and 1000/1200 m was occupied by mixed deciduous woodlands dominated by lime, spruce, and Scotch pine (Stieber 1967; Willis et al. 1997; 1998; Farcaş et al. 1999; Gardner 1999; 2002; 2005; Magyari et al. 1999; 2000; Tantau et al. 2006; Sümegi 2007a; 2007b; 2007c; 2010; Sümegi et al. 2012a). This represented the development of a zonal, upland vegetation during the Early Holocene in the Carpathian Basin regarding the differences in elevation. As a result of these transformations in the vegetation, the flora of the mid-mountains, the foothills, the hills, and the lowland floodplains became relatively homogeneous. However, the steppe and forest steppe vegetation survived in areas with lower groundwater levels or alkaline soils from as early as the end of the Pleistocene. We can therefore assume a mosaic-like complexity regarding the vegetation at both the local and the regional scale within the Carpathian Basin even at the time of the expansion of the closed oak woodlands (Sümegi 1986; 1989; 1996;

2007a, 2007b, 2007c; Sümegi et al. 1998; 2002; 2012a).

Parallel to the homogenisation of the vegetation at the onset of the 7th millennium BC, major technical and cultural transformations occurred on Mesolithic sites (Sümegi 1999; 2004a; 2004b; 2013). In addition to numerous similarities, the stone industries of several sites on the northern Great Hungarian Plain such as Jásztelek I (Kertész 1993), Tarpa-Márki-tanya, Ciumeşti II, and Kamenitsa I reflect tendencies which can perhaps be fitted into the above-mentioned process. Thus, for example, the cone-shaped corestones, the application of the micro-burin technology, as well as trapezoidal tools and traces of retouched truncations can be noted in the lithic assemblages and lithic industry of these sites (Kertész 1996).

Besides the dominance of closed forest dweller species, some xero-thermophilous, steppe, and forest steppe dweller molluscs *(Cepaea vindobonensis*, *Granaria frumentum)* were also identified in the Bátorliget profile during the 7th millennium cal BC, corresponding to the latest Mesolithic horizon characterised by trapezoidal blades (Sümegi 2004a). The emergence of a more open vegetation can perhaps be correlated with the settlement of Mesolithic hunting groups and the appearance of Mesolithic campsites during the active growth period in a woodland setting (Sümegi 1999; 2004a; 2004b; 2013a).

The initially spontaneous expansion and, later, the intentional encouragement of the spread of light-preferring plants such as hazel in the marginal vegetation must have triggered similar vegetation transformations (Kalicz / Makkay 1976). The creation of "hunting trails" to ease the pursuit of forest-dwelling game such as aurochs, deer, wild boar, and buffalo undoubtedly contributed to the appearance and expansion of steppe-like vegetation spots (Sümegi 1998; 1999; 2001; Sümegi / Kertész 2000; Sümegi et al. 2002). According to the radiocarbon dates for the Bátorliget marshland profile and the Kelemér, Csaroda, Nagybárkány, Fenékpuszta, and Balatonederics profiles, these vegetation and malacological changes occurred immediately before the appearance of the earliest Neolithic groups in the Carpathian Basin, namely the Körös and Starčevo population (Hertelendi et al. 1995).

The likelihood of spontaneous forest fires was greatly reduced in the North Hungarian Mountain Range following the retreat of coniferous woodlands from the area and the expansion of less flammable trees in the Early Holocene (Willis et al. 1997; 1998). Even so, forest fires did not fully cease in the area, as shown by the joint presence of closed forest-dweller and thermo-xerophilous mollusc species in the Bátorliget profile, although their intensities and frequencies declined. These minor flue-ash peaks tend to have a strong correlation with the decreases of the oak pollens *(Quercus)* and a simultaneous increase in hazel pollen *(Corylus)* between 7000–6000 cal BC (Willis et al. 1997). Similar transformations could be observed on other sites as well in the wooded areas of the Great Hungarian Plain and in the Transdanubian mountains and hills (Sümegi 1998; 1999; 2000; 2004a; 2004b; 2004c; 2013a; Juhász 2004; Sümegi et al. 2008a; 2008b; 2008c; 2009a; 2009b; 2011a; 2011b).

Even though the palaeoenvironmental investigation of Hungarian Mesolithic sites is still in its infancy (Kertész et al. 1994), there are several American and Australian (Mellars 1976), as well as Western European (Evans 1975) analogies indicating that hunter-forager communities employed forest burning for several purposes: hunting, the expansion of the marginal zone, and the creation of trails or pathways for the herds of hunted animals) (Smith 1970; Clark 1972; 1988; Clark et al. 1989; Bennett et al. 1992).

Although there is no archaeobotanical evidence for the collection of hazelnut from the Mesolithic sites of Hungary, there might be some correlation between the increase of hazel pollens and the possible human-induced forest burnings, similarly to the cases recorded at some Western European Mesolithic sites (Smith 1970). Comparable hazelnut peaks have been reported from the pollen profiles of western Transdanubia (Juhász 2002; 2004).

An increase in the ratio of hazel pollen between 7000–6000 cal BC following the minor flue-ash peaks could be observed in the neighbourhood of the Mesolithic sites in the northern part of the Great Hungarian Plain and the North Hungarian Mountain Range as well (Sümegi 1998; 1999; 2004a; 2004b; 2013a; Sümegi et al. 2002).

There seems to be an association between the appearance of open-vegetation dweller gastropods and steppe plants, the minor flue-ash peaks, the emergence of a complex, mosaic-like vegetation, the spread of hazel, as well as the new technologies in the lithic industry noted at the latest Mesolithic sites, such as trapezoidal blades and the appearance of a sickle-like tool, suggesting intensive foraging. These transformations all occurred during the 7th millennium cal BC, and suggesting that the period was characterised by more intensive foraging and hunting.

Although the Hajós and Császártöltés sites were part of the forest steppe zone during the Late Mesolithic (Sümegi 2004a; 2004b; 2013a), the apparent *Corylus* peak parallel to the increase in the ratio of *Artemisia* and Chenopodiaceae (cf. *Figs 18–19*) corresponds to the pre-Neolithic human impacts at the Pleistocene / Holocene boundary and between 6500–6000 cal BC.

Our data suggest the presence of certain Mesolithic groups before the arrival of the first farmers from the Balkans. It has been suggested that Late Mesolithic populations played a more important role in the formation of the Körös culture than previously assumed (Makkay 1982; Whittle 1996; 1998; 2004; 2007; Kalicz et al. 1998; Bánffy 2004; 2005; 2006; 2009; 2012). Nevertheless, in the lack of a fairly dense Mesolithic settlement patterns (Raczky 1983; Whittle 1996; 1998; 2000; 2004; 2007; Kalicz et al. 1998; Kozłowski 2005; Domboróczki 2005; Kaczanowska / Kozłowski 2008) as well as in the light of the new mtDNA research on early Neolithic skeletal material which, at the beginning, does not indicate the presence of any pre-Neolithic haplogroups (Szécsényi-Nagy et al. 2014; 2015), this issue remains to be resolved.

Between 6500–6200 cal BC, the ratio of *Corylus* and weeds increased, but the flue-ash ratio did not in the Császártöltés profile, indicating that the spread of *Corylus* was not induced by burning, but rather by the creation of hunting paths or by the cutting back of hazelnut. Interestingly, this area differs from the environment preferred by Körös groups, whose settlements, first founded around 6000 cal BC, show a concentration either on active floodplains with clay hydromorphic soils that are unsuitable for farming activities or on loess-covered higher elevations (Sümegi 2004b; 2004c; 2013a; Sümegi et al. 2013c). Gallery forests are unsuitable for plant cultivation, but highly suitable for traditional Mesolithic hunter-forager subsistence activities, and this preference might be a reflection of the continuation of Mesolithic traditions in the Körös culture. Unfortunately, Körös sites have solely been excavated on Pleistocene surfaces along rivers, none of the sites on active Holocene floodplains have yet been investigated (Banner 1937; Kalicz 1957; 1970; Trogmayer 1964; 1966; 1968a; 1968b; Trogmayer et al. 2006; Nandris 1970; 1972; Makkay 1981; 1982; 1992; 1996; Raczky 1976; 1983; 2009; Kosse 1979; Sherratt 1982; 1983; Whittle 2004; 2007; Domboróczki 2005; Domboróczki / Raczky 2010; Oross 2007; Paluch 2009a; 2009b; 2012; Paluch / Tóth 2005; Bácsmegi / Fogas 2009; Kozłowski / Raczky 2010). It would appear that the environmental changes during the transition from the Late Mesolithic to the Early Neolithic can be interpreted as reflecting the continuation of hunter-forager activities among Early Neolithic communities (Kalicz / Makkay 1972; Whittle 2007).

Neolithic and Early Copper Age (6000–4000 cal BC)

From the onset of the Neolithic, peat formation began and a reed swamp peatland evolved in both oxbow lakes with *Thelypteridi-Phragmitetum* and *Thelypteridi-Typhetum* communities. Beginning with the early Neolithic, the investigated area was dominated by the main tree species of the mixed forest steppe: *Quercus*, *Ulmus*, *Corylus avellana*, and *Tilia*, which were somewhat later complemented with *Carpinus* and *Fagus*. The most dominant non-arboreal remains are *Artemisia*, *Aster*-type, Poaceae, and Umbelliferae. Other important non-arboreal species are *Plantago lanceolata*, *Filipendula vulgaris*, and *Rumex*. The first anthropogenic impact in the form of cereal pollen was detected at the depth of 271 cm.

The appearance of cereals and weeds provides information about the earliest Neolithic Körös culture (Banner 1937; Kutzián 1944; Raczky / Kalicz 1981; Bánffy 2012; 2013a) as well as about the natural environment in the broader area of the Tisza and Körös rivers (Willis 2007; Whittle 2007; Sümegi et al. 2011a; Magyari et al. 2012). In fact, settlements of the Körös culture have been identified on the Danube alluvial plain near the Hajós and Császártöltés locations (Knipl / Sümegi 2011; 2012) *(Fig. 24)*.

The dominance values of weeds and cultivated plants (Behre 1988) were used to detect impacts of food production in the Neolithic and Copper Age (cf. *Figs 18–23*). In many cases, the pollen grains of weeds and cultivated plants cannot be identified more precisely than the genus level. Thus, certain species cannot be distinguished more precisely from each other and are classified into broad groups (e. g. *Artemisia*, Chenopodiaceae), which is a major uncertainty factor in their assessment.

Cultivated plant and weed pollen appeared along the northern reaches of the Maros River around 6000 cal BC (Whittle et al. 2002), corresponding to the arrival of the first farming groups from the northern Balkans (Banner 1937; Kutzián 1944; Whittle et al. 2002). The ratio of *Quercus* and shrubs persisted, and weeds and plant species indicating open lands increased significantly in the later Neolithic.

It is remarkable that between 6500–6000 cal BC, before the onset of the Neolithic, the ratio of *Salix* was quite remarkable in addition to intensely gathered *Corylus*. Both species spread easily in deforested areas, disturbed floodplains and gallery forests (Smith 1970; Prach et al. 2001; Stromberg et al. 2010). Thus, it can be reasonably assumed that the rise of *Corylus* and *Salix* during the Late Mesolithic and Early Neolithic can be linked to human disturbances, to widely utilised shrub plant preferences, and to a very early woodland

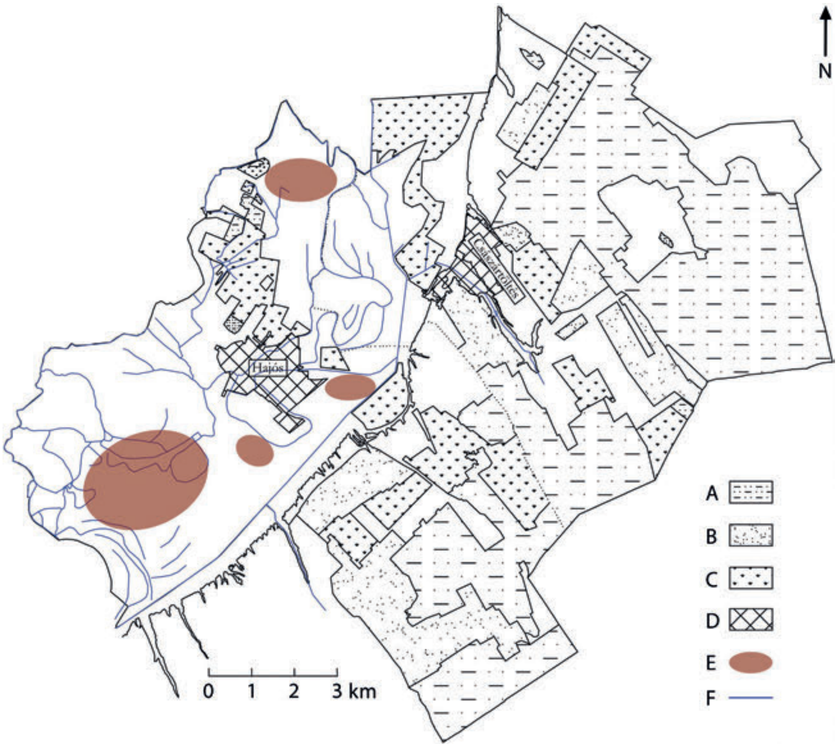

Fig. 24. Neolithic settlements of the Körös culture and Linienbandkeramik (LBK) in the analysed region (redraw after Knipl / Sümegi 2011). A = recent forest, B = recent fruit-growing / vineyard, C = recent pastureland, D = settlement inner area, E = Neolithic (Körös and Linienbandkeramik) settlement areas, F = ancient fluvial system.

management (Sümegi 1998; 1999). The increasing human impacts between 6000–5700 cal BC imply a human presence and settlement reflecting possible Neolithisation and the formation of the Körös culture.

The Hajós and Császártöltés profiles can be compared with reference data from the Tisza Valley and with the most recent pollen profile from Tiszagyulaháza (Magyari et al. 2010a; 2012). The profile comes from an oxbow lake surrounded by a gallery forest and is characterised by hydromorphic soils, but lies far from the above-mentioned regions. The first problem is that the pollen results relate to different regions of the Great Hungarian Plain: pollen changes that were valid for the Tisza Valley (Gábris et al. 2002; Gábris / Nagy 2005; Magyari et al. 2010a; 2012) were extrapolated for the Polgár alluvial island and for areas lying even farther, some 60 km from the study area, for the wholly different Hortobágy region (Magyari 2011; Fekete et al. 2012; 2014). There are no known profiles from the Great Hungarian Plain that would indicate very different types of vegetation coming from saline soils, steppe, forest steppe, or forested areas. However, despite the great distance, the findings of the pollen profiles from the Middle Tisza region were extrapolated for the Upper Tisza region (Chapman et al. 2010). Moreover, even though a minimum of 300–500 terrestrial pollen grains are necessary for statistical analysis, profiles yielding no more than 100 grains, including aquatic taxa, were taken into account in several cases (Magyari et al. 2010a; 2012). Consequently, the insufficient number of statistically evaluable pollen grains is unsuitable for statistical comparison, and also for a palaeoenvironmental analysis (Jakab / Magyari 1999; Magyari 2002).

The perhaps most problematic aspect of the Tiszagyulaháza publications (Magyari et al. 2010a; 2012) from an archaeological perspective is that the authors argue for a Körös colonisation (Magyari et al. 2012), even though no Körös sites were identified in the study region during the extensive archaeological field surveys (Hertelendi et al. 1998; Nagy 1998; Raczky 2002; 2012a; 2012b; Raczky / Anders 2006; Raczky et al. 2007).

In order to set our study sites in an Early Neolithic context, we reviewed the cores and the results of their analyses (pollen analytical, macrobotanical, phytolit, anthracological, and malacological) that had been collected at Körös sites or from oxbow lakes directly beside or in the immediate vicinity of Körös sites (Sümegi 2004a; 2004b; 2004c; 2013a; Bogaard et al. 2007; Madella 2007; Sümegi / Molnár 2007; Willis 2007; Windland 2007; Gulyás et al. 2010; Gulyás / Sümegi 2011a; 2011b; Sümegi et al. 2011c; 2013c;

Moskal-del Hoyo 2013). These are the following archaeological sites: Lake Kiri at Ecsegfalva (Whittle 2007; 2012), Tiszaszőlős-Domaháza (Domboróczki 2005), Ibrány-Nagyerdő (Domboróczki / Raczky 2010), Szajol-Felsőföld (Raczky 1988), Tiszapüspöki-Karancspart-Háromág, Nagykörű TSZ Gyümölcsös (Csányi 2003; Raczky 2012a; 2012b), Maroslele-Pana (Trogmayer 1964; 1966; 1968a; 1968b; Trogmayer et al. 2006; Paluch 2005; 2009a; 2009b), and Méhtelek-Nádas (Kalicz / Makkay 1976; Kalicz et al. 2013).

It must also be borne in mind that in addition to the Körös sites in the Hajós and Császártöltés areas, Starčevo sites are also known from the Sárköz region, from its western part in Tolna county (cf. *Fig. 22*) (Bánffy et al. 2010; Gallina et al. 2010). In the Late Mesolithic and Early Neolithic levels of the Hajós and Császártöltés profiles, the ratio of micro-charcoal changed together with weeds. The ratio of micro-charcoal and cereal sum changed linearly. The land was probably cleared by fire, and there is a possible link between cereal cultivation, the intensity of human impact, and the population number (buildings, households, hearths) (cf. *Figs 16–24*).

Similar processes were reconstructed from the radiocarbon-dated pollen profiles coming from areas to the east and north on the Great Hungarian Plain (Willis 1997; 2007; Sümegi et al. 2002; 2011c; Magyari et al. 2012). However, a significant cyclical *Corylus* and *Quercus* dominance change resembling the one in the northern Great Hungarian Plain (Magyari et al. 2012) could not be detected in the Sárköz region, characterised by a gradual, continuous change. In our profiles, the ratio of shrubs and trees – including *Corylus* and *Quercus* – decreased only after some centuries of a sedentary lifestyle (from 5600 cal BC).

Beginning with 5600 cal BC, human disturbance increased in both dry and forest-covered areas. The ratio of weeds rose and became homogenised (cf. *Figs 18–21*). This horizon corresponds to the emergence of the Linearbandkeramik (LBK) culture in the Carpathian Basin during the Middle Neolithic (Kalicz / Makkay 1977; Bánffy 2000; 2005; 2006; Oross / Bánffy 2009; Bánffy / Oross 2010; Bickle / Whittle 2013). The transition between the Early and the Middle Neolithic reflects a gradually intensifying human impact, with the ratio of cereals and micro-charcoal declining in both profiles, which suggest a possible increase in the population size between the Early and the Middle Neolithic at the time of the arrival of LBK groups (cf. *Figs 18–24*). The weed vegetation, cereals, and micro-charcoal ratios reflect a more significant impact on the natural environment by the LBK communities than the peoples living earlier in the area. Weeds indicating forest disturbance and the increase in the ratio of *Salix* that expanded in deforested areas point to clearings in the gallery forests. The continuous presence and the number of cereals and the accompanying weeds indicate the persistent use of the high river bank. The higher number of weed pollen that spread due to chewing and trampling reflects extensive grazing fields on the floodplain.

Clearings were presumably created on the forested floodplains (Iversen 1941). Following a few years of cultivation and grazing, farming may have ceased in these clearings. After several years of ley farming, young shoots and shrubs (mostly willow or hazelnut) were burnt and the ash was spread into the soil. This type of farming (landnam theory: Iversen 1941) would explain the decrease in the ratio of arboreal pollen and the increase in the number of non-arboreal taxa during this period. At the same time, the spread of willow and hazel could have been the result of conscious gallery woodland management (Out et al. 2013) as these species can be used for making hedges and for the construction of houses with wattle-and-daub walls.

Thus, we witness the expansion of willow during the Middle Neolithic at the study site, while hazel remained dominant over a longer time, during the pre-Neolithic and the Early Neolithic (cf. *Figs 18–24*). As a result, it can be assumed that the exploitation of the floodplain began following the settlement of Körös groups and after landnam-type management became significant during the Middle Neolithic. This picture is also supported by the archaeological record. Several settlements of the Early Neolithic Körös culture have been identified in the region during archaeological field surveys (Knipl / Sümegi 2011; 2012; Bánffy 2013a; 2013b; Kustár 2013; Knipl et al. 2014), and several extensive Middle Neolithic LBK settlements are known in the vicinity of the study sites (Kalicz 1994; Oross / Bánffy 2009; Bánffy / Oross 2010; Bánffy et al. 2014). The most significant human impact occurred at the close of the Middle Neolithic (c. 5300–5000 cal BC), when several other archaeological cultures are attested near the study site (Marton / Oross 2009; 2012; Bánffy et al. 2014), a period characterised by extensive, stratified Neolithic settlements (Bánffy et al. 2014).

The onset of the Late Neolithic (5000 cal BC) saw a significant decline in cereals and micro-charcoal, resembling the one in the case of the Middle Neolithic (cf. *Figs 18–24*). This change was observed in both profiles, and similar changes could be noted in both profiles from the Late Neolithic to the beginning of the Copper Age.

The region was occupied by the Sopot culture during this period and by the Lengyel culture at the turn of the 6th–5th millennia cal BC (Zalai-Gaál et al. 2011; 2014; Zalai-Gaál / Osztás 2009; Osztás et al. 2012; Bánffy et al. 2014). The Neolithic cereal pollen maximum occurred in this level of the profile alongside an

Depth (cm)	Time span (cal BC)	Description
230–240	4500–4000 (Early Copper Age)	new dominance maximum in cereal, weed and micro-charcoal content, *Ulmus*, *Quercus*, *Tilia* regeneration process started, *Corylus* decline
240–250	5000–4500 (Late Neolithic)	*Ulmus* decline, cereals, increasing flue-ash pollen
250–260	5500–5000 (Middle Neolithic)	*Salix* maximum, increase of weeds, weeds composition changed, continuous cereal, open vegetation land increase, possible creation of a Landnam system
260–270	6000–5500 (Early Neolithic)	*Corylus, Salix* maximum, increase of weeds, continuous cereals, paths and open areas were created in the gallery forest
270–275	6500–6000 (Late Mesolithic)	*Betula, Quercus* decline, *Corylus* maximum, first, although sporadic cereal pollens, weeds increase gradually

Tab. 10. Vegetation change and human impact in the Hajós profile from the Late Mesolithic to the Early Copper Age.

Ulmus decline, from the beginning of the Late Neolithic *(Tab. 10)*.

Although the *Ulmus* decline has been discussed in several studies (Troels-Smith 1953; Willis et al. 1998; Sümegi 1998), most of these ultimately invoke the arrival of Neolithic communities, leading to deforestation and changes in the forest composition as well as in the forest micro-climate, accompanied by funghi pathogenes and insects spreading along Neolithic clearings (Buckland / Sadler 1997; Buckland et al. 2004). The Late Neolithic *Ulmus* decline was followed by a quick *Ulmus* regeneration at the beginning of the Copper Age, similarly as in other areas of the Great Hungarian Plain (Willis 1997; 2007; Sümegi et al. 2011a; 2011c; Magyari et al. 2012). The appearance of *Quercus-Ulmus* forests on the Great Hungarian Plain differs from the forest evolution in the mountain zone (Willis et al. 1998; Sümegi 1998; 1999; Magyari et al. 2001; Sümegi et al. 2009a), principally because *Ulmus* populations in the lowland forest steppe areas are more resistant to plant pests and forest openings than *Ulmus* populations in upland areas in closed deciduous forests (Sümegi et al. 2012a; 2012b).

At the same time, the decrease of arboreal taxa pollen ratios in the Late Neolithic, the decrease of *Ulmus* pollen, the spread of weeds indicating disturbed forests, and the increase of micro-charcoal point to the intense exploitation of the floodplain area. The increase in cereal pollen ratio was not proportional to the drop of arboreal taxa ratio. Still, the number of weeds indicating trampling and grazing was significant in this level of the profile. Consequently, the area of grazing fields may have increased on the Sárköz floodplain during the Late Neolithic and the Early Copper Age *(Tab. 11)*.

A similar process was reconstructed from the Polgár profile and in the southern part of the Tisza Valley (Sümegi et al. 2002; 2005; 2011c). The ratio of the weed vegetation indicates that it expanded and that its composition changed during the Late Neolithic and the Early Copper Age, and that a subsistence based on farming became stable. This period is dominated by wheat-barley-rye cultivation (Sümegi et al. 2011c). However, apart from a few uncertain and badly preserved pollen grains, the presence of rye could not be demonstrated in the Hajós and Császártöltés profiles, and in this respect, these profiles differ markedly from the pollen profiles in the Tisza Valley (Sümegi et al. 2002; 2011c; Sümegi 2004b; 2004c; Magyari et al. 2010a; 2010b; 2012), in which a high number of *Secale* (rye) pollen grains were identified.

Naturally, the questions arise regarding to what extent this palaeoenvironmental record is valid for a larger region, e. g. for the Early Neolithic Starčevo settlements in the Tolna Sárköz region along the right Danube bank (Gallina et al. 2010; Osztás et al. 2012; Serlegi et al. 2013). Do these data have only a regional, local significance? The Starčevo settlement at Alsónyék-Bátaszék lies some 35–40 km from our study sites as the crow flies. This part of the Sárköz region is characterised by a geomorphological diversity and is not part of the active Danubian alluvial plain that developed during the Holocene (Sümegi et al. 2016). Not only does the geomorphological environment of the Starčevo site at Alsónyék–Bátaszék differ, but so does its hydrogeography, pedology, and vegetation. Thus, we cannot wholly adapt or extrapolate the palaeoenvironmental reconstruction for Hajós and Császártöltés to the Early, Middle, and Late Neolithic sites on the right Danube bank.

It also needs to be established whether the palaeoenvironmental record from these two profiles can be extended to two major sites, Fajsz-Garadomb and Fajsz-Kovácshalom, both lying some 12–15 km from the study area. These two sites are roughly coeval, dating from the late 6th, early 5th millennium cal BC: the Garadomb settlement is a multi-period horizontal site, which can perhaps be regarded as representing the initial phase of an aban-

Depth (cm)	Time span (cal BC)	Description
230–240	4500–4000 (Early Copper Age)	new dominance maximum in cereal, weed, and micro-charcoal content, start of *Ulmus, Quercus, Tilia* regeneration process, *Corylus* decline
240–250	5000–4500 (Late Neolithic)	*Ulmus* decline, cereals, increasing flue-ash pollen, non-arboreal pollen maximum
250–260	5500–5000 (Middle Neolithic)	*Salix* maximum, increase of weeds, weeds composition changed, continuous cereal, open vegetation land, intense *Fraxinus* decline, possible creation of a Landnam system
260–270	6000–5500 (Early Neolithic)	*Corylus, Salix* maximum, weeds dominance increased, continuous cereals, paths and open areas were created in the gallery forest
270–275	6500–6000 (Mesolithic)	*Betula* decline, *Corylus, Salix* dominance increased, first sporadic cereal pollens, increasing gradually

Tab. 11. Vegetation change and human impact in the Császártöltés profile from the Late Mesolithic to the Early Copper Age.

doned tell, while the Kovácshalom site is a tell settlement. The two sites are located on the Holocene Danubian alluvial plain, in its marginal zone, on island-like Pleistocene surfaces covered with loess-like sediments. These island-like areas played a crucial role in the Neolithic colonisation and the emergence of tell settlements on the Great Hungarian Plain (Sherratt 1982; 1983; Sümegi 2002; 2003b; 2003c; 2004c; 2007a; 2011; 2012; Sümegi et al. 2013d; 2013e). The vegetation and hydroseries of the surfaces covered with loess-like sediment differ from the development of the Danubian alluvial plain. At the same time, the palaeoenvironmental record of the Middle Neolithic based on the Hajós bog profile under the loess-covered high bluff can be useful for the interpretation of the Middle and Late Neolithic development at Fajsz–Garadomb, although there can be major differences regarding cultivated plants.

In contrast, the record from our two profiles cannot be used for reconstructing the environment of the Late Neolithic tell settlement at Fajsz-Kovácshalom because the impact of well-organised and centralised tell communities is more significant and they transformed their environment to a much larger extent (Sümegi 2002; 2003c; 2004b; 2011; 2013b; Sümegi et al. 2013e; Gulyás / Sümegi 2011a; 2011b). The transformations affected not only the vegetation and soil conditions, but also the hydrographic conditions through the creation of ditches and drainage systems in the vicinity of tell settlements. A comparable tell site and a similarly intensive human impact have not been documented near our study sites at Hajós and Császártöltés. There can be huge environmental differences in the Late Neolithic at our case study sites and the Fajsz-Kovácshalom site lying 15 km away, especially in terms of human impact. In order to clarify this question, new palaeoenvironmental studies need to be carried out in the area of the Fajsz-Kovácshalom tell site.

Middle Copper Age–Late Iron Age (4000–0 cal BC)

During this period, peat formation – dominated by reed – occurred at both sites, followed by *Caricetum elatae*, *Cypero-Juncetum bufonii*, and *Nymphaeetum albo-luteae* tussock-hollow formation. The principal tree species in this zone are *Quercus*, *Carpinus betulus*, *Fagus*, and *Alnus*. Total arboreal pollen accounts for 35–40 %. Mixed oak and oak-hornbeam forests are typical. Strong anthropogenic impacts and an extensive forest steppe area were detected in this zone. Poaceae, *Artemisia*, and Chenopodiaceae pollen dominance reached the maximum level (cf. *Figs 22–23*).

From the Middle Copper Age to the end of the Iron Age, human impact changed cyclically, but the basic structure of vegetation and forest steppe persisted despite the occasionally very intense human impact. Thus, models on the vegetation development of the Great Hungarian Plain from forest steppe to cultural steppe (Chapman et al. 2009; Magyari et al. 2010a; 2010b) are not valid for this area (Sümegi et al. 2005; 2006; 2011c). Our data support earlier published findings indicating the spatial and temporal differences of vegetation development on the Great Hungarian Plain, reflecting a great diversity (Sümegi / Törőcsik 2007). It is to be stressed again that the palaeoenvironmental record as well as earlier studies on the Hajós site (Jakab et al. 2004a; 2004b) indicate that vegetation changes noted at a single site should not be extrapolated for the entire Great Hungarian Plain, a landscape with a mosaic vegetation patterning (Borhidi 1961; Szelepcsényi et al. 2014a; 2014b) and with geological and pedological traits that are as diverse as the vegetation (Sümegi 1995; 2004a; 2004b; 2004c; 2008). These differences became even more explicit owing to the different landscape utilisation strategies employed by various archaeological cultures

(Sümegi 1995; 1998; 1999; 2002; 2007a). Hungarian archaeologists have emphasised the different landscape utilisation strategies on the Great Hungarian Plain (Gábori 1980; 1981; 1984), a point also supported by the malacological data (Sümegi 1986; 1989; 1995; 1996; 2004a; 2004b; 2004c; 2007a; 2007b; 2007c; Sümegi et al. 2015a).

The landscape homogenisation that was earlier believed to have occurred at the end of the Bronze Age (Chapman et al. 2009; Magyari et al. 2012) had in fact evolved no earlier than the 19th century in the wake of river regulations and extensive drainage operations (Sümegi 2012).

Climate changes occurred during the Copper Age, the Bronze Age, and the Iron Age in the study area, but these shall not be discussed here. The reconstruction and regional comparison of the Copper Age, Bronze Age, and Iron Age changes and their correlation with the archaeological record will be a future project.

The next stage in food production developed in the Bronze Age, a process indicated by the weed vegetation and the *Achillea* dominance, similarly to the record from the Tisza Valley and the Kiskunság region (Sümegi et al. 2011b; 2011c).

Roman Imperial period (0–500 cal AD)

Aside from the Modern Age, the most significant anthropogenic impact can be noted during the Late Roman period in the study area. Cereal and weed pollen ratio reached maximum values in the profile. In addition to wheat and barley pollen, *Secale* pollen grains appeared with high values. Based on these species, there was a rich and diverse cereal cultivation in the vicinity of the study sites. The high river bank west of the oxbow lake in Transdanubia lay in the Empire's frontier zone, near the Roman *limes*. The population groups of the Roman centuries played an important role in the Sárköz region, not least because of the assumed important route leading to the east (Kőhegyi 1972), which probably ran between the two study sites. A rampart was constructed and maintained north of the Hajós site between the 3rd and 5th centuries (Sümegi 2005b).

The construction activities between river basins, the building of roads and ramparts, as well as constructions on settlements, all involved extreme human impacts, also reflected by the pollen data. At the same time, these changes are minor compared to the record from the inner areas of Transdanubia during the existence of the Roman province of Pannonia (Sümegi et al. 2009a; 2009b; 2011a; 2011b). The Sarmatians living on the Great Hungarian Plain also had a major impact on their environment (Náfrádi et al. 2011), but it is hardly comparable to the degree of anthropogenic impact observed in the Roman province (cf. *Figs 22–23*).

Early Medieval and Hungarian Conquest period (500–1000 cal AD)

During the early Medieval period, also called the Migration period, *Carex*-dominated peat formation was dominant. Forest regeneration began, but did not extend beyond the forest steppe state. *Alnus*, *Salix*, *Quercus*, *Ulmus*, *Fraxinus*, and *Carpinus* species dominated. At the same time, cultivated cereals and weeds still occurred in this level of the profile, although with lower values. Oat pollen grains were present as well, although the identification of the taxa is problematic (Beug 1961; 2004; Andersen 1979; Andersen / Bertelsen 1972; Dickson 1988). The non-arboreal pollen indicates that animal husbandry dominated at the open landscape. Although the cyclic ratio of *Quercus*, *Ulmus*, *Fraxinus*, *Corylus*, *Fagus*, and *Carpinus* reflect a significant climate change during the Migration period, the forest steppe nature of the vegetation persisted (cf. *Figs 22–23*).

Middle Ages and Ottoman period (1000–1700 AD)

The accumulation of sedge peat continued during the Medieval period in both sedimentary basins. The pollen composition indicates that human impacts became stronger, while arable farming and animal husbandry played an equal role. Cultivated land, grazing fields, and forests probably had the same extent during this period, and more dispersed settlements appeared in the study region (Wicker / Knipl 2005; Knipl / Sümegi 2011; 2012; Knipl et al. 2014). As a result, the mosaic patterning of the environment increased, and there emerged a land management system characterised by the alteration of forests with cultivated land and grazing fields alongside fallow land.

This landscape utilisation is one of the most important traits of the economy of the ancient Hungarians in the 9th–10th centuries (Sümegi 1998; 2000), to which their successful medieval farming activity can probably be attributed (Sümegi 2012). The presence of *Juglans*, *Vitis*, and *Prunus* indicate a horticulture from the 11th–12th centuries *(Figs 22–23)*.

At the end of the Medieval period, during the Ottoman occupation of Hungary, further reforestation started. The pollen ratio of weeds and cultivated plants declined drastically, *Juglans*, *Vitis*, and *Prunus* pollen disappeared from the profile. The population decreased, as did the human impact. *Fagus* and *Carpinus* increased significantly among arboreal taxa, which can be linked to the colder climate of the late medieval Little Ice Age. However, the spread of *Fagus* and *Carpinus* might also be a consequence of the military industry of the Ottoman wars, since almost the entire area of the Carpathian Basin was a military zone, involving large-scale metallurgy, coinage, and smithing.

The production of the charcoal needed for metalworking called for intensive charcoal pit management.

The most important taxa in charcoal pit management are *Fagus* and *Carpinus* in the temperate zone as these species provide the highest amount of charcoal (60–70 kg charcoal from 1 m^3 of wood material) (Lukács / Marton 1968; Willis et al. 1998). Moreover, the heating value of these species (17–20 MJ / m^3, 4000–5000 calories / m^3) is on par with the calorific value of brown coal. In war zones, where the production of weapons and gunpowder, the repair of harnesses, and the production of horseshoes was an integral part of daily life, tremendous amounts of charcoal were needed. It seems likely that this also played an important role in the increases of hornbeam and beech in addition to the cooler and wetter climate phase that was also conducive to the spread of these two species.

Post-medieval and Modern Age (last 300 years)

Peat formation continued; however, the Császártöltés profile was unsuitable for determining the environmental changes during this period owing to the drainage activity in the 19th–20th centuries. From the 18th century onward, *Quercus* dominated among forest taxa, and human impact became more significant. Cereal cultivation reached a peak: *Triticum* type, *Hordeum* type, *Secale* and *Avena* type pollen grains were identified. *Vitis*, *Juglans*, and *Prunus* ratios increased, indicating horticulture from the mid-18th century. Historical, agricultural, and forestry records are available for the last 300 years (Arnold / Knipl 2002) for palaeoenvironmental reconstruction (cf. *Figs 22–23*).

Summary

The evaluation of the cores extracted at the two study sites yielded the first new macrobotanical, pollen analytical, and malacological findings, occasionally completed with geochemical and sedimentological results, spanning the period from the end of the Pleistocene through the Holocene in the eastern Sárköz area. Our goal was to reconstruct the environment of the southern Danube-Tisza interfluve, from the Upper Palaeolithic to the close of Medieval period, particularly the environmental background to the Neolithic transition and the centuries of the Neolithic. The second goal was to test the hypothesis of Willis / Bennett (1994) on the spread of farming based on the pollen record from one of the most important Neolithisation areas, namely the Danube Valley of the Great Hungarian Plain. This is the area where the earliest Neolithic settlements are 8000 years old, dating from 6000 cal BC. We also tested theories regarding the development of cultural steppes on the Great Hungarian Plain that emerged over the past 3000 years according to some studies (Chapman 2008; Magyari et al. 2010a; 2010b).

Our first study site near the modern village Hajós lies in a former basin of the Danube, a classic oxbow lake bed in the eastern part of the alluvial plain of the Danube, resembling the former river bed at Császártöltés (cf. *Fig. 3*).

These former river channels are located on the Danubian alluvial fan characterised by a high groundwater level. At the same time, the drier areas lie a few metres away from the river channel with deep (over 5–10 m deep) groundwater level, meaning that these former river channels are located in the transition zone between two regions characterised by different environmental conditions.

The vegetation and environmental changes indicated by these southern Hungarian sites differ considerably from other parts of the Great Hungarian Plain, beginning from the Marine Isotope Stage 3 (MIS3) / Marine Isotope Stage 2 (MIS2) and in the MIS2 level. The pollen influx and composition indicate that a diverse vegetation with a mosaic patterning developed as a result of the mixed taiga, tundra, and Boreal forest that evolved in the Upper Pleistocene. At the same time, the species composition and vegetation cover differed from the one in the northern part of the Great Hungarian Plain.

This record supports the earlier theories (Gábori 1980; 1981; 1984) and more recent palaeoenvironmental data (Sümegi 1995; 1996; 2011; 2012; 2013a; 2013b; Sümegi / Krolopp 1995; 2002), indicating that the southern and northern part of the Great Hungarian Plain evolved differently and that there is a Pleistocene environmental boundary between the two regions (Sümegi 1996). Upper Palaeolithic (Gravettian) groups lived in both of these different regions: in a *Picea*-dominated parkland in the northern part and in a *Pinus sylvestris–Betula*-dominated Boreal forest steppe in the southern part of the Great Hungarian Plain. This is also supported by the charcoal data of loess profiles (Sümegi 1996; Sümegi / Rudner 2001; Willis et al. 2000; Rudner / Sümegi 2001; 2002).

During the Late Glacial (16 000 cal BP), a Boreal forest steppe developed: a steppe-open parkland on the high river bank and a closed mixed taiga forest on the alluvium. This forest steppe has persisted to the present. During this period, Pleistocene and Holocene temperate taxa appeared together at the study sites. From the onset of the Holocene, the number of the formerly dominant Pleistocene taxa gradually decreased and thermophilous temperate elements expanded, giving rise to a temperate forest steppe. These changes correlate well with previous pollen and anthracological analyses (Sümegi 2003b; 2003c; 2003d; Sümegi / Törőcsik 2007; Sümegi et al. 2011a; 2011b; 2011c; Náfrádi et al. 2011; 2013; 2014), indicating a forest steppe vegetation at the onset of the Late Glacial and a southern species exchange (Sümegi 2012; Sümegi et al. 2012a; 2012b). Accordingly, Epipalaeolithic and Mesolithic population groups lived in a locally and regionally forest steppe with a mosaic patterning containing both temperate and Boreal forest steppe taxa.

Although human impact intensified from the later Copper Age to the close of Iron Age, the forest steppe continued to thrive at the study site. The most significant climatic changes occurred in the Late Bronze Age and the Early Iron Age.

The profiles from Hajós and Császártöltés in the eastern Kalocsa Sárköz region provide an important palaeoenvironmental record and enable statistical comparisons with other sites investigated in the area. These new datasets can be partly compared with the record of climatic and vegetation changes, as well as anthropogenic impacts from other sites of the Carpathian Basin, and they can also be used for comparisons with both on-site environmental data and new archaeological and bioarchaeological findings.

The climate gradually grew warmer and more humid at the onset of the Mesolithic (Járainé-Komlódi 1969). The vegetation of the mixed deciduous taiga changed and a forest steppe and grassy steppe with birch groves in the sand- and loess-covered areas evolved. The temperate forest steppe was characterised by *Betula*, *Quercus*, *Fraxinus*, *Ulmus*, and *Corylus*. The flue-ash peaks and the growing importance of hazelnut are most likely a reflection of human activities at the close of the Mesolithic. The area was hardly densely populated even assuming the latter.

The environment was transformed at the turn of the 7th–6th millennia cal BC. The dry Boreal climate was gradually supplanted by the warmer and more humid Atlantic phase (Járainé-Komlódi 1988). Willow, poplar, and alder groves spread on the floodplain areas, while the higher-lying Császártöltés ridge saw the presence of oak, ash, and elm, and the decline of Scots pine *(Pinus sylvestris)*. A temperate steppe with smaller oak forests appeared in the higher-lying areas. The proportion of *Triticum* type pollen, noted from the beginning of the period, increased continuously, as did the species reflecting trampling and disturbance.

Settlements of the Starčevo culture are known from the area near the western Danube bank in the Early Neolithic, while a dense chain of Körös settlements has been identified on the eastern bank, in the Kalocsa Sárköz region, in the study area. Eight sites of the earliest food-producing culture have been identified near Hajós (Knipl 2014), and 15 sites in the neighbouring Homokmégy area have yielded Körös finds (Tóth 1998). The Körös settlements all lie on island-like elevations beside former water channels (that were still active during the Neolithic). The sites extending for some 300–1100 m along the channels are visibly associated with the former watercourses and follow the line of the channels. The settlements were not occupied simultaneously, but rather reflect a continuous shift in occupation following the exhaustion of the cultivated land (Tóth 1998).

Although human impact increased from the later Copper Age to the close of the Iron Age, the forest steppe survived at the study site. The most significant climatic changes occurred in the Late Bronze Age and the Early Iron Age.

The Hajós and Császártöltés sites in the eastern, Kalocsa Sárköz region have yielded important palaeoenvironmental data, enabling statistical comparisons with other sites in the area. These new datasets can be compared with the climatic and vegetation changes and anthropogenic impacts reconstructed for other sites in the Carpathian Basin, as well as with both on-site environmental data and with new archaeological and bioarchaeological results.

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Abstract: Prehistoric environment of the Sárköz region in the Danube Valley, southern Hungary. Case studies from infilled oxbow lakes

This study offers a broad and comprehensive overview of the geographic setting and environment on the alluvial plain known as the Sárköz ("mudland") in the southern Danube Valley in the Carpathian Basin. In order to undertake the palaeo-ecological investigations, samples were collected by coring performed with an extraction method that has a long-established history in the analysis of the geochemical composition of lacustrine sediments. Samples were also routinely submitted for radiocarbon dating. The results enrich our knowledge of the environmental background and history of early sedentary and food-producing communities. Our main focus is on the onset of the Neolithic (early 6th millennium cal BC) and the ensuing two millennia. On the testimony of the archaeological record, this region can be regarded as the last arena of the Neolithic transition in the southern Carpathian Basin located between South-East and Central Europe, which led to the emergence of food-producing economies and the shift to sedentary lifeways. This period, designated as the time of the "first farmers" across the vast loess areas of Europe, is followed by the groups of the Linearbandkeramik (LBK), characterised by fully sedentary lifeways. This analysis offers a broad outline of the environmental background of a region that can be regarded as one of the key areas in the transition to sedentary life in Central Europe.

Zusammenfassung: Die prähistorische Umwelt der Sárköz-Region im Donautal, Südungarn. Fallstudien an verfüllten Altwasserseen

Diese Untersuchung legt eine breite und umfassende Übersicht über den geographischen Rahmen und die Umwelt der alluvialen Ebene vor, die als Sárköz („Sumpfland") bezeichnet wird und im südlichen Donautal im Karpathenbecken liegt. Für die paläoökologischen Untersuchungen wurden Proben durch Bohrungen mittels eines neuen Verfahrens gewonnen, das in Analysen der geochemischen Zusammensetzung von Seeablagerungen bereits seit langem angewandt wird. Auch wurden routinemäßig Radiokarbondatierungen an Proben genommen. Die Ergebnisse bereichern unsere Kenntnisse zur Umwelt und zur Geschichte der frühen sesshaften und nahrungsmittelproduzierenden Gemeinschaften. Unser zentraler Fokus liegt auf dem Begin des Neolithikums (frühes 6. Jahrtausend cal BC) und den folgenden beiden Jahrtausenden. Auf Grundlage der archäologischen Zeugnisse kann diese Region als der letzte Raum des Übergangs zum Neolithikum im südlichen Karpathenbecken zwischen Südost- und Mitteleuropa betrachtet werden, in dem es zur produzierenden Wirtschaftsweise und zur sesshaften Lebensweise kam. Diese Epoche, die als die Zeit der „ersten Ackerbauern" in den weiten Lössgebieten Europas bezeichnet wird, wird abgelöst von den Gruppen der Linearbandkeramik (LBK), die durch eine entwickelte sesshafte Lebensweise charakterisiert ist. Diese Untersuchung bietet einen breiten Überblick über die ökologischen Grundlagen einer Region, die als eines der Schlüsselgebiete im Übergang zur sesshaften Lebensweise in Mitteleuropa verstanden werden kann.

Absztrakt: A dél-magyarországi Duna-vidék, a Sárköz környezettörténete az őskorban. Esettanulmányok betöltődött holtágak területéről

Ez a fejezet átfogó összegzést ad a Duna dél-magyarországi szakasza, a Sárköz-vidék földrajzi és környezettörténeti adottságairól. Paleo-ökológiai vizsgálatainkhoz a vízjárta üledékek geokémiai elemzéséhez kidolgozott módszerrel vettünk fúrásmintákat. A furatokból meghatározott mélységenként radiokarbon-mintákat is vettünk. Az eredmények elsősorban a legkorábbi, i. e. 6. évezred elején élt földművelő és élelemtermelő közösségek életét befolyásoló környezeti tényezőkről, valamint az utána következő évezred környezettörténetéről adnak eddig nem ismert részleteket. A régészeti adatok alapján ez a vidék kulcsszerepet játszhatott a neolitikus, letelepült életforma Délkelet-Európából Közép-Európa felé terjedésében. Az "első földművelők" által meghatározott évszázadok után a Vonaldíszes edények népének kultúrája (LBK) hagyományai uralták az évezred második felét. Az okokról és a történeti átalakulás környezetéi hátteréről szólnak a fejezetben olvasható eredmények.

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References of figures:
Fig. 1. redrawn after Clarke 1965. – *Fig. 2*: redrawn after Sümegi 2003. – *Figs 3*, *8–13*, *16–23*: P. Sümegi. – *Fig. 4*, *24*: redrawn after Knipl / Sümegi 2011. – *Fig. 5*: redrawn after Sümeghy 1953; 1955; Pécsi 1959. – *Figs 6–7*, *14–15*: redrawn after Jakab / Sümegi 2011. *Tabs 1–2*, *4–11*: authors; graphics: K. Ruppel (RGK). – *Tab. 3*: after Jakab et al. 2004a; 2004b.