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LATE QUATERNARY VEGETATION HISTORY IN THE HORTOBÁGY STEPPE AND MIDDLE TISZA FLOODPLAIN, NE HUNGARY

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Palaeoecological records of the last glacial period and the Holocene in NE Hungary are summarised on the basis of the field guide the author had prepared for the excursion to the Hortobágy National Park on the occasion of the 8th European Palaeobotany-Palynology Conference in 2010. New pollen records from the Hortobágy and the neighbouring Middle Tisza floodplain suggest that during the Upper Pleniglacial period (including the last glacial maximum between 23,000–18,000 cal yr BP) the current area of Hortobágy was mainly covered by mosaics of boreal wooded steppe, steppe tundra, and extensive boreal mires in an alluvial landscape. The pollen evidence for the presence of saline plant communities in this period is yet ambiguous, but the fossil molluscan assemblages imply that saline habitats were likely present in the Hortobágy and Hajdúság. In the Holocene, various wooded steppe associations followed each other in the Middle Tisza floodplain: in the early and mid-Holocene (until 4,200 cal yr BP) they were characterised by stands of *Quercus-Ulmus-Corylus*, followed by *Quercus-Carpinus betulus*, and from 3,200 cal yr BP *Quercus-Fagus sylvatica*. A pollen record from the Hortobágy furthermore suggests that the distribution of steppe oak woodlands might have been limited here during the entire Holocene, instead, the area was dominated by natural saline steppe-like formations. It would be desirable to verify this inference by further radiometrically dated pollen records, as several other pollen records from the Tisza alluvial plain suggest that woodland clearances connected to extensive grazing since the Late Bronze Age–Early Iron Age destroyed large tracts of woodland areas in this part of Hungary, and thus woodland clearances might have also facilitated the demise of the alluvial forests of the Hortobágy, at least to some extent.

Key words: Eastern Hungary, Holocene, Oxygen Isotope Stage 2, pollen and plant macrofossil analysis, steppe vegetation

INTRODUCTION

This paper is a part of an excursion guide prepared for the pre-conference fieldtrip of the 8th European Palaeobotany-Palynology Conference

(EPPC 2010, 6–10 July, 2010, Budapest, Hungary) led to the town of Polgár and the Hortobágy National Park.

The Hortobágy is the largest protected, almost unwooded, saline area in East Central Europe. Shaped by pastoral societies, it has the appearance of a steppe; it is completely flat yet its plainness is far from boring. The Hortobágy landscape is a colourful habitat for various plant and animal communities on the saline grasslands and loess fields, in the floodplain forests, marshes, and the artificial wetland habitats, the fishponds. These latter bear added significance for the local birdlife, and also for Europe's migrating birds, which rest here on their way south.

For any scientist dealing with the Quaternary vegetation history, probably the most exciting question is how much this saline "steppe" and salt-marsh dominated landscape is a natural phenomenon and to what extent prehistoric and historic human impact altered its flora and vegetation? Was it always predominantly treeless or there were periods during its Late Quaternary history when formations usually called "wooded steppe" expanded? This paper attempts to answer these questions by summarising existing scientific data on its landscape evolution, vegetation and soil science and other relevant disciplines.

Conserving the Hortobágy is a compulsory and huge task – that is why the Hortobágy National Park was established in 1973 as the first and still the largest national park of Hungary. Its territory exceeds 82,000 ha, 52,000 ha of which is declared as UNESCO Biosphere Reserve. The entire area is a World Heritage Site and almost 24,000 ha are classified as wetlands of international importance under the Ramsar Convention (KLOPFER 2006).

Steppe woodland and floodplain forests or pristine steppe?

For several generations, a paradigm of Hungarian plant science was that herdsmen of the eastern steppes arrived in a wooded marshy landscape in the Hortobágy during the Bronze and Iron Ages, and the demise of our extensive lowland woodlands was a consequence of overgrazing, establishment of wide cattle-driving roads, the Tatar and Turkish subjugations, charcoal smelting, and charcoal soap production, and not at last the embankment of the Tisza river that led to sinking groundwater, soil surface desiccation and enhanced near-surface salt accumulation in the soils (RAPAICS 1916, 1918, SOÓ 1931, 1933, 1959). Overall, this school believed that deforestation and enhanced salinisation of the Hortobágy is attestable to human impact.

Supporters of this idea brought in historical documents that mention rights of the nearby city of Debrecen to manage (cut if necessary) forest parcels in the Hortobágy. Especially, some noted 20th-century botanists like Rezső Soó and Pál Jakucs were on the opinion that the few remaining forest stands in the Hortobágy (*e.g.* the Tilos-forest at Újszentmargita) are remnants of the pristine Hortobágy that was once occupied by high floodplain woodlands and extensive marshlands, while patches of salt-steppes were restricted to forest openings on wetland edges (JAKUCS 1976, SOÓ 1931). In the last two decades, however, this conception has been challenged by several authors, as more and more analytical data came forward to support a much longer history of salinisation and the forestless nature of the Hortobágy, since at least the last full glacial period (LGM) (MOLNÁR 1999, MOLNÁR and BORHIDI 2003, SÜMEGI 2005, SÜMEGI *et al.* 2000, 2005*a*, TÓTH 2000, 2003). Vegetation scientists (*e.g.* MOLNÁR and BORHIDI 2003) also provided evidence that salt-steppe communities similar to modern ones were present 200 years ago, well before the river regulations started. Further support for the "pristine steppe" and "salt marshy steppe" theory came from historic maps (1st and 2nd Military Surveys) that indicated hardly any forest in the Hortobágy, but extensive marshlands.

So, more and more data have accumulated in favour of the second theory, i.e. the Hortobágy has not been forested since at least 20–30 thousand years and saline soil development started already during the cold and extremely dry full glacial period and in association with it, salt-tolerant vegetation appeared in the Hortobágy at the same time and persisted during the Holocene.

Landscape evolution and Late Quaternary palaeoenvironment in the light of new research results

Earlier ideas of landscape development in the Hortobágy area were considerably modified by Quaternary palaeoenvironmental studies done in this area in the last few years (BARCZI *et al.* 2006, BORSY and FÉLEGYHÁZI 1983, FÉLEGYHÁZI and TÓTH 2003, JOÓ *et al.* 2007, NYILAS and SÜMEGI 1992, SÜMEGI *et al.* 2000, SZÖŐR *et al.* 1992). Geochemical, mollusc, radiocarbon, pollen- and mineralogical analyses of loess and palaeochannel deposits suggested that the surface deposits of the Hortobágy consist of infusion loess and alluvial sediments, dating back to 20,000–50,000 yr BP (unless indicated otherwise, all dates mentioned in the text are uncalibrated ^{14}C years), have not been reworked by any later river activity (the former view was that the Tisza river meandered through the Hortobágy during the Early and mid-Holocene).

The surface of the Hortobágy preserves several palaeochannels (Fig. 1), few of which have been studied recently for their mineral composition in the bottom gravely sediments. These studies suggested that the ancient channels belonged to the Sajó–Hernád river system that drained mainly the Bükk Mts and brought loamy and silicate-rich sediment to the Hortobágy between 20,000–50,000 BP that was enriched by eolic loess accumulation during the Upper Pleniglacial. The Tisza appeared in the northwestern part of the Hortobágy *ca* 20,000 yr ago, when these N–S running glacial riverbeds were abruptly abandoned (beheaded), and especially the eastern part of the Hortobágy lost its riverine water supply (Fig. 2).

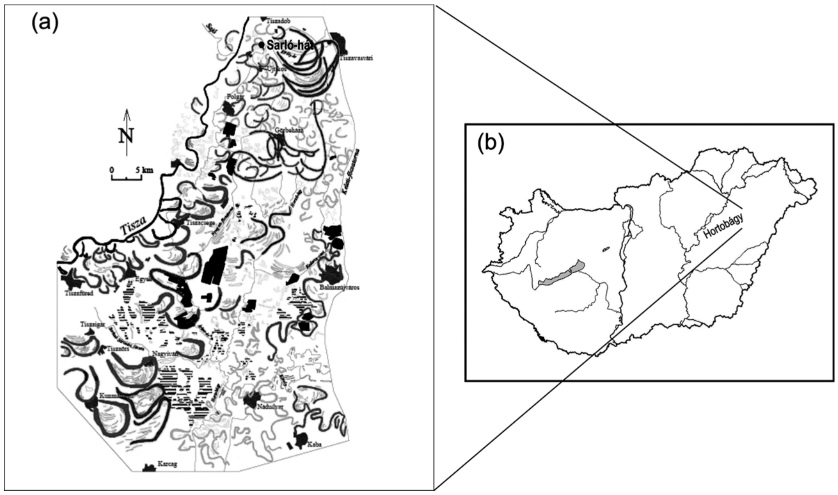

Fig. 1. Abandoned riverbeds in the Hortobágy (a) and location within Hungary (b). Figure 1a was redrawn and modified from TÓTH (2003) with the permission of the author

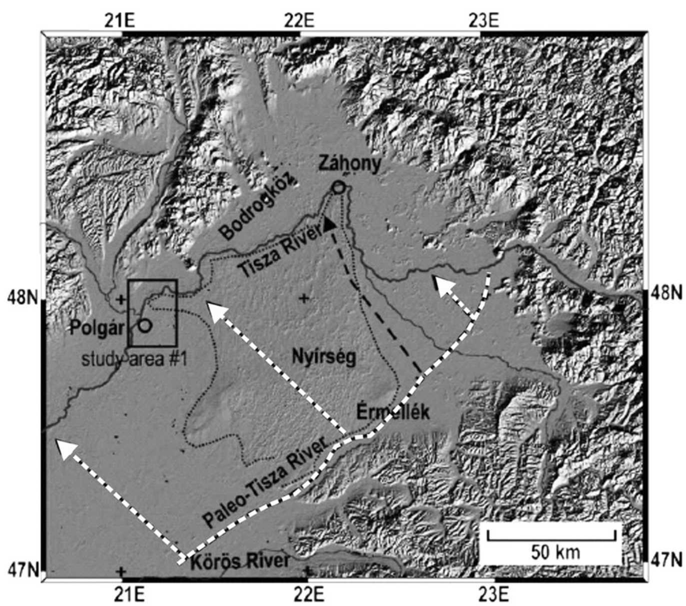

Fig. 2. A major fluvial change in the Great Hungarian Plain during the last glacial period, the "Záhony avulsion". Switch of the Tisza channel from the Ér valley towards the west, to its present course is indicated by light gray dashed lines and arrows. The avulsion likely took place 16,000–18,000 radiocarbon years ago (or later, during the late glacial as new high-resolution radiocarbon data from the first Tisza channel, the Sarló-hát meander suggest (MAGYARI *et al.* 2010)). Redrawn and modified from TIMÁR *et al.* (2005)

According to the model of SÜMEGI *et al.* (2000) the Late Pleistocene terrain with slight, but to lowland-standards relatively large elevation differences (4–5 m), received annual floods from the Tisza. Floodwater entered the Hortobágy along the abandoned riverbeds. The floodwater increased the groundwater table, while following the retreat of floods extensive areas remained inundated that dried up gradually during the late spring and summer seasons, while the groundwater table also decreased. The consequences of the periodic groundwater fluctuations were twofold. 1) The carbonate content of the alluvial sediments went into solution, making the groundwater saline; silicates with high Na and K content (feldspars) started to weather in the alkaline groundwater, silica and cations were released and hydrated and eventually the groundwater enriched in them. 2) In the drying soil surfaces narrow cracks developed; capillary force in these cracks raised the groundwater and dissolved silica and sodium and potassium oxyhydrates precipitated near the surface as evaporation oversaturated the groundwater. These were the most important steps of saline soil initiation in the Hortobágy and SÜMEGI *et al.* (2000) suggested that the conditions for salinisation were made already in the full glacial period.

Due to its landscape evolution, the Hortobágy has been characterised by surface floods, inundations and high water table fluctuation since at least 30,000 years. Areas of surprising similarity can be found in the short-grassed steppe zone and the older parts of floodland areas in cold semideserts, *e.g.* in Mongolia (SÜMEGI *et al.* 2000).

In support of the Sümegi's model, geochemical analyses of fossil soils dated to 20,000–30,000 yr in the eastern fringe of the Hortobágy proved the presence of gypsum and amorph silica jelly (SZÖŐR *et al.* 1992). Similarly, buried solonetz soils were found beneath the Neolithic and Bronze Age tells and burial mounds (BARCZI *et al.* 2006, SÜMEGI *et al.* 2000) and at Nyírő-lapos, boreal salt-marsh snail species were found in great abundance in late glacial loess sediments (15,000–12,000 BP; SÜMEGI 2005, SÜMEGI *et al.* 2000).

This model and the supporting palaeo-data thus imply that salinisation has long been acting in the Hortobágy, but we are still uncertain about the glacial and postglacial coverage of saline soils that likely limited woodland distribution in this area. Also notable is the fact that the full glacial and late glacial mollusc assemblages recovered at Nyírő-lapos were indicative of a mosaic environment with boreal floodplain meadows, peat-bogs and boreal floodplain forests (with characteristic species including *Columella columella*, *Vertigo genesii*, *V. modesta*; see SÜMEGI 2005).

Surface landforms within the saline grasslands have been recently studied by TÓTH (1999, 2003). Using a backing index for salt berm microform formation, TÓTH (2000, 2003) calculated the age of salt berms to 7,500–6,550 yr. The average backing index suggested that salt berm formation most likely started in the Hortobágy somewhat earlier than 3,000 years ago. Although TÓTH (2003) argues that salt berm formation was a natural process that predated river-regulation works, this date (3,000 BP) coincides with the Late Bronze Age/Early Iron Age transition, when the scarcity of archaeological remains suggest temporary de-population in this area, however, pollen diagrams (*e.g.* Sarló-hát; Fig. 3) suggest a step-wise increase in human impact, mainly in form of floodplain forest clearance and creation of grazing pastures in the floodplain zone of the Tisza near Tiszadob (CHAPMAN *et al.* 2009; see below).

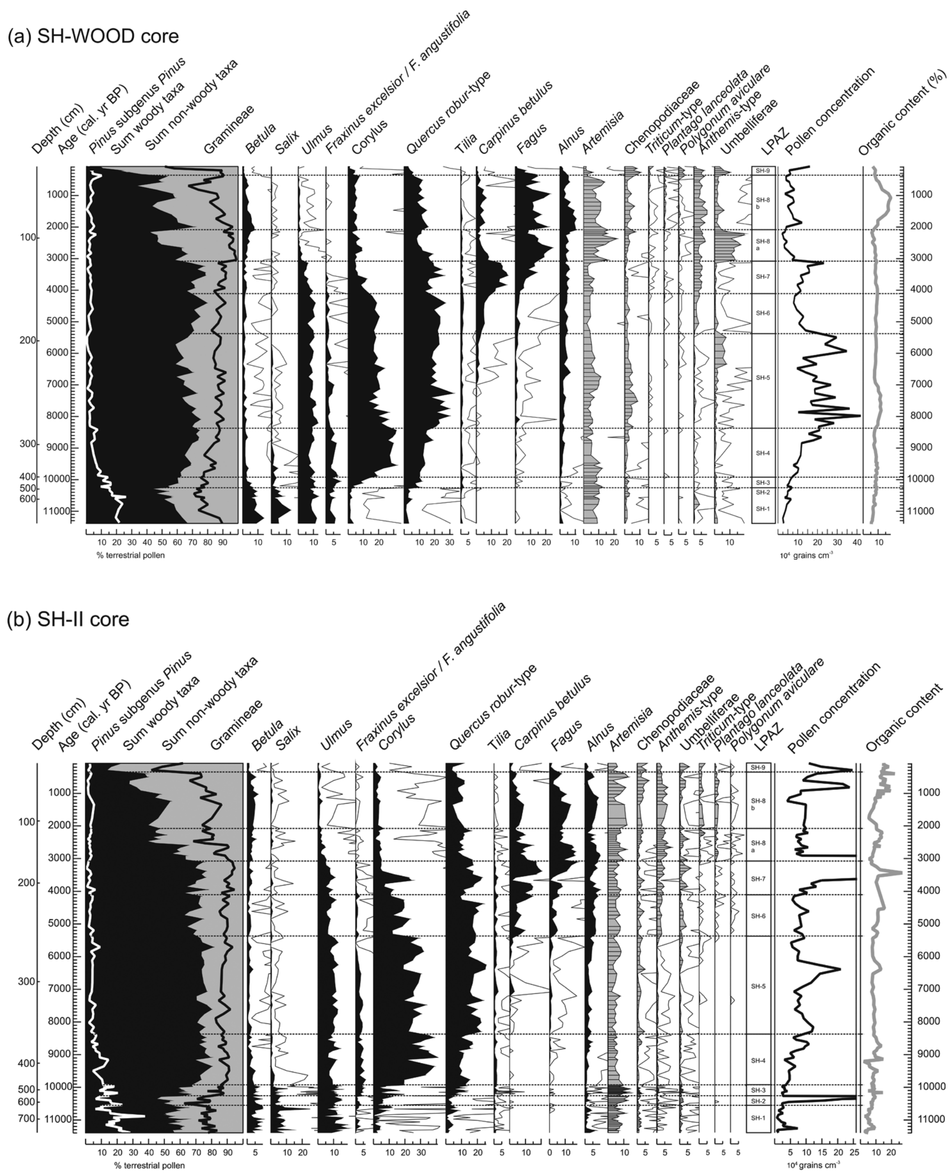

Fig. 3. Pollen percentage diagrams from Sarló-hát near villages Tiszadob and Tiszagyulaháza in the Borsod floodplain. (a) Pollen percentage diagram for the SH-WOOD core. (b) Pollen percentage diagram for the SH-II core. In both cases, percentages of selected terrestrial pollen taxa are plotted against age (calibrated year BP), the depth scale also being indicated. Overall concentration of pollen of terrestrial taxa and sediment organic content are also shown. Redrawn from MAGYARI *et al.* (2010)

CHAPMAN *et al.* (2009) suggested that despite the scarcity of material remains, nomadic tribes likely settled in the Tisza lowland and possibly also in the Hortobágy, and extensive pastoralism likely accelerated saline microlandform development. Thus, the human factor in the spread of saline landforms (and their characteristic "saline steppe" communities) cannot be ruled out.

Late Quaternary vegetation development in the Hortobágy

Late Würm and Holocene vegetation history of the Hortobágy are recorded in two pollen diagrams, both coming from Halas-fenék near Zám village (Fig. 4; FÉLEGYHÁZI and TÓTH 2003, SÜMEGI *et al.* 2005*a*). These palaeochannel sediments accumulated in an old Sajó-channel, the basal deposits were dated to > 30,000 BP (10 m) and > 35,000 BP (9.1–9.2 m) by radiocarbon. FÉLEGYHÁZI and TÓTH (2003) found pollen in the sediment between 820–1,020 cm only; above this depth pollen was not preserved. The pollen assemblages showed the dominance of *Pinus* subgenus *Diploxylon*, *Picea*, *Betula* and arboreal pollen percentages were usually above 80% (Fig. 4a). Their pollen data on the whole suggested the presence of Scots pine (*Pinus sylvestris*) dominated woodlands around the oxbow lake with the admixture of spruce (*Picea*) and birch (*Betula*). Sporadic findings of deciduous pollen were taken to infer local sporadic presence of deciduous trees (mainly *Quercus* and *Carpinus betulus*). Aquatic plants (*Myriophyllum* and *Nymphaea*) suggested shallow open water that later turned into a fen rich in bryophytes, *Carex*, *Typha* and species of Umbelliferae; *Sphagnum* species also occurred here. This relatively mild and forested interval was correlated with the Stillfried B interstadial (in Austria dated between 27,000–33,000 BP, also called Denekamp interstadial). In the upper part of the pollen-bearing layers, the disappearance of *Picea* and *Betula*, and the nearly monodominat *Pinus* subgenus *Diploxylon* pollen assemblages were interpreted to indicate dry and cold climate. The fen in the palaeochannel likely dried out seasonally and loess accumulation intensified.

The other pollen diagram from Halas-fenék (SÜMEGI *et al.* 2005*a*) contained pollen in most sediment units, and in the lower part of this core pollen assemblages were very similar to the above detailed pollen sequence (Fig. 4b), but have not been interpreted. This was followed by a *ca* 150 cm thick hiatus due to insufficient pollen preservation. Above this layer, between 800 and 630 cm, *Pinus* and *Picea* were associated with *Betula*, *Larix*, *Juniperus*, and several deciduous pollen types were present. In addition, several herbaceous pollen types obtained high relative frequencies (*e.g.* Poaceae, *Artemisia*, Chenopodiaceae, *Achillea*, *Helianthemum*). Arboreal pollen frequencies fluctuated between *ca* 50–75% (Fig. 4b). On the basis of these pollen assemblages SÜMEGI *et al.* (2005*a*) inferred mixed-leaved gallery forests, oak-ash-elm high floodplain woodlands and willow and alder forest stands in the vicinity of the meander. Saline meadows were also inferred, so as *Glyceria* and *Phragmites* marshes, and green algae (*Botryococcus*, *Mougeotia*, *Pediastrum kawraisky*) suggested mesotrophic conditions. Unfortunately, the pollen diagram displayed several herbaceous taxa identified to species level (*e.g. Artemisia maritima*, *Knautia arvensis*, *Atriplex tatarica*).

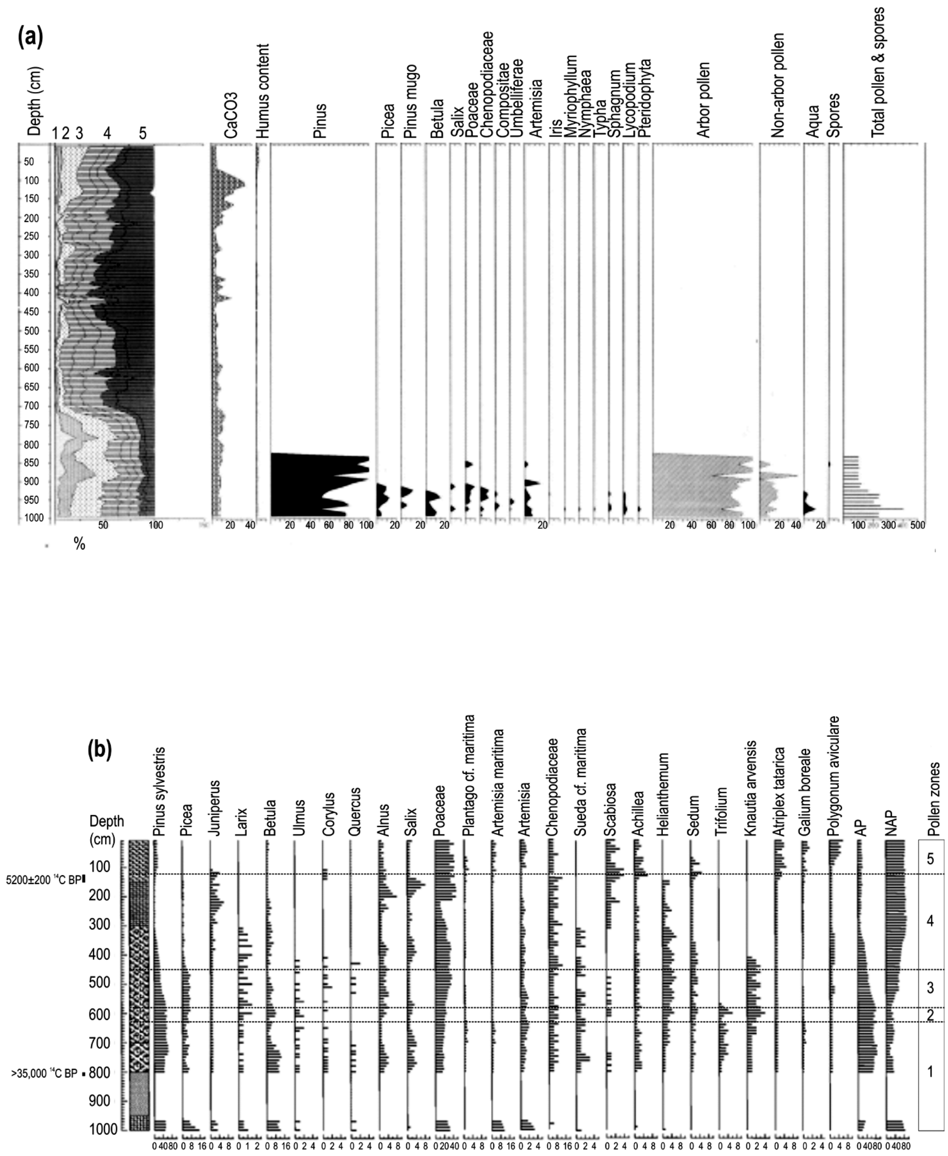

Fig. 4. Pollen percentage diagrams from Halas-fenék near Zám village in the Hortobágy. (a) Pollen diagram from the study of FÉLEGYHÁZI and TÓTH (2003) 1. fine sand, 2. coarse sand, 3. coarse silt (loess), 4. fine silt, 5. clay. (b) Pollen diagram from the study of SÜMEGI *et al.* (2005*a*). Note different scales for each taxon!

In fact, none of these taxa can securely be identified to species level as related species with similar pollen morphology are expected in this region (BEUG 2004). The text discusses the presence of further salt-tolerant herbs (not displayed on the pollen diagram) in support of extensive alkalinisation in this period. Disregarding this possible trespass, these pollen assemblages on the whole surely indicate ruderal herbaceous communities probably living on the seasonally exposed lake and mire shores in the backswamps, and the presence of *Sueda* hints at saline lakes or lakeshores that seasonally dried out. Also, the low relative frequencies of deciduous arboreal pollen types more realistically suggest pine-spruce-larch and birch dominated boreal forest steppe on the levees in which deciduous species were admixed, but oak-ash-elm high floodplain woodlands were likely not present in this phase. Interpolation between the two radiocarbon dates would place this zone between *ca* 32,000–25,000 BP (SÜMEGI *et al*. 2005*a*).

The second pollen zone was characterised by significant decrease in pollen concentrations (SÜMEGI *et al*. 2005*a*). Poorly preserved pollen assemblages hinted at the decrease of *Pinus* and increase of herbaceous taxa, mainly Poaceae, *Knautia* and *Sedum*. The disappearance of green algae and increase of Cyperaceae and Poaceae suggested that the lake was overgrown by swamp and marsh vegetation (SÜMEGI *et al*. 2005*a*). Drier climatic conditions were inferred that favoured the expansion of saline steppes. As we move further up in the pollen sequence, several pollen zones are defined, they generally reflect slightly wetter and drier phases, but the pollen assemblages remain dominated by herbaceous taxa. Of the trees only *Juniperus*, *Alnus* and *Salix* are frequent; the typical deciduous taxa (*e.g. Quercus*, *Ulmus*, *Corylus*) that in other pollen diagrams of the Great Hungarian Plain always attain high frequencies in the Holocene are either completely missing or only sporadically present. The late glacial/Holocene boundary cannot be clearly positioned; however, SÜMEGI *et al*. (2005*a*) argued that it can be placed to *ca* 300 cm, where *Juniperus* shows an increase. Overall, the Holocene is characterised by the dominance of herbaceous pollen types on the basis of which the expansion of temperate grasslands and saline steppes was inferred in the Holocene and de-forestation rather than afforestation. The authors argue that this pollen sequence represents the entire Holocene and no hiatuses are expected, therefore the pollen-inferred steppe dominance with alternating moisture availability and hence wetland inundation was characteristic for the entire Holocene. In order to make sure that these inferences are correct and representative for the entire Holocene, further radiocarbon dating of this sequence would be highly desirable.

Late Quaternary vegetation development in the Middle Tisza Plain

As we move to the northern part of the Hortobágy and the neighbouring Borsod floodplain (Fig. 5), ancient meanders become more abundant. In recent years, oxbow lake deposits from this low-lying floodplain zone were extensively studied for pollen, and provided vegetation reconstruction for the last *ca* 25,000–30,000 years (CHAPMAN *et al*. 2003, 2009, Davis unpublished, FÉLEGYHÁZI 1998, MAGYARI *et al*. 2010).

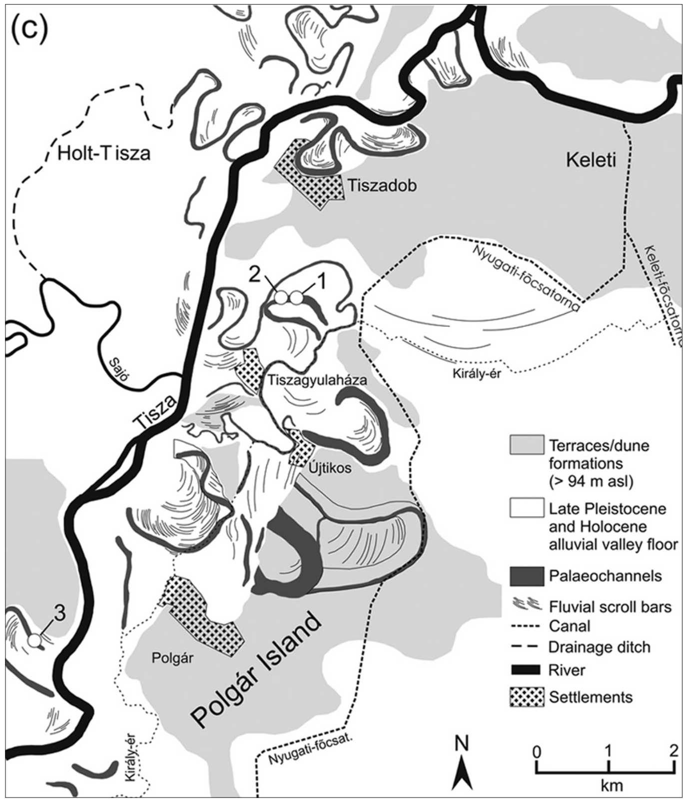

Fig. 5. Map of the Polgár Region (Borsod floodplain) showing the location of Sarló-hát oxbow lake, core locations (1 = SH-II core; 2 = SH-WOOD core; Polgar 2a core) and other local place names mentioned in the text. Redrawn from MAGYARI *et al.* (2010)

Full glacial pollen assemblages from Kengyel-ér and Hódos-ér dated around 30,000–20,000 calibrated yr BP indicated that before the last glacial maximum this area was covered by mixed conifer-hardwood forest stands composed of *Hippophäe*, *Salix*, *Populus*, *Sambucus*, *Alnus*, *Betula*, *Sorbus*, *Pinus cembra*, *Picea abies*, *Larix* and *Pinus sylvestris* in the low and high floodplain zones. In these forests the sporadic presence of thermophilous deciduous trees was inferred, similarly to the Hortobágy. All vegetation reconstructions argue that even in the milder interstades, forests were restricted to the floodplain, while older, elevated loess terraces and sandy areas (like the Polgár Island, see Fig. 5) likely hosted cold continental steppe-grasslands (rich in *Artemisia*, *Helianthemum*, Chenopodiaceae and Poaceae) and boreal wooded steppe (FÉLEGYHÁZI 1998, MAGYARI 2002, SÜMEGI 2005, SÜMEGI *et al.* 2005*b*). Extensive floodplain meadows with tall-herb communities were also inferred both on the basis of pollen and loess mollusc records (with *Thalictrum*, *Sanguisorba*, *Angelica*, *Campanula*, *Filipendula*; FÉLEGYHÁZI 1998, SÜMEGI 2005). The occurrence of *Pinus mugo* in boreal brown moss and *Sphagnum* mires was also assumed (FÉLEGYHÁZI 1998). For the last glacial maximum (LGM), both pollen and loess mollusc assemblage-based palaeoclimate reconstructions suggested that the mean temperature of the warmest month decreased to 13–15 °C in the Trans-Tisza region of the Great Hungarian Plain that is *ca* 6 °C cooler than today (MAGYARI 2002, MAGYARI *et al*. 2001, NYILAS and SÜMEGI 1992, SÜMEGI 2005, SÜMEGI *et al*. 2000, TÓTH 2003). Although we have no pollen diagram in this floodplain zone that covers the LGM, a pollen record from Kardoskút in the south Great Hungarian Plain suggests that large areas formerly covered by boreal wooded steppe were replaced by cold continental steppe or steppe tundra (MAGYARI 2002, SÜMEGI 2005, SÜMEGI *et al*. 1999). The mollusc record from the Nyírő-lapos loess profile in the Hortobágy also shows the spread of cryophilous cold steppe and desert-steppe associated species during the LGM (SÜMEGI 2005, TÓTH 2003). During the milder intervals (so-called microinterstadials that can be correlated with the North Atlantic Dansgaard/Oeschger cycles, *e.g.* the Ságvár-Lascaux interstadial after the LGM (SÜMEGI and KROLOPP 2000, SÜMEGI *et al*. 1998) summer temperatures increased to 16–18 °C.

The late glacial is represented in one pollen diagram near Polgár (Polgár 2a, Stevenson in CHAPMAN *et al.* (2003); Fig. 6). Although undated, the temporary increase in *Artemisia* before the expansion of deciduous trees points to the Younger Dryas reversal. In this diagram the late glacial pollen assemblages are dominated by *Pinus*, *Betula* and *Salix*, and several thermophilous deciduous tree taxa are present and attain 1–10% (*e.g. Quercus robur*-type, *Ulmus*, *Corylus*) suggesting that a mixed-leaved boreo-nemoral wooded steppe covered most of the high floodplain and elevated loess surfaces, while the low floodplain was likely forested by *Salix*, *Alnus*, *Betula* and *Fraxinus*.

The Holocene vegetation development is best recorded in the pollen diagrams of Sarló-hát (Fig. 3; CHAPMAN *et al*. 2009, MAGYARI *et al*. 2010). As demonstrated by TIMÁR *et al.* (2005), this palaeochannel (Ludas-ér) belongs to the first generation of Tisza channels in this area. Supplied by twelve radiocarbon dates, the pollen diagrams from this channel (one lake-marginal and one lake-central diagram) provide the most detailed and so far best dated-record for Holocene vegetation changes in the northern part of the Great Hungarian Plain (MAGYARI *et al*. 2010).

This channel was likely active during the late glacial, as the cut-off time can be estimated around 11,400 cal yr BP. Following palaeochannel isolation, initial sediment accumulation was rapid; the lower 4 m was deposited in *ca* 2,200 years. Such rapid initial sedimentation following isolation parallels observations from other palaeochannels on the Great Hungarian Plain (MAGYARI 2002). The upper 3.2 m of sediment, in contrast, spans *ca* 8,800 years. This example of Sarló-hát warns that a simple linear interpolation age-depth model between a basal and a near-surface radiocarbon date can lead to strongly biased chronologies, therefore the chronology of Halas-fenék (SÜMEGI *et al*. 2005*a*), should be taken with caution.

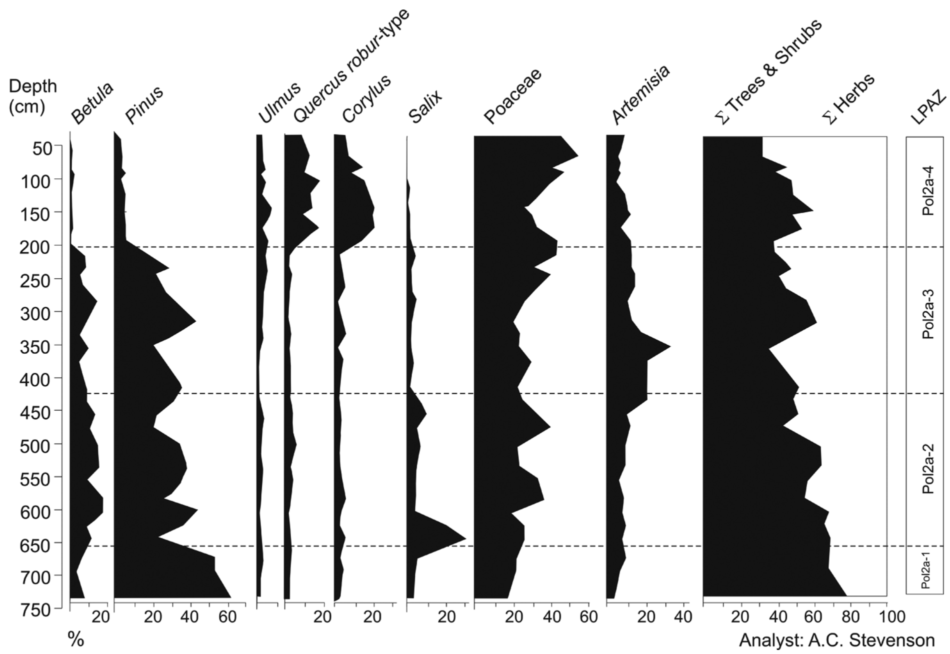

Fig. 6. Percentage pollen diagram of Polgár 2a. Although no radiocarbon dates are available from this core, comparison of the pollen sequence with other full glacial and Holocene pollen diagrams from the area (Kengyel-ér: FÉLEGYHÁZI (1998); Sarló-hát: MAGYARI *et al.* (2010)) suggests that the lowermost pollen zone (Pol2a-1) extends to the late glacial and a clear Younger Dryas climatic reversal is detectable by the *Artemisia* percentage peak in Pol2a-3

Local pollen assemblage zones (LPAZ) from the Sarló-hát pollen diagrams indicate that in the earliest Holocene, between *ca* 11,400–10,250 cal yr BP (SH-1 and SH-2), warm temperate wooded steppe and warm steppe were present in this region with *Corylus*, *Fraxinus excelsior*/*F. angustifolia*, *Quercus robur*-type and *Tilia*. 40–55% of pollen of woody taxa suggested relatively low woodland cover on the alluvial soils of the floodplain, and *Fraxinus*, *Ulmus*, *Betula* and *Salix* were prominent in the canopy of the latter. The occurrence of a range of pollen taxa representing forbs characteristic of wet meadows or marshes were taken to reflect stands of tall herbaceous vegetation on the floodplain. Micro-charcoal was abundant in the sediments of these zones, suggesting that fires were frequent.

From 10,250 cal yr BP the pollen of woody taxa, initially principally of *Quercus robur*-type and *Fraxinus excelsior*/*F. angustifolia*, but after *ca* 10,000 cal yr BP also of *Corylus*, increased (Fig. 3). Pollen of herbaceous taxa, however, continued to be abundant, comprising 27–40% of the terrestrial pollen sum. The reconstructed biome was predominantly temperate deciduous wooded steppe. MAGYARI *et al.* (2010) inferred from the abundance and range of pollen taxa representing herbaceous plants that continental steppe vegetation remained extensive on the loess terraces and that wet meadows continued to occupy substantial areas of the floodplain. Micro-charcoal accumulation rates were even higher than previously, suggesting that wildfires may have played an important role in maintaining the openness of the vegetation. Similar high early Holocene micro-charcoal abundance was found at Bátorliget (WILLIS *et al.* 1995), indicating that fires may have been of general importance at this time in the northeastern part of the Great Hungarian Plain.

Between 9,900–5,400 cal yr BP (LPAZs SH-4 and SH-5) pollen of herbaceous taxa continued to be relatively abundant (25–42%) and pollen of steppe-indicator taxa averaged 12%, indicating that open vegetation continued to be extensive on the surrounding landscape. MAGYARI *et al.* (2010) inferred that the loess terraces supported temperate deciduous wooded steppe throughout both LPAZs, with the main trees being those associated with the *Quercus robur*-type, *Ulmus*, *Tilia* and *Corylus* pollen taxa. The floodplain, however, probably continued to support localised stands of temperate deciduous forest, the extent of which increased during LPAZ SH-4. The canopy of these floodplain forests was a mixture of *Corylus*, *Fraxinus*, *Quercus*, *Alnus* and *Ulmus*. The transition from SH-4 to SH-5 at 8,400 cal yr BP was marked by an increase in abundance of pollen of *Quercus robur*-type and a corresponding decrease in *Corylus*. This coincided with a marked drop in water depth in the oxbow lake, indicated by changes in the assemblage of microfossils of wetland taxa and in the sediment lithology. Micro-charcoal abundance increased at this time, as did the abundance of pollen of herbaceous taxa, the latter especially in the marginal SH-WOOD core. The latter probably reflected the development of seasonally-inundated areas around the lake that, when exposed, supported communities of Chenopodiaceae and various ruderals (*e.g. Polygonum aviculare*). MAGYARI *et al.* (2010) inferred from this that summer conditions became drier after 8,400 cal yr BP. The drier conditions resulted in reduced and seasonally-fluctuating water levels in the lake and an increase in frequency and/or intensity of fires. Although pollen of salt-tolerant herbaceous plants was not detected in the Sarló-hát cores, therefore these lakeshore ruderal associations were not necessarily saline in the Tisza floodplain zone, this dry-summer interval likely experienced similar high amplitude lake-level fluctuation in the palaeochannels and seasonally inundated areas of the Hortobágy, where different edaphic conditions likely facilitated the expansion of saline wetland and steppe plant communities naturally from 8,400 cal yr BP.

A further decrease in the abundance of pollen of woody plants after *ca* 7,600 cal yr BP, which is expressed more strongly in the marginal SH-WOOD core, coincided with brief peaks in micro-charcoal accumulation and with the appearance of pollen taxa probably indicative of anthropogenic disturbance (*e.g. Triticum*-type). This indicated the onset of episodic clearances of woodland areas by Neolithic groups, the presence of which in the area at this time has been well documented by detailed archaeological research (CHAPMAN *et al.* 2003, RACZKY *et al.* 2002). Subsequent fluctuations in the extent of tree cover on the surrounding landscape, reflected by changes in the proportion of pollen of woody taxa, reflected changes in the intensity of human occupation and activity in the area rather than climatic changes. Nonetheless, it is likely that the decrease in abundance of Chenopodiaceae pollen and corresponding increase in Umbelliferae *ca* 6,400 cal yr BP reflects more seasonally stable water levels in the lake, wet meadow vegetation with various forbs replacing the seasonal communities of ruderals around its shore, and that this in turn reflects a climatic change, probably moister summer conditions.

From 5,400 cal yr BP LPAZ (SH-6) marked increases in the abundance of pollen of *Carpinus betulus* and *Fagus* and decreases in *Corylus* pollen together with a marked decrease in micro-charcoal abundance suggested that *Carpinus betulus* and *Fagus sylvatica* appeared in the floodplain woodlands of the Tisza River. The increased abundance of *Anthemis*-type pollen, which represents several genera of forbs common today in dry and saline meadows, pastures and ruderal communities (*e.g. Anthemis*, *Chrysanthemum*, *Leucanthemum*, *Matricaria*), indicated a general shift in the composition of the herbaceous communities on the floodplain around Sarló-hát. Given that this signal was expressed more strongly in the SH-WOOD core, it is likely that these changes predominantly were in the floodplain meadow communities rather than in the herbaceous component of the wooded steppe on the loess terraces. Although these changes most probably were a response to increasing moisture availability during the growing season, and an associated decline in fire frequency indicated by the decreased micro-charcoal abundance, the possibility cannot be excluded that they reflect an increase in pastoral activity.

Between 4,100–3,100 cal yr BP (LPAZ SH-7) a peak in abundance of *Carpinus betulus* pollen, a marked decrease in *Corylus* pollen and a progressive increase in *Fagus* pollen suggested a further increase of these mesic trees in the floodplain forests.

At 3,100 cal yr BP the first of a series of episodic sharp decreases in abundance of pollen of woody taxa was detected, herbaceous pollen accounted for 30–60% thereafter. The shifting composition of the regional woodlands, with increasing abundance of late-successional mesic trees (Ellenberg 1988), reflected changes in both fire frequency and moisture availability. Initially, peak abundance of *Carpinus betulus* corresponded to a peak in micro-charcoal abundance, perhaps indicative of an interval of relatively drier conditions. The subsequent increase to peak values of *Fagus* corresponded to a sharp decrease in micro-charcoal abundance, probably indicating a shift to greater growing season moisture availability. Several independent proxies also suggest that moisture availability increased during this period (Constantin *et al.* 2007, Feurdean 2005, Magyari *et al.* 2001, Schnitchen *et al.* 2003). In the absence of human activity, this climatic trend would be expected to have resulted in a general increase in the extent of tree cover. Instead, tree cover decreased markedly from 3,100 cal yr BP. This increase in the extent of open areas corresponded to increases in the abundance of pollen of taxa associated with disturbance (*e.g. Polygonum aviculare*), pastoral activity (*e.g. Plantago lanceolata*) and arable agriculture (*e.g.* cereals), strongly implicating anthropogenic activity as the principal cause of the decreased tree cover. The relatively low abundance of micro-charcoal at this time suggests that anthropogenic fires were not the principal cause of the reduced tree cover. The increases in herbaceous taxa characteristic of steppe and meadow communities suggested that pastoralism may have been a major factor leading to the decrease in tree cover.

These findings in the Tisza floodplain have some implications for the possible vegetation changes of the Hortobágy at the same time. Seasonal water-table fluctuation must have also become weaker in the Hortobágy from 3,100 cal yr BP, but on the other hand pastoralism likely affected the landscape and probably acted against the natural processes even if we assume less population density here than in the Polgár Region (Sümegi *et al.* 2000).

As evidenced by TÓTH (2003), salt-berm formation intensified from *ca* 3,000 cal yr BP and if we consider that groundwater fluctuation likely weakened from 3,100 cal yr BP, then these changes can hardly be interpreted without intensified human disturbance (pastoralism).

The transition to SH-8b (2,100 cal yr BP) initially was marked by an increase in pollen of woody taxa, especially in SH-WOOD, indicating an increase in tree cover locally on the landscape around Sarló-hát. *Alnus* pollen, in particular, increased in the SH-WOOD core, probably indicating the development of local fenwoods around the lake margin. Thereafter, however, the overall trend during this sub-zone and the subsequent LPAZ SH-9 was one of rapidly decreasing abundance of pollen of woody taxa, the corresponding increase in abundance of herbaceous taxa being accounted for principally by Poaceae. The predominant reconstructed biome was warm steppe. The loss of tree cover on the surrounding landscape, both on the loess terraces and the floodplain, during the last two millennia was almost certainly a result principally of intensifying agricultural exploitation of the area. Pastoralism predominated until relatively recently when water resource management and the construction of water storage reservoirs from the 18th century onwards enabled arable agriculture to be practised over increasing areas.

CONCLUDING REMARKS

Palaeoenvironmental data presented in the previous sections highlighted that over the last two-three decades a considerable progress has been made on both the physical geographic and palaeoenvironmental assessments of the Hortobágy. These studies clearly demonstrated that the Hortobágy is an ancient alluvial landscape formed by rivers coming from the Northern Hungarian Mountains during the last glacial period, but still within this period, direct fluvial activity ceased with the sudden relocation of the Tisza channel to the north of Hortobágy (the "Záhony avulsion"). According to our present knowledge, this avulsion took place 16,000–18,000 cal yr BP (TIMÁR *et al.* 2005), although the basal age of the Sarló-hát meander (11,400 cal yr BP; MAGYARI *et al.* 2010), which belongs to the first channel generation of the Tisza after the avulsion, suggests that the avulsion might have taken place later, during the late glacial period (between 14,500–11,500 cal yr BP). Pollen data suggested that during the Upper Pleniglacial period (including the last glacial maximum) the Hortobágy supported mainly boreal wooded steppe, steppe tundra vegetation and extensive boreal mires in an alluvial landscape. Overall, forests were still present in the landscape and especially the loess-mollusc profiles, palaeosoil data and less soundly the pollen diagram of Halas-fenék suggested saline habitats on palaeochannel margins, where seasonal water table fluctuation was high. It is thus probable that the saline landscape has already developed 30,000–20,000 years ago (SÜMEGI *et al.* 2005*a*), but the extent of saline marshy and steppe habitats and its temporal changes are still poorly understood. The present popular view places the emphasis on the naturally unwooded and saline nature of the Hortobágy; however, there is also evidence on the profound impact of extensive grazing by prehistoric and historic pastoral communities on the vegetation and their role in the demise of open forests. Thus, an opposing view that steppe oak woodlands were more extensive at least in the vicinity of ancient riverbeds in the Hortobágy prior to the settlement of nomadic tribes is also conceivable. At least, pollen diagrams from the nearby Middle Tisza Plain support this view. In order to assess temporal changes in wooded steppe and saline steppes during the late glacial and Holocene in the Hortobágy, further palaeoenvironmental data are strongly needed, and this is an extremely difficult task as sedimentary archives with well-preserved pollen are real curiosity in this seasonally dry landscape with alkaline sediments.

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