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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 Forschung*en, 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

Eszter Bánffy

The Danubian Sárköz: A geographic, prehistoric, and historic region in the southern Hungarian section of the Danube Valley. An introduction

Archaeological investigations involving the use of precise geographic maps, let alone of aerial photography, were impossible in Hungary for long decades in the 20th century, as these were forbidden in the Eastern European countries behind the Iron Curtain. Environmental archaeology was therefore virtually restricted to the work undertaken by geologists and botanists. Military maps with a scale smaller than 1 : 25 000 were classified and kept under strict control. These maps were made available to professional archaeologists exclusively for field surveys in smaller areas, for example along a stream, or for areas encompassing the territory of no more than a few villages. Aerial archaeology was unknown for the very same reasons.

One of the main concerns of archaeological research into the Neolithic of the Carpathian Basin was the creation of a firm relative chronological sequence, primarily based on ceramics, less frequently on stone tools or other artefact types. As a result of archaeological work, the typological description of the finds and the nature of the interaction between the period's cultures were largely clarified by the later 20th century.

Any modern environmental work on the Neolithic of the riverine plains can only be based on the previous work of Krisztina Kosse, Nándor Kalicz, János Makkay, Ottó Trogmayer, and Pál Raczky (Kosse 1979; Kalicz 1965; Kalicz / Makkay 1972; 1977; Makkay 1982; Trogmayer 1968; Raczky 1983; 1988). Based on this past research work, the pioneering fieldwork by Pál Sümegi and his co-authors and students means a step change, along with novel investigations on the fluctuation of groundwater over millennia by Gábor Serlegi (see these studies in the present volume with relevant literature).

Archaeological research on the Neolithic and Copper Age lagged behind in the western half of the Carpathian Basin. This is especially valid for the Early Neolithic, i. e. the earlier 6th millennium BC. In 1990, N. Kalicz published a monograph summarising our knowledge of the Early Neolithic of Transdanubia, principally based on the evidence from field surveys and smaller excavations that indicated that the first farmers from the northern Balkans, various Starčevo communities, had crossed the Drava and had advanced as far as the hilly region near Lake Balaton. For many years, his study was an essential textbook for research on the Transdanubian Early Neolithic. Regarding the later 6th millennium BC, the first major advances were brought by the large-scale preventive projects. The investigation of extensive areas brought to light hundreds of LBK sites (Bánffy / Oross 2009; Marton / Oross 2012). In contrast to the earlier Neolithic, the intensive presence of Lengyel cultural features was identified already in the early days of Hungarian archaeology, particularly in the south-eastern corner of Transdanubia, which was intensively studied by István Zalai-Gaál for many years (Zalai-Gaál 1986; 2002).

Following the transition in 1989, the methods employed in landscape archaeology began to develop rapidly and the number of specialists partaking in this work also increased. Significant advances have been made in the study of the northern frontier of the Körös culture in the Alföld (Great Hungarian Plain) through the insights gained from new sites investigated with wholly new research questions in mind, which also explored the nature of the interaction between prehistoric communities and their environment. The excavations conducted by Alasdair Whittle and his team at Ecsegfalva, Békés county, and the work by László Domboróczki must be mentioned in this respect (Whittle 2007; Domboróczki / Raczky 2010; Domboróczki et al. 2010).

The large-scale salvage excavations ahead of motorway constructions in the 1990s and especially from the

2000s brought an entirely fresh perspective on the internal chronology and the social changes in the 6th millennium BC, while smaller planned excavations shed exciting new light on the finer details of the blend between the Balkanic groups and the local population, as well as on the various dimensions of the transition to the Neolithic. These projects of preventive archaeology brought striking new results everywhere, but they proved to be particularly important for regions that had been under-researched. First of all, three micro-regional projects grew out of these major preventive archaeological investigations, one in the western Balaton region and two in regions lying farther to its west. The new data on the 6th/5th millennium BC settlement history in western Transdanubia contributed profoundly to our understanding of the Neolithic transformation in the Balkans and Central Europe, of which the study area represented the northernmost region (Bánffy 2000; 2004; 2006; 2007; Bánffy et al. 2007; Bánffy / Oross 2009; Bánffy / Sümegi 2011; Regenye 2008). In later centuries, the impacts reaching the area from the northern Balkans resulted in a kaleidoscopic blend of the new impulses and the already compound local substrate.

Since the fall of the Iron Curtain, all branches of geoarchaeology have become an integral part of studies on cultural development and (pre)historic processes in Hungary. The new findings of geology, geophysics, hydrology, geochemistry, botany, malacology, and vertebrate archaeozoology have been integrated into virtually every major research project. Studies on the diet and migrations of prehistoric populations increasingly rely on the findings of mitochondrial aDNA and stable isotope analyses, both important parts of bioarchaeology. Models and reconstructions of the initial phases of food production now incorporate the research results of hard science, while the interpretation of these results with a relevance for social interaction and social identities is largely the field of social archaeology.

In the Institute of Archaeology (RCH) of the Hungarian Academy of Sciences[1] (HAS) in Budapest for example, the geoarchaeological approach gained currency in the early 2000s: the first monographs on the environmental background of prehistoric and later cultures were written by research groups made up of archaeologists, geoarchaeologists, botanists, and malacologists (one of these was a volume on environmental archaeology in Transdanubia: Zatykó et al. 2007). Simultaneously, the close cooperation with the Geoarchaeology Graduate School at the University of Szeged also brought new possibilities in working with PhD students, supervising their dissertations and involving them in the field surveys of the Budapest Institute of Archaeology.

In the early 2000s, a team of the Institute of Archaeology began to investigate a concentration of Neolithic settlements extending for some 25 km along the eastern (left) Danube bank. The twin sites of Fajsz-Garadomb and Fajsz-Kovácshalom, both Bács-Kiskun county, as well as the early Neolithic settlement of Szakmár-Kisülés, Bács-Kiskun county, all lie in this alluvial, riverine flat landscape. The latter was excavated in the 1970s, but remained unpublished. A description of the Early Neolithic settlement, including the publication of what could be gleaned from the surviving documentation and finds of the Szakmár-Kisülés site, was published a few years ago (Bánffy 2013). Meanwhile, one of the above-mentioned preventive archaeology projects was undertaken on the western Danube bank, quite close to the Fajsz research project. The latter, necessitated by the construction of the M6 motorway, brought to light an exceptionally large site at Alsónyék, Tolna county. This settlement and burial place, with its estimated extent of 80 ha (as indicated by the excavated area and the geophysical prospections), is possibly not only the largest Neolithic site in Europe, but also an exceptionally important element of European heritage. The excavation of the site between 2006 and 2009 was followed by extensive analyses, still ongoing, much of it involving international cooperation. This work was supported by grants from the Hungarian Research Fund (OTKA)[2] for post-excavation work, the German Research Fund (DFG)[3] for aDNA analyses, and collaboration with the European Research Council-funded project "The Times of Their Lives" (ToTL)[4].

To set the scene, some concise basic geological information about the heartland of the Carpathian Basin seems in order. As a result of a collision of the Eurasian and north African plates (Horváth et al. 2015), the basin was submerged in the Miocene (Horváth 1993). After the Pannonian Lake dried out, the region became bisected by two major rivers, the Tisza and the Danube and their many tributaries. While the Tisza flows in the eastern lowland (Alföld) region, the Danube cuts the alluvial lowland from the hilly and forested western section in Transdanubia. The central section of this major river that flows across vast European regions with a mainly north-west to south-east course, from the Black Forest in Germany to the Black Sea in Romania, is the

1 Since 2019 the Institute belongs to the Eötvös Loránd Kutatási Hálózat (ELKH).

2 Alsónyék: az élelemtermelés kezdeteitől az újkőkor végéig K 81230 (Alsónyék: from the beginnings of food production to the end of the Neolithic), led by Eszter Bánffy.

3 Bevölkerungsgeschichte des Karpatenbeckens in der Jungsteinzeit und ihr Einfluss auf die Besiedlung Mitteleuropas, led by Kurt W. Alt.

4 The Times of Their Lives: towards precise narratives of change in the European Neolithic through formal chronological modelling (ERC Advanced Investigator Grant 295412), led by Alasdair Whittle and Alex Bayliss.

Carpathian Basin. The present volume is dedicated to various investigations and their many-sided assessments that are in one way or another related to the Danube in southern Hungary, in the Sárköz region.

Aside from the decisive role of the Danube, the Sárköz region has another intriguing feature which merits scholarly attention. This is the marginal zone flanking the central Carpathian Basin, which appears to have acted both as an important divide and as a contact zone exactly in the region of our study area. From their studies on the changing climatic proxies and the associated substantial changes in the landscape conducted over a decade ago, environmental historian Pál Sümegi and archaeologist Róbert Kertész proposed the model of an ecological barrier running south-west to north-east that divided the Carpathian Basin into two halves, with the southern half largely part of the South-East European ecological zone and the northern half, especially Transdanubia with its heavily forested hills, part of the Atlantic climatic zone (Sümegi / Kertész 2001). The line of the barrier roughly coincides with the divide in the geological structure. The region's current geological structure is essentially determined by the above-described collision of the European and African continental plate margins during the early evolutionary stages. Their tectonic deformation and uplifting led to the formation of the large Pannonian Basin; the barrier runs roughly through the central part of the Pannonian Basin, along the divide between the two ecological zones (Haas 2015). This division, a collision between the tectonically less active Bohemian Massif and the Dinaric Plate with a higher seismic activity, can be noted along a south-west to north-east axis across the Pannonian Plain, causing different thermal conditions that influence the soil's heat flow and, as a consequence, the composition of the flora and fauna too (Lenkey et al. 2002). A glance at the mountain ranges running from southern Transdanubia to north-eastern Hungary in a clearly south-west to north-east direction also reflects the position of the different tectonic plates, again conforming to the direction of the barrier described by Sümegi / Kertész (2001).

The previous archaeological investigations and the associated projects all imply that one important task is to investigate smaller regions with a combination of on-site and off-site analyses. It was realised quite early on, when the sites along both Danube banks were investigated, that the alluvial riverine wetland known as the Sárköz region flanking both the western bank of the Danube (Tolna Sárköz) and the river's eastern bank (Kalocsa Sárköz) is a unified and compact region in both the geographical and the historical sense.

The region's most prominent geographic element is the Danube, the river flowing across the greater part of the European continent. A closer examination of old maps and the findings of geological investigations both indicate that the wide waterway we see today flowing between two banks did not exist before the river's regulation. The Danube split into two branches after leaving Budapest: one branch flowed slightly eastward and, winding along the edge of the drift-sand, reached the river's current main channel at the town of Baja. The main Danube bed shifted westward together with the old branches that later disappeared, and a marshland laced with streamlets providing excellent channels of communication extended along both river banks. Flanking both banks of the Danube, the Sárköz region formed a transition between the Great Hungarian Plain and Transdanubia (Nebojszki 2006). Sámuel Mikoviny's military map commissioned by the Habsburgs in the 18th century depicts the still existing colourful mosaic of countless bends, side-branches, active channels, and periodically flooded floodplains dotting the marshland. The map of the First Ordnance Survey (1782–1785) recorded a similar environment. The current landscape of cultivated fields criss-crossed by channels was created by the river regulations begun in the later 19th century. The Danube had simply not existed as a frontier river in the 6th millennium BC: instead, the river branches meandered across a waterlogged marshland dotted with shallow sand-bars. Many of these branches were living rivers, while others were branches transformed into living water only during times of flood, or oxbows cut off from the main channel at some earlier time. The region was far from impenetrable: communication between the river's two banks was continuous during the past millennia, the only exception being the Roman *limes* along the river, although the Roman imports appearing in the heritage of the Sarmatian tribes living on the river's left bank suggest that the Roman frontier was not as impenetrable as it might seem and could be negotiated to some extent. Similarly, there is ample evidence for exchange between Transdanubia and the Körös valleys during the Neolithic, many millennia before the Roman rule.

The former Danube channels on the left bank shifted westward as the river's flow direction changed. Deposits from these former channels can be identified with the gravel and sand layers lying at a depth of c. 2 m (Pécsi et al. 1981). The current north to south channel developed at the close of the Upper Pleistocene; the river has since remained the single natural drainage in the region (Romsics 1998). The area known as the Kalocsa Sárköz is a high floodplain extending for some 20 km from the Danube, whose terraced levees, rising no more than a few meters above the surrounding land, are criss-crossed by streamlets and the oxbows detached from the palaeo-Danube. Extensive areas are covered with alluvial silt; the excellent humified alluvial soils evolving from them make the area of the Sárköz region lying in the

Danube-Tisza interfluve one of the most fertile agricultural regions (Romsics 1998).

The right bank of the Danube is covered with a waterlogged floodplain dissected by oxbow lakes up to the Szekszárd Hills. The small islets rising above the marshy floodplain were the remnants of one-time alluvial cones, the single flood-free areas during the long millennia before the river's regulation. These alluvial terraces were the only areas suitable for farming since the lower-lying areas were covered with gallery woods. The area is now predominantly covered with alluvial soils, with the occasional meadow chernozem on the higher terraces (Marosi / Somogyi 1990).

It is clear from the above brief overview that similar geomorphological and hydrological conditions characterised both banks of the Danube. According to Imre Katona, "an extensive water-world and marshland extended from the Szekszárd Hills to the sand-banks of the Danube-Tisza interfluve, with its own distinct lifeways and habits, a water-world which was neither part of Transdanubia, nor of the Great Hungarian Plain, but acted as a transition between the two. Lying between the Szekszárd Hills and the high sand ridges of the Danube-Tisza interfluve was a deep, marshy Danube trough, on whose floor wound the unregulated Danube, roughly in its middle. The river between the two banks did not form a divide as it does today: the communities living on the opposite banks could communicate with each other without any hindrance. The real barrier between Transdanubia and the Great Hungarian Plain was the edge of the marshland flanking the river" (Katona 1954, 2; my translation). The above description is an excellent summary of the environmental conditions in the Sárköz region: it was a uniform landscape before the river regulations, and thus also in the 6th–5th millennium BC.

The present studies not only focus on the alluvial plain, but also on the broader area of the forested and hilly landscapes in Transdanubia in the western Carpathian Basin. The reason for choosing a larger area is the chance for comparison: we can thus include the archaeological results of the neighbouring regions of central and western Transdanubia where fundamental research advances have been made during the past two decades.

It must at this point be recalled that Starčevo groups had also settled in roughly similar environments south of the Sárköz region: marshy loess dominates the areas bordering on the 90–200 m high alluvial soils between the Drava and the Sava, where floods occurred regularly (Šparica 2007). In the Srem region, the Starčevo settlements similarly lie on high plateaus (Petrović 1976; 1984 / 85), resembling the location of the culture's sites in the Szekszárd area. According to Kornelija Minichreiter, the settlements lay "on riverbank terraces, on sun-drenched, lower-lying gentle hill slopes in stream valleys and near water sources […] on the plain next to former watercourses, of which only dry beds remain today" (Minichreiter 2006, 80). The single major difference between the two regions was that Transdanubia was more heavily forested (Sümegi 2004).

It is important to bear in mind that apart from being a unique alluvial wetland along the Danube, the Sárköz region is also a liminal, marginal zone, lying between the South-East European lowland (i. e. the Voivodina and the Banat in the northern Balkans) and the cool and forested hills of Transdanubia that have more in common with the Atlantic Central European landscapes. A growing interest in the frontier zones in the Carpathian Basin has appeared in prehistoric archaeological research. Many models have been proposed for explaining the divides and frontiers between cultures and population groups as reflected in the archaeological record. These frontier studies reflect an awareness among archaeologists that research on the internal development of a particular archaeological unit should be coupled with the examination of the reasons for the halt in the spread of a culture if it was not caused by a geographic barrier, as well as of the reasons for the lack of interaction with neighbouring cultures in order to gain a better understanding of cultural development. Models on archaic frontiers have changed significantly during the past decades. Earlier, frontiers were generally conceived of as an impassable demarcation line (Ehrich 1961), even though boundaries of this kind hardly existed in Europe before the emergence of nation-states and their closely guarded borders. More recently, border zones are conceptualised as permeable areas, porous and dynamic, providing ample opportunities for interaction between different communities, and resembling frontiers rather than boundaries, whose mediating role is at least as important as their presence as a barrier.

The spread of sedentism and food-producing economies in the earlier 6th millennium BC represented a major advance towards civilisation in Europe. Studies shedding light on various dimensions of this process have an overall relevance for European prehistory. This is perhaps one of the main reasons why, besides the obvious interest in this subject in Hungary, new advances in frontier studies and discussions on the potential regions where innovations were transmitted, as well as on the modes and the actors of transmission have always been followed with keen interest.

A change in conditions can be caused by many different factors: different soils, fluctuating groundwater levels, topographic conditions, vegetation, and temperature – these are the environmental factors. Marginal conditions can also evolve owing to a change in subsistence practices, or between two groups in a frontier region as a consequence of political, religious, linguistic or other factors leading to isolation (Coles / Mills 1998). Some marginalising factors such as temperature, hydrological conditions, and natural topography are independent of a region's occupants, while others such as subsistence strategies have a strong impact on whether or not a particular group becomes marginal. What might be a disadvantage for one group can be an advantage for another one with a different life-style (Halstead / O'Shea 1982). An environmental marginality certainly existed in the case of the Szekszárd Hills region.

Living in a frontier zone of this type demanded a strong measure of adaptation from the communities settling there. This is a crucial dimension in any examination of the reasons of why the Körös groups played an insubstantial role among the first farmer groups migrating to the heartland of Central Europe along the Danube, while the Starčevo communities left an indelible mark. It seems to me that this transitional, marginal zone played a key role in the adaptation of the Transdanubian Starčevo groups and their willingness to make contact, without which there could have been no interaction with the local forager population, leading to the emergence of the formative Linearbandkeramik culture (LBK). Thus, the Danubian floodplains in southern Hungary and the adjacent Szekszárd Hills region played a prominent role in the Neolithisation of Europe.

Accepting the assumption that the Körös and Starčevo populations had belonged to different language families (or were part of the same language family, but spoke different tongues that had separated them to the extent of preventing mutual understanding), as had the northern and southern Transdanubian LBK groups and, later still, the Lengyel communities and the Neolithic groups to their south in the Drava region (the Sopot and Vinča groups), we should be able to define when and where these differences had evolved. The Körös and Starčevo populations were still part of the same cultural complex in the culture's early phase, which lasted until the turn of the 7th/6th millennia BC in the northern Balkans, not far from Hungary's current southern border. The early LBK can, for the greater part, be derived from the Starčevo culture, while the late LBK groups were the descendants of a single, early cultural unit with a lapse of a few generations, and the Lengyel culture is clearly descended from LBK. New cultural impulses, if any, could only have arrived from the northern Balkans, the very region from which this culture set itself apart. How can different language groups be assumed among the Neolithic populations of Transdanubia in the light of such a clear-cut genealogic order? It follows from the above that the current archaeological record is unsuitable for the study of the possible linguistic aspects of the Neolithic of the Carpathian Basin and thus linguistic explanations cannot be invoked in the frontier models suggested for this region.

In the Transdanubian Sárköz region, the LBK settlement territory does not overlap with the Starčevo distribution, and, as the observations made at Alsónyék show, there might have been a gap between the site's two occupation phases. The reason for this gap may possibly be that the formative LBK area lay north of the Sárköz region, in central and western Transdanubia, in the Balaton region. After this short gap, the LBK spread across the entire Sárköz and the immediately adjacent regions (Bánffy 2003; Marton / Oross 2012; Jakucs et al. 2016; 2018), as reflected by the often extensive and intensely occupied settlements. Another important issue is to what extent a newly arriving Sopot group from the Drava region had made a deliberate choice to occupy the Alsónyék site and to construct a circular ditch in the vicinity of the LBK house area, and, particularly, why a Lengyel community chose the very same flat hillslope for its settlement slightly later (the successive occupations and internal chronology of this long-lived settlement have been discussed in a volume published in 2016: Osztás et al. 2016 and further contributions in the same volume).

The appearance of the Sopot culture north of the Drava River and north of its core area in Croatia is often considered to be a catalyst for the birth of the Lengyel culture from late LBK groups, and marks the advent of the local Late Neolithic at the turn of the 5th millennium BC. Given this broad situation, the eastern part of the Sárköz region, including its eastern end, the Vörös mocsár (Red swamp) area is notable not only for the major stratified Sopot settlement at Fajsz-Garadomb, but also for the north-westernmost Neolithic tell settlement in Europe. Fajsz-Kovácshalom is therefore a key site for understanding the shifts in land use immediately before the emergence of the Lengyel culture, the large cultural complex spreading to vast regions of Central Europe (Bánffy 2003; Bánffy et al. 2014). The chronological position of the Sopot culture is even more intriguing in the western part of the Sárköz region, for example at Alsónyék, where the Sopot site lies just 1 km away from the Lengyel core settlement, with which it proved to be partly coeval (cf. Oross et al. 2016).

The beginning of the 5th millennium BC saw the emergence of the huge Lengyel cultural orbit; in the Sárköz region this period is represented by the Lengyel settlement and cemetery at Alsónyék. Nearly 9000 of the approximately 15 000 excavated features can be assigned to the Lengyel phase, including 2359 burials, numerous pits and pit complexes, and 123 post-framed houses. Thus, the Lengyel presence and impact is one of the salient questions in the investigation of the environment and of land use.

A little farther to the north-west, the lacustrine area of Lake Balaton, surrounded by marshy creek valleys, was an ideal habitat for hunter-gatherers (Zatykó et al. 2007; Bánffy et al. 2007). When examining how the settlements of both the Starčevo and earliest LBK cultures correlated with the wetland and lakeshore environments, which are more typical for Mesolithic foragers than for the habitats preferred by farmers, a local population has been generally assumed. As a matter of fact, the recent significant increase in relevant data has yielded both archaeological and environmental evidence for pre-Neolithic settlements.

The first data on the water level fluctuations of Lake Balaton, which postulated a rather high water table and an extended marshland around the lake at the dawn of the LBK, were published several decades ago (Bodor 1987; Nagy-Bodor / Járai-Komlódi 1999). More recently, a detailed environmental analysis of the Mid-Transdanubian Balaton region has been undertaken as part of a large-scale research project. This project targeted a full reconstruction of the region's geohistory based on all possible means of geoarchaeological and palaeoecological investigations (pollen, macrofossils, mollusca, sediments, and hydrology). Led and evaluated by Pál Sümegi and his colleagues, the project's goal was to reconstruct the anthropogenic impacts and the changes in their wake in the context of settlement strategies and land use (Zatykó et al. 2007). The most recent investigations have indicated a climatic shift to a wetter period in the 6th and 5th millennia BC, including a fairly sudden rise in the lake's water level. The first study, by Knut Rassmann and colleagues, in this book is based on a method that has become a routine exercise during the past decade, but was truly pioneering when it was first employed. The geophysical prospections at the Alsónyék site were conducted in the area beyond the planned motorway track, which was therefore not excavated. The first results called for further investigations, and by the time the joint RGK and Institute of Archaeology (HAS) projects had been completed, several other small regions around the Neolithic sites of the Sárköz were included in the research project. Each year of the project, some novel method appeared that was tested and included in this work. The current state of research is reflected in the chapter by K. Rassmann et al. – however, given the rapid increase in new methods, it also provides a snapshot, an overview of the current methodological arsenal. The main author of the next chapter, Pál Sümegi, is an environmental specialist, a geoarchaeologist, who has been involved in the study of hydrological conditions and their changes over the centuries or, better said, over the millennia in southern Transdanubia. Lake Balaton is one of the most whimsical waters in the entire region, whose water level fluctuated in the wake of even minor or minimal climatic changes. The study focusing on the Neolithic and the immediately ensuing period offers a good overview of the changes in the settlement history in the broader region.

P. Sümegi and his team, including several PhD students of the Szeged graduate school, focus on the environmental history of the Danube alluvial wetland and its margins in the west (in Transdanubia) and in the east (in the Danube-Tisza interfluve). The comprehensive analysis in the chapter is based on many years of intensive environmental and geoarchaeological research. Sedimentology and pollen analysis are the two ends of the scale, when proceeding from the analysis of inorganic to organic remains.

The next chapter might seem a small detour in geographical terms, but it gives a good insight in the hydrological conditions of the southern shore of Lake Balaton and the adjacent areas in southern Transdanubia in total, to which also the Sárköz region belongs. Gábor Serlegi analyses the settlement positions of the different archaeological periods beginning with the Neolithic and Chalcolithic. One of the most important hydrological factors is the groundwater level of the hillsides. He creates models on how the possible settlements on the lakeshore, river banks, or more often higher terraces and hill slopes were determined by the groundwater level, also in terms of storage pits that had to be safe from the groundwater, and e. g. wells dug in different depths. The results are compared with stratigraphic data gained from excavations and from offsite corings around the settlements.

The last, rather lengthy chapter in this volume offers an overview of the macrobotanical investigations on several sites of the Sárköz region. Angela Kreuz initially began to work with on- and off-site samples with Péter Pomázi, a young Hungarian archaeologist and botanist, who regrettably stopped working on the interpretation of the samples and thus A. Kreuz was kind enough to complete the work herself. However, once she devoted herself to this immense work, she also included all the other Hungarian Neolithic sites she had been working on. The result is a major comparative study, providing a comprehensive overview of the major fields of archaeobotanical work in the Sárköz and other regions.

Thus, the present volume can hardly be regarded as an ultimate concluding work, but much rather as an introduction in at least two senses. Firstly, because the results – as set down in the other chapters of the book – reflect a certain stage of research, which, as we all know, changes rapidly with the introduction of new methods and theoretical approaches in prehistoric research. The other reason for the introductory nature of the present volume is that a series of further studies are currently in progress, covering osteology, aDNA, and stable isotope analyses, Early Neolithic clay houses, Late Neolithic settlement structure and architecture, settlement pottery, and household analyses, interpretation of the thousands of the Neolithic burials, just to name some of the tasks still ahead of us in the Sárköz, this very special southern Transdanubian region. Most of the individual chapters of this introductory volume were initially not scheduled for publication here, but it seemed prudent to bring them together, as – according to my hope – the sum will be more than its details. The present volume intends to "set the scene", in the hope that soon the new facets of the Sárköz Neolithic will follow this introductory publication.

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Windows onto the landscape: Prospections on the prehistoric sites at Alsónyék, Fajsz-Kovácshalom, Fajsz-Garadomb, and Tolna-Mözs in the Sárköz region

Keywords: Neolithic, Sárköz region, non-invasive investigations, geomagnetic prospections, spatial analysis, soil chemistry

Schlagwörter: Neolithikum, Sárköz-Region, nicht-invasive Untersuchungen, geomagnetische Prospektion, Raumanalyse, Bodenchemie

Kulcsszavak: Újkőkor, Sárköz, roncsolásmentes vizsgálatok, geomágneses prospekció, térinformatikai vizsgálatok, talajkémia

Introduction

Long-term archaeological research in the Sárköz region and large-scale rescue excavations during the past three decades have yielded rich and valuable archaeological data. This paper will focus on the complex non-invasive (and minimal-invasive) research as well as the magnetic prospections on archaeological sites near Alsónyék, Tolna-Mözs, and Fajsz in the Sárköz region that were undertaken between 2011 and 2015 *(Fig. 1)*[1].

The archaeological setting

Prehistoric research in the heartland of the Carpathian Basin has turned with a growing interest to regions that had not been studied intensively before. Among these areas, the Danube riverine landscape with its adjacent hills in southern Hungary, which proved to be a key region in the cultural exchange and communication network between the northern Balkans and Central Europe, is of a special interest. The region known as the Sárköz is located along the Danube and is made up of two parts: the Tolna Sárköz on the right bank and the Kalocsa Sárköz on the left bank. The region's most prominent feature is the Danube, although it must be noted that river regulations in the late 19th century completely changed the original geomorphological features of the area. Before this, the Danube did not have one main riverbed, but rather consisted of many larger and smaller branches, flowing across a waterlogged marshland dotted with low sandbanks.

The Sárköz region has been researched within the framework of two very different projects. In the eastern part, the Kalocsa Sárköz, systematic and planned research was carried out in the early 2000s, which also involved cross-checking and integrating earlier field walking, and scattered reports on Neolithic sites there (Vadász 1967; Horváth 1972; 1987; Bognár-Kutzián 1977; Kalicz 1994; Wicker et al. 2001; Bánffy 2003). Between 2000 and 2001, a grant from the German Research Fund (DFG) supported our joint work with colleagues from Tübingen[2] to undertake surveys on the Fajsz-Garadomb and Fajsz-Kovácshalom sites, which was followed by a Hungarian Research Fund (OTKA)

1 The prospections between 2011 and 2015 were conducted by Kay Winkelmann, Gábor Serlegi, Maria Ivanova, Carsten Mischka, Martin Furholt, René Ohlrau, Kai Radloff, Frank Stevens, and Wouter Verschoof (Serlegi et al. 2013; Rassmann et al. 2015a; 2015b).

2 Die Besiedlungsgeschichte der Siedlungskammer um Fajsz (Komitat Bács-Kiskun, Südungarn) in der Ältesten Bandkeramik, led by Jörg Petrasch and Eszter Bánffy.

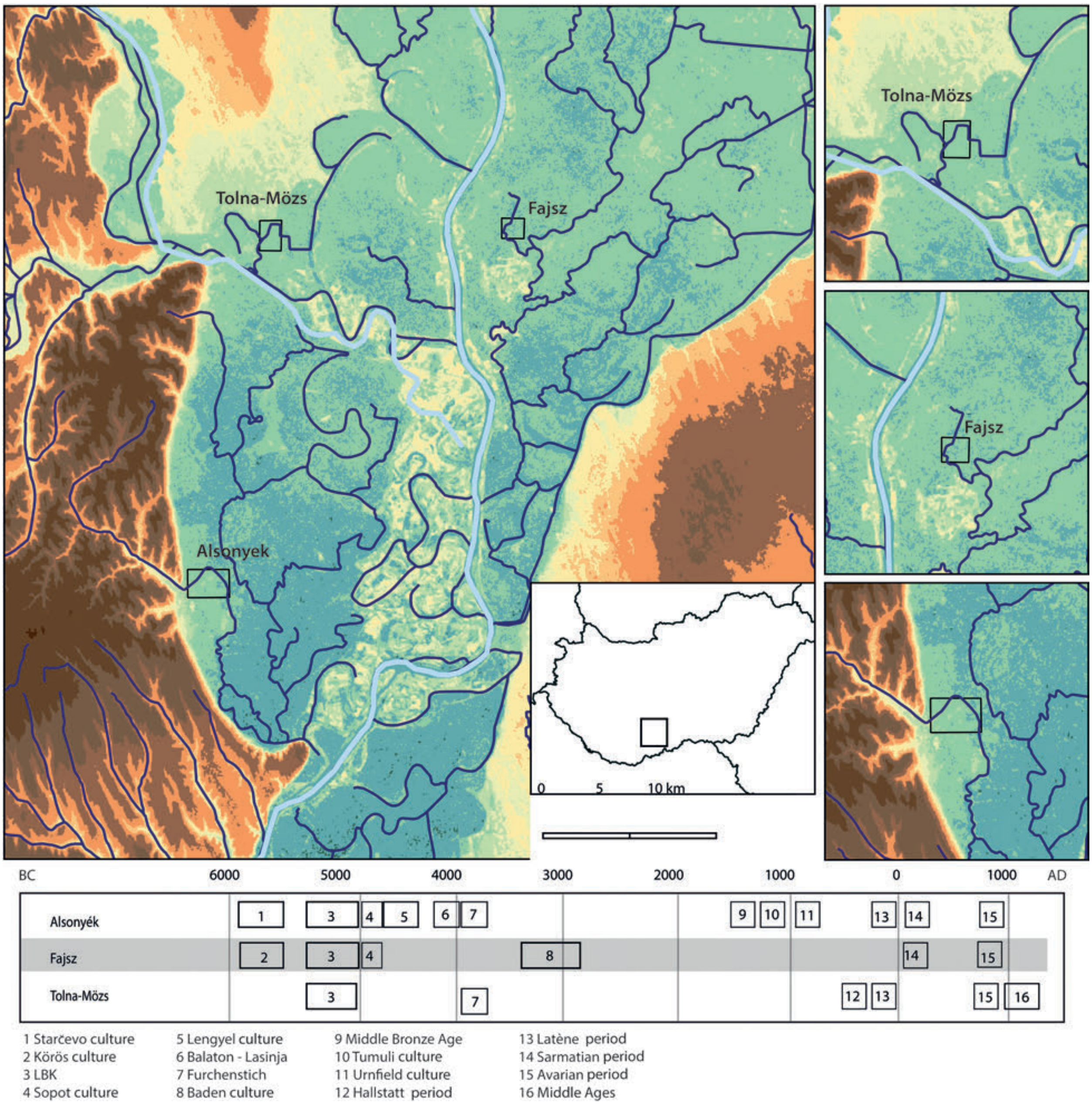


Fig. 1. Overview of the research areas around the multi-period sites of Tolna-Mözs, Fajsz, and Alsónyék with the present periods and archaeological cultures.

project between 2006 and 2010[3], with excavations at the Fajsz-Garadomb (flat settlement) site and surveys on the Fajsz-Kovácshalom (tell) site. After the project, the evaluation proposal remained unsuccessful, but in 2013, a monograph was published about the Early Neolithic of the Danube-Tisza interfluve (Bánffy 2013), which includes a report by Rozália Kustár on the 50 Early Neolithic (Körös culture) sites as well as the evaluation of the Körös settlement at Szakmár-Kisülés.

Parallel to our excavation and assessment of the findings in the eastern, Kalocsa Sárköz area, archaeological work started ahead of the construction of the M6 motorway. The Institute of Archaeology of the Hungarian Academy of Sciences (HAS)[4] was involved in the work and conducted several excavations on the planned mo-

3 Fajsz: The beginnings and early stages of food production in Southern Transdanubia, between Lake Balaton and the Danube valley. K61935, led by Eszter Bánffy.

4 The Institute of Archaeology of the Hungarian Academy of Sciences existed in this form between 1958 and 2012. Between 2012 and 2019 it was part of the Research Centre for the Humanities (RCH) within the Hungarian Academy of Sciences. After 1st Sepember 2019, all Institutes were taken from the Hungarian Academy of Sciences. Today its official name is Institute of Archaeology, Research Centre for the Humanities (RCH). Since the staff and the work has not changed, hereinafter, we shall use the simple name of "Institute of Archaeology".

torway track. Our team worked at several Neolithic sites that lie in the western Tolna Sárköz area, one of which was an exceptionally large site at Alsónyék (Zalai-Gaál / Osztás 2009a; 2009b; Osztás et al. 2012). This settlement and burial place might not only be the largest Neolithic site in Central Europe but also an exceptionally important element of European heritage. The excavation of the site between 2006 and 2009 was followed by extensive analyses, still ongoing, much of it involving international cooperation. This work has been supported by grants from the OTKA fund for post-excavation investigations of various kinds, from the DFG[5] for aDNA analyses, and collaboration with the European Research Council-funded project "The Times of Their Lives" (ToTL)[6]. The Tolna-Mözs-Községi-Csádésföldek settlement became part of a new investigation supported by a new OTKA (NKFI) grant[7] that explores the settlement patterns and contact networks in southern Transdanubia.

Due to the rather fortunate constellation of circumstances, the Sárköz became one of the most intensively researched micro-regions in southern Central Europe, which also provided a good opportunity for inviting the work team for non-invasive landscape surveys from the Römisch-Germanische Kommission (RGK) to the region in order to clarify the human impact on the not yet excavated parts of the settlements. Since 2011, and especially after 2013, with the ties becoming closer, the intensive non-invasive work turned out to be much more than simply a geomagnetic prospection. The present study is an outline of the entire non-invasive research in the Sárköz region.

The significance of the non-invasive research plans

The research agenda at these sites focused on different aspects as the involved sites are different and they had a different agenda in terms of their excavation and post-excavation process. Alsónyék and Tolna-Mözs were chosen because the large-scale rescue excavations at these sites brought to light extraordinarily rich archaeological data from different periods. This already resulted in major publications under the umbrella of the above-mentioned international research projects (Bánffy 2016, 5 f.; Bánffy et al. 2010; 2014; 2016; 2017; Osztás et al. 2016a; 2016b). Fajsz is very important for the Late Neolithic (Sopot culture period) in the Sárköz region owing to the joint presence of both a tell mound and a flat settlement in one micro-region. The site has been under investigation by a joint Hungarian-German project team with a research excavation between 2006 and 2008.

Research design, methods, and equipment

Desk-based assessment: Maps, other GIS data, and archaeological data

Our research frame was the collaboration between the RGK and the Institute of Archaeology of the Hungarian Academy of Sciences (HAS). Since 2014, the cooperation is further supported by the newly founded German Archaeological Institute (DAI)-RGK Research Unit Budapest. The joint investigations starting in 2011 were on the one hand embedded in the RGK's programme of settlement patterns research in Central and Eastern Europe (Rassmann et al. 2014), and on the other hand in the long-term research of the Hungarian Academy of Sciences and its Hungarian partners under the direction of Eszter Bánffy since the early 2000s.

The ambitiously extended prospections were possible through the utilisation of the vehicle-towed 16-channel magnetometer system. This system made it possible to undertake magnetic prospections on the scale of square kilometres rather than square metres, thus enabling the complete investigation of archaeological sites, their closer periphery, and the surrounding landscape.

In order to benefit from the potentials of the magnetic data, they have to be analysed in the context of other data including soil chemistry, aerial photos, topography, etc. The comparison of numerous magnetic anomalies with specific excavated structures is crucial to the interpretation of magnetometric data. In the Fajsz project area, several magnetic anomalies were compared with the thickness and extent of the occupation layers of the Garadomb and Kovácshalom sites by means of borehole sampling.

The interdisciplinary approach is fundamental to classifying magnetic anomalies, to identifying relevant archaeological features, and to enhancing the understanding of magnetic signatures and their archaeological context. Thus, we are able to trace archaeological features from the excavation area into neighbouring prospection areas. An attempt to develop a holistic ar-

5 Bevölkerungsgeschichte des Karpatenbeckens in der Jungsteinzeit und ihr Einfluss auf die Besiedlung Mitteleuropas, led by Kurt W. Alt.

6 The Times of Their Lives: towards precise narratives of change in the European Neolithic through formal chronological modelling (ERC Advanced Investigator Grant 295412, led by Alasdair Whittle and Alex Bayliss).

7 Újkőkori közösségek a Balkán és Közép-Európa érintkezési övezetében a Kr. e. 6. évezred második felében (Neolithic communities in the contact zone between the Balkans and Central Europe in the second half of the 6th millennium BC; grant code: K 112366), led by Krisztián Oross.

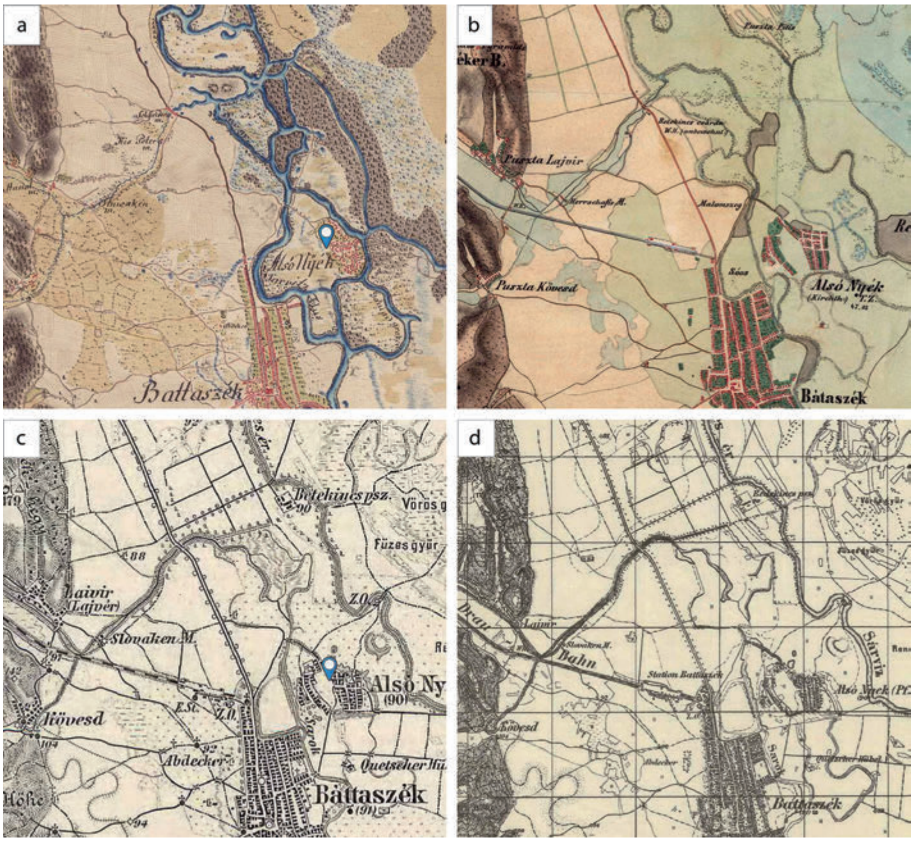


Fig. 2. Alsónyék-Bátaszék. a Josephinian cadastre, 1782–1785; b Franciscan cadastre, 1806–1869; c Franciscan-Josephinian survey, 1869–1887; d Hungarian survey, 1941.

chaeological approach is important to facilitate more precise estimations on settlements sizes, their internal spatial organisation, and their changes over time.

The profound changes in the landscape of the Sárköz and other regions in the Pannonian Basin over the last centuries are clearly visible on historical maps from the 18th and 19th centuries. The first systematic land surveying and topographic mapping in the Kingdom of Hungary was accomplished between 1782–1785 under the reign of Emperor Joseph II and later continued with the Franciscan cadastre from 1806–1869. The Franciscan-Josephinian survey (1869–1887) resulted in maps at the scale of 1 : 25 000 for historical Hungary, Transylvania, and Croatia (Biszak et al. 2017, 204; http://mapire.eu). Older surveys provide particularly valuable insights and data on hydrology and landscape use before the river regulation in the 19th and 20th centuries. They are crucial for both understanding the potentials of the landscape, e. g. modelling carrying capacity, and for estimating the impact of intensive agriculture, increasing urban, commercial, and industrial development, including the development of traffic infrastructure, on archaeological monuments *(Fig. 2)*. Recent landscape data are precisely recorded on topographic maps (scale 1:10 000). For calculating digital elevation models, the data of the Shuttle Radar Topography Mission (SRTM) in a resolution of 1 Arc-Second Global (corresponding to c. 21 m at 46° northern latitude in the Tolna region) were used. Additionally, we used open geodata such as

	scale	**resolution**
Josephinian cadastre, 1782 – 1785	1:28 800	
Franziscan cadastre, 1806 – 1869	1:28 800	
Franciscan-Josephinian survey, 1869 – 1887	1:25 000	
Hungarian survey, 1941	1:25 000	
Topographical survey 1950s (?)	1:10 000	
Shuttle Radar Topography Mission (SRTM)		1 Arc-Second
Google Earth		c. 0.6 m
Microsoft bing (Digital Globe)		c. 1 – 2 m

Tab. 1. Overview of the topographical and remote sensing data used.

Fig. 3. The vehicle-towed 16-channel magnetometer system (SENSYS MAGNETO®-MX ARCH) at Tolna-Mözs.

Fig. 4. The 5-channel magnetometer (SENSYS MAGNETO®-MX ARCH) in use (with Gábor Serlegi) at Alsónyék. Sensors spaced at 50 cm intervals.

satellite imagery provided by Google Earth and Microsoft Bing *(Tab. 1)*.

Magnetic prospection

The archaeological data of sites in the surrounding of the prospected sites were collected from various archaeological publications and records in the archives of the regional museums in Szekszárd and Kalocsa. The magnetic prospection started in 2011 at Tolna-Mözs and Alsónyék-Bátaszék and was continued with prospection campaigns in 2013, 2014, and 2015 on both sites as well as on the sites of Kovácshalom and Garadomb near Fajsz.

The magnetic prospection was conducted using two 16-channel fluxgate vertical gradiometer magnetometer systems from Sensys GmbH, Bad Saarow (Germany). In large areas, a 16-channel magnetometer system was employed in 2012–2014, whereas in 2015, a 5-channel magnetometer was used for smaller, more targeted prospecting.

MAGNETO® MX ARCH 16-channel system

The 16-channel magnetometer system was mounted on a vehicle-towed, non-magnetic array *(Fig. 3)*. The gradiometers were set at 0.25 m intervals on a 4 m wide sensor array, itself set at right-angles with a 6 m long tow bar. With speeds of approximately 12–16 km / h and a sample rate of 20 readings per second (Hertz), the system provided 15 magnetometer readings per square metre on average. The 16 magnetometers used were FGM-650B tension band fluxgate vertical gradiometers with 650 mm sensor separation, a ± 3000 nT measurement range and 0.1 nT sensitivity. For a precise georeferencing of the magnetometer data, Trimble RTK-DGPS systems consisting of a base station and a rover with the DGPS antenna mounted centrally on the magnetometer array were used. The accuracy of the georeferencing achieved is usually ± 0.05 m.

MAGNETO® MX ARCH 5-channel system

The 5-channel magnetometer was mounted on a push-cart fibreglass array *(Fig. 4)*. The gradiometers were set at of 0.25 or 0.50 m intervals. At a walking pace of c. 4–5 km / h and a sampling rate of 20 samples per second (Hertz), the system provided c. 60–80 magnetometer data points per square metre. The magnetometers used were the same FGM-650B as those on the MAGNETO® MX ARCH 16-channel system. Precise georeferencing with an accuracy of c. ± 0.05 m was similarly achieved through the utilisation of a Leica RTK-DGPS (base / rover) system.

The respective survey base station was precisely positioned using a Leica VIVA GS14. The coordinate reference system used was HD72/EOV (EPSG 23 700).

Data acquisition, processing, and analysis

The data acquisition, processing, and analysis have already been published (Rassmann et al. 2015a), and therefore the description here is limited to a short overview.

The SENSYS data acquisition software MonMX® for data acquisition of the 16-channel magnetometer system runs on a ruggedised notebook with Microsoft Windows® operating system. The smaller MAGNETO® MX ARCH 5-channel system data recording is accomplished with a PDA with Windows® Mobile operating system and MXPDA data acquisition software.

The magnetic data were saved on a line by line basis in separate files by SENSYS MonMX® respectively

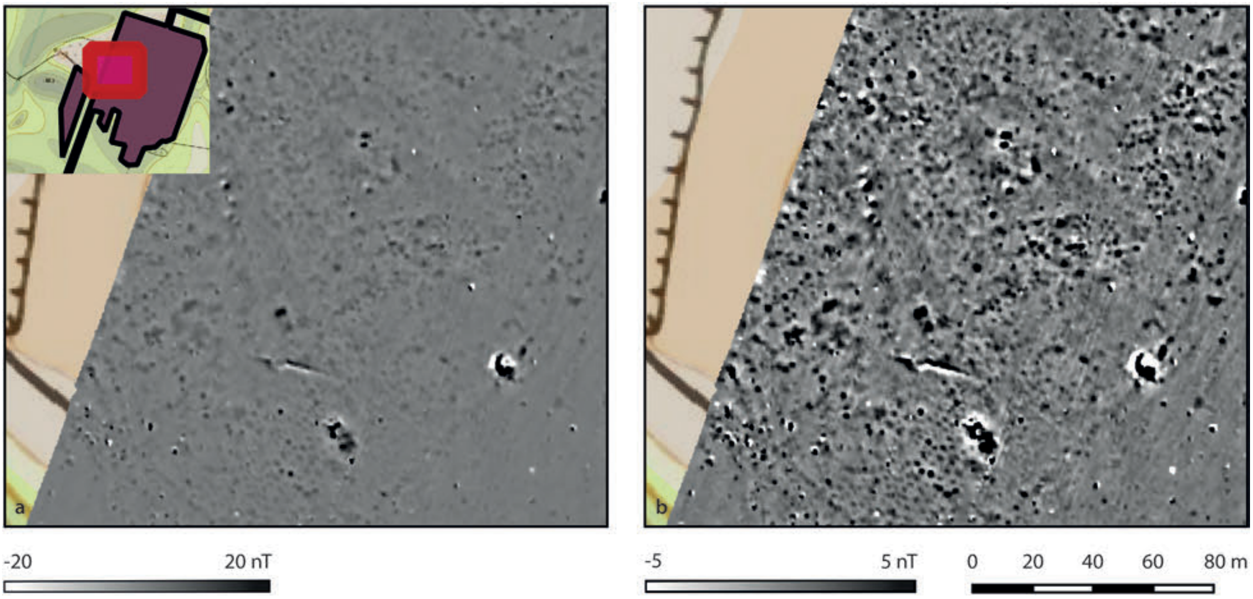


Fig. 5. Fajsz-Garadomb. Magnetic map of the eastern settlement area. a Range of scale: +/- 20 nT. b Range of scale: +/- 5 nT.

MXPDA software. A prospection with the MAGNETO® MX ARCH 16-channel system of an area of 1 ha (100 x 100 m) requires 19 tracks (instrument width 4.00 m; width of the measured track 4.25 m). For the MAGNETO® MX ARCH 5-channel system with gradiometers spaced at intervals of 0.5 m (instrument width 2.0 m; width of the surveyed track 2.5 m), we calculate 40 lines per hectare.

For pre-processing after the conclusion of the survey work in the field, the individual track (line) files were imported into the DLMGPS software and exported into one large ASCII text file for each subsection (survey area). The format of the exported, simple text file is as follows:

X-coordinate	Y-coordinate	nT	track-file	magnetometer-number
34340748.010	5140263.576	-59.5	fa123.prm	1
34340748.092	5140263.340	-3.7	fa123.prm	2
34340748.174	5140263.104	1.8	fa123.prm	3
34340748.257	5140262.868	-4.6	fa123.prm	4
34340748.339	5140262.632	-13.1	fa123.prm	5

The ASCII files were then edited with a text editor. It has to be a high performance editor because 1 ha (100 x 100 m) comprises up to 800 000 data points (lines in the file). The largest files from Alsónyék covering c. 15 ha comprise c. 2.5 million measurements, respectively lines in the ASC file.

In the next step, the TXT file was imported and processed in the Geosoft Oasis montaj® software (version 8) and the final results were later exported as a Surfer 7 grid file that is compatible with various GIS software. The maps presented here were produced with QGIS 2.14–18.

The analytical workflow in Open GIS

The Surfer 7 files imported in QGIS were processed for archaeological interpretation in a multistage workflow, illustrated here by an example from the flat settlement at Fajsz-Garadomb *(Figs 5–6)*. The resulting archaeological interpretation will be discussed in detail below. The design of the raster map can easily be optimised through the style function in QGIS by the selection of the threshold for the colour- or grey-scale and the appropriate minimum and maximum amplitudes for the display of the magnetic field anomalies *(Fig. 5)*. The visualisation of relevant archaeological features by the raster map is the first analytical step, which then has to be followed by the quantification of anomalies and cross-correlation with other relevant data.

Based on the raster map *(Fig. 6.1)*, contour lines emphasising the different field strengths of the magnetic field anomalies in the vertical gradients (unit nT) were extracted at intervals of 0.5–20 nT (0.5 nT levels) using the GRASS-tool *r.countour.step (Fig. 6.2)*. In the next step, the contour lines were compared with clearly visible archaeological features such as settlement ditches, pits, house remains, etc. The relevant level selected for Fajsz-Garadomb is the 2 nT contour line. All 2 nT

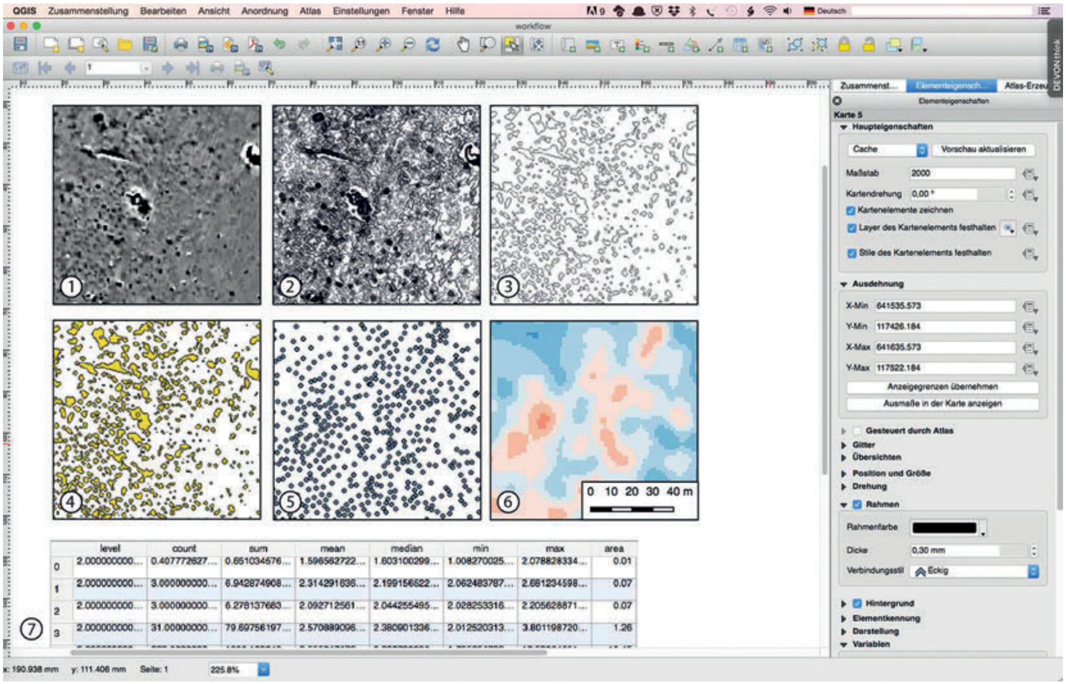


Fig. 6. Workflow for processing the archaeological magnetic prospection data. 1 Magnetic map; 2 calculation of the contour map in steps of 0.5 nT; 3 selection of 1 nT line; 4 conversion of the 1 nT line into polygons; 5 collecting the key values of the magnetic map and calculating the size / area of the anomalies; 6 selecting anomalies and calculating the centroids of the polygons; 7 calculating the kernel density estimation (KDE) of the selected anomalies / centroids.

contour lines were filtered and saved in separate vector shapefiles (*.shp) *(Fig. 6.3)*. By using the GDAL vector geometry tool *lines to polygons*, the contour lines were transformed into polygons *(Fig. 6.4)*. The latter can then be used to calculate the area size of each individual object (spatial anomaly in the magnetometer data). Next, all polygons larger than 0.4 m^2 were selected. The core of the workflow is the QGIS-plugin raster / *zonal statistics*[8].

Using this tool, the vector map was processed in combination with the raster grid of the magnetic prospection data. The tool *zonal statistics* calculates the values of the specific raster cells covered by each polygon.

The following statistics are available for further interpretation:

Count: to count the number of pixels,
Sum: to sum the pixel values,
Mean: to get the mean of pixel values,
Median: to get the median of pixel values,
StDev: to get the standard deviation of pixel values,
Min: to get the minimum of pixel values,
Max: to get the maximum of pixel values,
Range: to get the range (max – min) of pixel values,
Minority: to get the less represented pixel value,
Majority: to get the most represented pixel value,
Variety: to count the number of distinct pixel values.

Our empirical experience indicates that the Mean, Max, and Variety values are the most suitable for archaeological interpretation. The final result contains an attribute table for the polygons as part of the vector shapefile. Each row of the spread sheet corresponds to a polygon, with a different parameter set of the mean, median, minima, and maxima of the covered raster cells. The results are saved in separate columns of the attribute table *(Fig. 6.7)*. The combination of the size of the polygons and the different parameters of the magnetic anomalies serve as basis for their further archaeological interpretation.

To reveal the general tendency in the distribution of archaeological features on a site, significant areas of higher density with archaeological features can be calculated by kernel density estimation (KDE). It is a non-parametric possibility to estimate the probability density function of a random variable and is often used in archaeology to calculate the spatial distribution of various phenomena (Wheatley / Gillings 2002, 186 f.; Herzog 2012, 201). The centroids of the selected polygons which might be archaeological features *(Fig. 6.5)* are the basis for this analysis. The KDE raster was calculated for a radius of 20 m. The selection of the radius depends on the size of the analysed spatial structure and can be derived from the average distance between the centroids.

8 https://docs.qgis.org/2.18/en/docs/user_manual/plugins/plugins_zonal_statistics.html.

In our experience, the KDE raster map reliably quantifies the differences in the distribution of archaeological features. The contour map highlights areas with a higher density of archaeological features, which reveals more substantial settlement areas as *Fig. 6.6* shows.

Pedological studies: Borehole sampling and soil chemistry

The prospections at Fajsz were accompanied by a drilling campaign with a pile core sampling rig (Makita HM1400) and Pürckhauer Auger. The cores acquired with the Pürckhauer were documented in the field, whereas the cores of the pile core sampling were archived in PVC transparent liners with a core diameter of 50 mm and a length of 1 m each. The liners were opened in the RGK laboratory in Frankfurt am Main (Germany), where they were meticulously documented and sampled. The sampling distance for the chemical analysis varies and corresponds to the thickness of the layers identified during the documentation by visual means.

Multi-element chemical analysis was supplemented with magnetic susceptibility measurements of the cores using Bartington susceptibility metres. The equipment used was a Bartington MS3 in combination with the MS2C loop sensor and the MS2K surface sensor. Magnetic susceptibility was measured with both sensors at intervals of 5 cm. The general tendency of the measurements obtained with both sensors is similar. Differences observed are obviously due to the differences of the sensors and their penetration of the sample. The MS2C loop sensor utilises a stronger magnetic field, investigating the core to a depth of estimated 20 mm, whereas the MS2K surface sensor has a small penetration depth of c. 0–3 mm. Therefore, the different volumes were investigated with each sensor and the inhomogeneity in the sample cores.

In the near future, we plan to utilise the MS2H downhole sensor for measuring magnetic susceptibility *in situ* in boreholes created with a gouge auger or Pürckhauer and the pile core sampling equipment during field campaigns. This will substantially increase the volume investigated, and thus further eliminate the effects of small inhomogeneity in the samples. Each core was documented by a sketch at a scale of 1 : 10 and a normalised description of the opened core. The main tool for multi-element chemical analysis was X-ray fluorescence spectroscopy (XRF) using a portable instrument (pXRF). For analysis, the pXRF sample material was dried, ground, and homogenised down to a particle size of below 20 mm. The material was analysed as a condensed powder filled in sample cups covered with 6 µm polypropylene foil. The samples were analysed using the

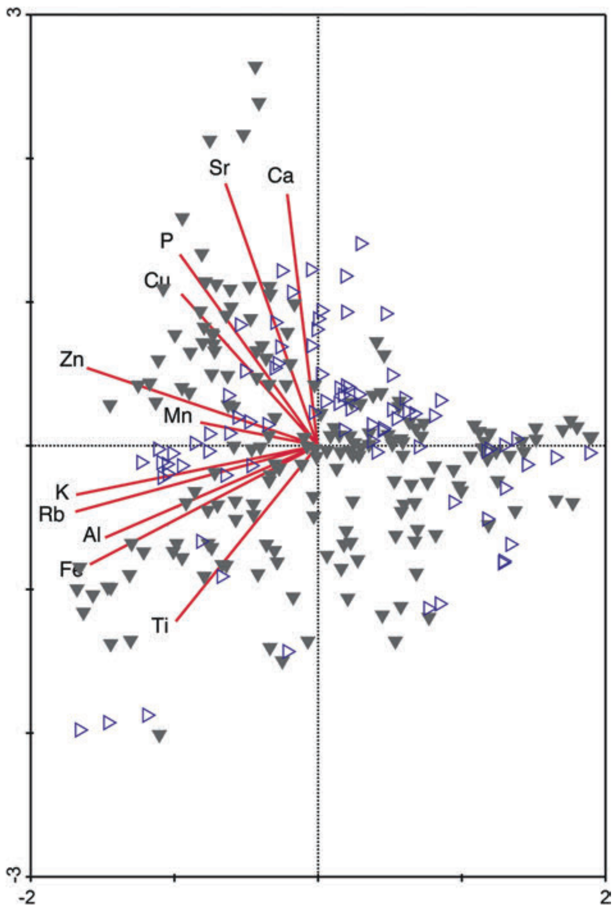


Fig. 7. Fajsz. Principal component analysis (PCA) of the chemical analysis of soil samples from the drilling cores from Garadomb (blue triangles) and Kovácshalom (grey triangles) (software Canoco 4.5).

portable XRF instrument XL3 t 900-series GOLD produced by Thermo Scientific Niton Analysers. The instrument is equipped with an X-ray tube containing a silver anode and is able to run at tube voltages of 6e50 kV and beam currents of up to 200 mA (maximum output power: 2 W). The instrument incorporates a 6-position filter wheel. Unfortunately, their composition and thickness are not provided by Thermo Scientific Niton Analysers. A helium purge enhances the quantitative measurements of light elements, most importantly of phosphorous.

During all analyses, the pXRF instrument was fixed in a mobile test stand in order to provide reproducible measurement conditions. The measurement routine developed in this project runs four excitation conditions with an overall measurement time of 150 s: (1) main filter, 30 s; (2) low filter, 30 s; (3) high filter, 30 s; and (4) light filter, 60 s. But in fact, the measuring time could be changed because the quantification is based on cps / mA. The spectra were quantified using a fundamental parameter algorithm that comes with a specific measuring mode implemented in the device ('mining Cu / Zn mode'). The total amount of the light elements that cannot be determined by XRF using the instrument is returned as 'balance'. It is estimated by calibrating the sum of the truly measured elements in real samples against the respective Compton peaks. The measured data as well as the balance value are normalised to 100 %. In a second step performed by the user in order to optimise the results, the data for each element, except for the balance values, were empirically adjusted against the factory calibration by measurement of certified reference materials. These correction factors are specific to the XRF device used. During each measurement series, at every ten samples, the soil standard TILL 4 was measured as a reference.

The results of the analyses are presented in *Tables 2–3*. To reveal the general tendency in the data, a principal component analysis (PCA) was calculated for the XRF data *(Fig. 7)*. Three groups of elements are evident in the data. The first comprises phosphorus (P), strontium (Sr), calcium (Ca), and copper (Cu). These elements are an indication of the human impact. The interpretation of P, Sr, and Ca is often used for the analysis of data from settlements (Gauss et al. 2013; Nowaczinski et al. 2013), whereas the interpretation of Cu is more difficult. At Fajsz, all soil samples have Cu concentrations of 50–100 ppm. The interpretation of an environmental effect is reasonable. The second group of elements comprises potassium (K), rubidium (Rb), titanium (Ti), iron (Fe), and aluminium (Al). These elements are typical components of the environmental background signature. A third group of elements including zinc (Zn) and manganese (Mn) likely indicates a separate autochthone signal.

To improve our topographic data, a survey with a drone (DJI Phantom III) was conducted at Fajsz[9]. The surveyed area extended over 3.5 km^2 around the flat settlement of Garadomb and the Kovácshalom tell. A total of 384 photos were taken with an average overlap of 40 %. The resolution of the resulting orthophotos created from this data set is 10 x 10 cm and a digital elevation model (DEM) was derived. The accuracy of the digital elevation model was evaluated by a mesh of c. 4 x 2 m resulting from the 1 PPS RTK-DGPS data points acquired with the MAGNETO® MX ARCH 16-channel system inside the magnetic prospection area. Both data sets appeared to be consistent with each other.

Magnetic prospections, UAV-photos, magnetic susceptibility measurements, coring, and multi-element chemical analysis provide a multi-dimensional space of data which is fundamental to planning an excavation and clarifying research questions. Thus, the prospection following the desk-based assessment is the second stage in a field project, while the excavation is the third and final stage. At Fajsz, Alsónyék, and Tolna-Mözs the prospection took place after the completion of previous excavations (rescue excavations during large-scale infrastructure projects). In this reversed context, prospections are of value for setting the excavation results into a broader context, while the excavation data contribute to a better understanding of the magnetic prospection.

Results

Fajsz-Kovácshalom and Fajsz-Garadomb

Location, topography, and archaeological research

The Neolithic settlement mound of Fajsz-Kovácshalom is located on the Danubian floodplain. Due to modern agriculture, its archaeological structures are endangered. Therefore, the settlement mound is under protection since 2007, yet, in the past few years, the mound has been ploughed again for growing seasoning paprika. The tell mound is still visible, albeit probably in a strongly eroded state, rising no higher than 2.8 m above the floodplain. In the vicinity of the tell settlement, at a distance of 800 m (as the crow flies) lies the flat settlement Fajsz-Garadomb with its overwhelmingly Late Neolithic occupation that can be considered to be co-eval with Kovácshalom. The surface of the tell site is rather densely covered with lithics, many of them produced from Transdanubian red radiolarite and even some obsidian artefacts from the Tokaj-Zemplén Mountains in north-eastern Hungary. The hundreds of potsherds can be predominantly assigned to the Sopot 2-Vinča B2–C period, alongside many pottery fragments from the Late Roman / Sarmatian period. Some Late Medieval vessel fragments and a coin from this period confirm that land use remained continuous until modern times, and the few metres high elevation – especially in flat alluvial lowland – seemed to be suitable for a (probably) Late Medieval cemetery, from which scattered bones could be seen in the ploughed area, also an indication of the strongly eroded surface.

The tell site was measured and cored in the early 2000s, indicating the presence of multiple burnt layers at several points and, also, a probable oxbow of the Danube flowing around the western half of the mound. The coring was carried out by Pál Sümegi and his team from the University of Szeged and was used later for his comprehensive overview of the Sárköz region (cf. Sümegi et al. in the present volume).

The multi-period site Fajsz-Garadomb has been under investigation by the Institute of Archaeology of the

9 Survey and postprocessing were executed by Johannes Kalmbach, RGK.

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
K02	0	1897	194	15554	91570	2269	73	157	69
K02	0.1	1800	187	15560	88371	2563	82	259	60
K02	0.2	1826	177	15717	85432	2258	79	480	69
K02	0.3	1677	182	14787	91838	1840	69	237	58
K02	0.4	1311	146	13134	69890	2377	60	264	35
K02	0.5	1116	139	10147	70856	1895	46	0	15
K02	0.6	503	160	10373	79003	2002	43	348	15
K02	0.7	581	164	9263	78947	1647	42	123	17
K02	0.8	516	181	11989	103655	2133	49	114	24
K02	0.9	520	195	12484	120199	2521	50	0	34
K02	1	516	194	10865	108748	2134	51	101	18
K02	1.1	1092	171	14586	78689	2180	69	343	49
K02	1.2	314	237	14200	170492	1890	62	0	50
K02	1.3	399	130	12250	59024	1351	49	0	0
K02	1.4	231	110	9774	40148	1030	41	0	0
K02	1.5	345	188	15120	98002	1810	68	380	47
K02	1.6	305	213	14931	137924	2214	64	480	41
K02	1.7	289	210	15016	125569	2362	65	603	44
K02	1.8	230	199	14254	118345	2545	64	390	37
K02	1.9	498	204	14369	118385	4520	61	504	43
K02	2	244	222	16791	124928	2568	72	538	47
K02	2.1	435	158	11012	82968	3009	46	588	38
K02	2.2	312	132	11772	61920	1700	50	448	0
K02	2.3	326	148	13186	72246	1752	48	453	0
K02	2.4	248	152	12708	73681	1756	44	0	26
K02	2.5	308	142	10475	68057	1963	43	0	0
K02	2.6	344	110	10171	35447	1031	39	0	0
K02	2.7	222	112	10977	39775	1633	38	421	0
K02	2.8	164	107	10851	43753	985	37	0	0
K02	2.9	175	151	11100	67429	1842	42	449	0
K02	3	396	154	12644	68200	1883	50	411	32
K04	0	2093	294	18381	129150	2541	87	551	110
K04	0.1	2689	308	18267	135791	2559	82	536	105
K04	0.2	2219	294	18623	132932	2911	89	456	96
K04	0.3	2331	290	18437	132185	2404	84	500	97
K04	0.4	2884	302	18295	124435	2045	89	592	113
K04	0.5	3015	303	18246	123668	2538	92	528	123
K04	0.6	2752	307	18364	118624	2304	82	433	114
K04	0.7	1309	225	18756	105774	2298	93	412	73
K04	0.8	2324	250	19074	106499	2342	96	348	101
K04	0.9	3992	376	17664	152484	1441	84	383	136
K04	1	4716	264	19252	111678	2292	94	452	108
K04	1.1	2290	294	18404	131255	2387	90	484	96
K04	1.2	2044	268	18306	122428	2515	88	492	95
K04	1.3	2125	310	17828	157198	2096	83	533	70
K04	1.4	1828	118	20025	36846	2246	83	497	77
K04	1.5	1419	131	17956	50508	2738	76	458	48
K04	1.6	1714	177	17639	92658	2405	70	480	61
K04	1.7	3857	157	14194	72433	1811	51	365	51
K04	1.8	677	149	12275	69293	1602	47	0	0
K04	1.9	702	179	15969	84767	2315	61	435	25
K04	2	962	194	16155	113207	2330	59	503	37
K52	0	2206	269	18792	123569	2601	89	534	83
K52	0.1	2126	264	19110	122558	2460	91	579	103
K52	0.2	2204	274	18805	124259	2333	91	575	96
K52	0.3	2341	273	18490	122091	2591	92	553	88

Tab. 2. pXRF analyses of percussion drillings in Fajsz-Garadomb (G) and Fajsz-Kovácshalom (K) with 10 cm sampling. For the position of the drilling see *Fig. 15*. Concentrations are given in ppm.

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
K52	0.4	2493	275	18178	123553	2766	97	509	100
K52	0.5	2708	288	18551	123459	2807	90	584	104
K52	0.6	2783	283	17714	126981	2273	90	554	95
K52	0.7	2749	277	18679	116523	2484	100	583	118
K52	0.8	3016	288	18461	121178	2118	85	476	100
K52	0.9	3160	211	18796	82404	2695	83	428	90
K52	1	2115	165	18490	65394	2889	78	420	79
K52	1.1	1479	179	17211	77048	2633	95	491	79
K52	1.2	1436	183	17184	81530	2914	95	452	78
K52	1.3	2365	195	17399	76142	2791	98	791	88
K52	1.4	1351	181	17074	79586	2827	97	692	98
K52	1.5	1499	187	16335	74414	2568	96	365	90
K52	1.6	1217	179	16119	76726	2346	87	0	80
K52	1.7	1043	190	16222	91426	2767	78	329	73
K52	1.8	1059	193	16028	96267	2400	75	556	64
K52	1.9	738	180	16686	92944	2599	79	336	67
K52	2	560	182	16904	85638	3027	79	713	80
K52	2.1	2029	230	18813	100589	2609	92	566	97
K52	2.2	1813	234	18838	100357	2758	99	594	92
K52	2.3	2149	230	19030	104299	2293	94	586	79
K52	2.4	2023	227	18775	101644	2747	91	592	89
K52	2.5	1993	227	18852	97102	2812	99	651	97
K52	2.6	2057	207	18521	88214	2539	94	691	103
K52	2.7	1626	191	18166	80598	3182	101	529	90
K52	2.8	1517	186	17507	79161	2665	96	490	85
K52	2.9	2112	195	17504	87758	2744	95	574	77
K52	3	1740	173	17774	74158	2564	104	656	67
K66	0	1269	166	18900	61571	2821	93	634	70
K66	0.1	1287	165	18806	59725	2896	96	508	77
K66	0.2	1566	167	18689	63526	2612	97	542	74
K66	0.3	1247	174	19219	64448	2870	95	481	78
K66	0.4	884	129	17538	29726	3191	101	382	71
K66	0.5	701	124	16778	31215	3224	90	0	52
K66	0.6	1167	116	16774	33446	3045	86	0	58
K66	0.7	1541	112	17468	28596	3200	91	428	62
K66	0.8	1119	119	18411	34808	3596	94	348	78
K66	0.9	730	122	17114	53566	3124	92	568	70
K66	1	602	160	15257	113883	2911	77	397	58
K66	1.1	1090	165	18417	70588	2835	96	562	75
K66	1.2	480	200	15082	166737	2349	68	427	60
K66	1.3	407	212	15102	161054	2277	66	582	57
K66	1.4	411	211	14463	172507	1877	69	597	60
K66	1.5	419	216	15476	147442	1872	71	689	66
K66	1.6	428	197	15789	115075	2147	74	0	59
K66	1.7	484	165	14938	89904	1658	62	0	41
K66	1.8	330	161	13791	89507	2151	60	0	28
K66	1.9	388	194	12961	114712	2241	58	297	41
K66	2	596	155	12236	99454	1953	53	114	29
G11	0	1060	254	18735	112013	2141	102	508	76
G11	0.1	835	263	18275	111126	2445	91	503	71
G11	0.2	762	254	17095	107416	2457	93	524	71
G11	0.3	678	252	17504	108949	2204	91	519	74
G11	0.4	275	349	15517	138501	1696	79	480	53
G11	0.5	528	304	15194	143151	2230	68	640	49
G11	0.6	273	316	15016	149555	1768	69	842	50
G11	0.7	279	321	15671	147491	1933	70	836	54

Tab. 2. (continued).

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
G11	0.8	374	278	14812	152179	2085	62	560	52
G11	0.9	377	214	13526	109358	2521	54	381	42
G11	1	301	249	14195	146749	1916	62	479	49
G14	0	1224	197	19634	97653	2222	102	685	91
G14	0.1	1357	195	19669	97759	2634	105	648	88
G14	0.2	1292	200	19638	101511	2242	105	645	98
G14	0.3	1423	212	19390	106839	2724	101	665	92
G14	0.4	436	315	16603	168688	2258	90	345	70
G14	0.5	436	279	16868	159787	1723	86	586	61
G14	0.6	289	306	16558	164868	2222	81	563	60
G14	0.7	260	290	16521	157262	2404	80	600	68
G14	0.8	326	297	15906	162507	2826	65	538	61
G14	0.9	338	274	16043	151135	2525	72	554	57
G14	1	481	244	15509	135637	2121	61	561	50
K26S	0	1042	192	20827	80516	2910	108	795	90
K26S	0.1	816	193	20607	80297	3064	109	782	93
K26S	0.2	872	183	20511	79275	3271	105	821	92
K26S	0.3	613	186	21107	75543	3709	117	846	94
K26S	0.4	366	199	20573	93862	3391	106	998	79
K26S	0.5	302	196	20617	91512	2761	102	856	80
K26S	0.6	337	184	18158	83543	3315	95	649	62
K26S	0.7	607	171	17915	77926	2960	86	517	67
K26S	0.8	599	172	16869	81266	3115	86	588	62
K26S	0.9	870	178	17524	85867	2976	88	534	76
K26S	1	1772	198	15989	96044	2357	81	518	85
K26S	1.1	1282	194	15593	102183	2911	72	900	62
K26S	1.2	951	207	14784	113090	2329	69	519	59
K26S	1.3	739	213	14891	131950	2007	67	562	61
K26S	1.4	514	223	14438	137883	2256	60	531	37
K26S	1.5	145	235	13789	164390	1603	57	535	43
K26S	1.6	405	240	14390	162725	2093	58	1065	44
K26S	1.7	507	223	14950	135157	1574	63	384	43
K26S	1.8	381	217	14181	136063	2046	64	601	45
K26S	1.9	312	208	13791	117064	2111	61	306	40
K26S	2	485	205	15515	109861	2860	73	369	42
K57	0	1125	188	20064	80303	2737	110	665	92
K57	0.1	899	191	21257	80405	3003	108	718	93
K57	0.2	1133	193	20855	81060	3286	101	791	98
K57	0.3	1184	195	20891	81703	3783	105	828	97
K57	0.4	962	188	20844	78649	2380	112	801	96
K57	0.5	518	203	19677	91647	2953	100	834	74
K57	0.6	626	195	20163	85797	3267	100	592	86
K57	0.7	546	203	19351	89510	2892	93	776	84
K57	0.8	457	198	19284	88793	3175	94	654	78
K57	0.9	516	191	20661	85927	2926	100	627	89
K57	1	590	189	18167	88064	2386	86	493	67
K57	1.1	328	188	18423	87872	3076	84	438	62
K57	1.2	485	181	17684	86747	2790	83	415	57
K57	1.3	510	182	18828	81207	2806	89	341	72
K57	1.4	339	169	19414	72790	3083	113	656	79
K57	1.5	412	188	18290	100917	2774	94	411	69
K57	1.6	361	195	18423	108926	3134	86	868	61
K57	1.7	510	201	17301	114600	2773	75	544	47
K57	1.8	544	195	17246	109038	2754	81	416	68
K57	1.9	515	210	17524	127368	2964	78	788	68
K57	2	490	209	18187	115747	2831	83	600	69

Tab. 2. (continued).

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
G16	0	1342	197	20300	96537	2670	105	658	89
G16	0.1	1354	198	20319	96462	2558	100	636	99
G16	0.2	1707	196	20402	97263	2619	105	699	88
G16	0.3	1399	202	20399	98273	2581	100	722	89
G16	0.4	1460	211	19001	110630	2382	93	636	85
G16	0.5	1096	329	15800	172400	397	77	451	66
G16	0.6	711	300	15806	149217	2140	71	505	56
G16	0.7	426	220	14293	115591	2147	57	378	38
G16	0.8	456	259	15107	135063	2436	59	503	45
G16	0.9	478	246	14987	129147	2315	64	386	50
G16	1	420	269	14926	135959	2372	65	397	49
G09	0	913	213	18377	106255	2325	81	657	74
G09	0.1	949	219	18643	107625	1956	81	611	74
G09	0.2	1230	215	18912	104905	2360	78	553	74
G09	0.3	945	222	17244	114472	2259	70	531	69
G09	0.4	383	231	15049	119877	1764	58	461	49
G09	0.5	480	198	13699	95444	2013	48	455	37
G09	0.6	539	198	12052	103017	2520	41	412	35
G09	0.7	360	223	13802	119432	2382	54	376	33
G09	0.8	408	261	15050	138125	2312	53	393	37
G09	0.9	330	170	11714	89627	2595	44	440	20
G09	1	393	163	13264	86278	2234	48	398	30
G10	0	1613	199	19462	104737	2351	95	602	100
G10	0.1	1515	195	19087	102171	2169	93	618	88
G10	0.2	1550	192	18738	104718	2111	102	535	92
G10	0.3	1438	201	18559	107289	2083	101	576	84
G10	0.4	738	280	15406	180923	1610	80	358	53
G10	0.5	563	265	16805	150347	2064	91	462	57
G10	0.6	425	245	17386	133782	1903	94	451	69
G10	0.7	442	243	16096	139632	2284	80	506	55
G10	0.8	346	246	15830	150694	1749	75	500	40
G10	0.9	515	227	15233	134051	2272	65	433	39
G10	1	398	234	15653	129698	2640	64	501	37

Tab. 2. (continued).

Hungarian Academy of Science (HAS) and its project partners from the University of Tübingen since 2001. At Fajsz-Garadomb, a 6 x 110 m trench was excavated between 2007 and 2008, yielding a large number of archaeological features of different periods, from the Neolithic to the Late Roman / Sarmatian and Early Medieval / Avar period. The majority of the features can be dated to the Sopot culture, at the beginning of the Late Neolithic.

Fajsz-Kovácshalom has only been investigated through drilling campaigns by Pál Sümegi (cf. in the present volume) and Frank Stevens (Rassmann et al. 2015b, 5 f.). Additionally, in 2009, a surface collection was conducted to survey both sites.

The state of the current preservation of the tell mound allows some estimations with respect to the extent of the erosion (and thereby the associated risk with respect to the preservation of the Neolithic material). One can assume that the Neolithic layers would erode at a rate of 2–4 cm a year since the introduction of modern agriculture, i. e. over the past 100 years, resulting in a total erosion of 2–4 m over a century. This is massively destructive to any potential Neolithic discoveries. In this sense, the two-dimensional information provided by geomagnetic exploration has an even greater value.

On the Garadomb settlement, excavations were carried out between 2006 and 2008. Apart from some surface finds and parts of a heavily burnt house (or oven), indicating that Garadomb was occupied by the semi-mobile groups of the Körös culture as part of their dense settlement pattern in the Kalocsa Sárköz (Bánffy 2013), the features belonged to a smaller extent to the early (but not the earliest / formative) Linearbandkeramik (LBK) culture, while the vast majority of the Neolithic features could be assigned to the later Neolithic Sopot culture.

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
G12	0.20	1799	201	15823	106852	2377	85	447	69
G12	0.40	1568	384	11483	174872	1728	58	219	46
G12	0.51	1164	329	12127	155396	2088	64	337	46
G12	0.64	807	254	11802	137147	2331	52	357	26
G12	0.77	788	157	8559	99253	2467	38	402	0
G12	0.83	807	216	11098	122020	2452	50	328	21
G12	0.89	633	274	11881	138369	2328	52	452	33
G12	0.95	715	213	11125	116184	2778	50	309	26
G13	0.15	1377	204	14137	97712	1974	88	475	62
G13	0.25	1709	212	16580	116393	2558	89	447	63
G13	0.34	1222	281	13096	174131	1915	65	262	42
G13	0.45	1455	324	12583	175033	1871	63	252	45
G13	0.60	525	207	11934	119843	2026	49	225	15
G13	0.73	320	261	12476	137229	2035	51	389	21
G13	0.85	397	215	11982	118999	2136	49	315	23
G13	0.93	281	127	8512	94598	1924	36	494	0
G13	0.97	598	210	10957	127081	2597	48	365	21
G15	0.25	1737	196	16795	99295	2600	95	558	69
G15	0.35	1863	190	16645	99123	2567	94	524	70
G15	0.56	2207	327	13229	182059	1927	68	341	56
G15	0.72	1979	334	14165	155349	2137	76	335	61
G15	0.83	884	344	12314	163253	2025	60	369	42
G15	0.92	909	290	12590	142951	2216	61	418	34
G15	0.97	709	272	12048	137739	2228	54	373	31
G15	1.17	880	262	12772	138359	2235	54	368	25
G15	1.26	719	178	11246	107833	2403	44	388	15
G15	1.33	859	212	10293	115517	2295	48	324	19
G15	1.44	722	251	12315	124552	2633	54	344	29
G15	1.50	624	349	11011	156571	2050	48	428	24
G15	1.54	492	119	8511	89900	2764	37	375	0
G15	1.61	457	116	8026	70648	1921	34	235	0
G15	1.72	710	135	6978	98544	3811	34	365	0
G15	1.85	534	112	7240	68688	1834	35	143	0
G15	1.95	440	147	6812	92934	2784	36	273	0
K37	0.10	2698	265	15486	125237	2492	84	390	85
K37	0.35	3318	253	18243	97577	2527	100	509	105
K37	0.43	3779	303	15440	154375	2105	80	362	80
K37	0.45	2815	252	16804	106501	2488	93	531	105
K37	0.50	3062	346	15125	154405	2309	71	317	79
K37	0.60	2828	303	15786	131350	2357	76	357	81
K37	0.77	2361	276	16811	129149	2448	83	368	66
K37	0.92	1521	198	17383	107017	2624	90	355	57
K37	1.20	1665	173	17848	93717	2575	88	421	55
K37	1.25	997	154	16801	78670	2503	84	368	45
K37	1.40	1175	176	17262	95417	2611	84	381	52
K37	1.60	782	200	13319	130871	2043	54	303	17
K37	1.77	652	160	9893	98539	2039	41	390	0
K37	1.95	241	148	8939	73921	1500	38	91	0
K05	0.20	3176	266	15360	129796	2401	81	439	77
K05	0.33	3484	291	15833	133169	2368	81	368	71
K05	0.45	2588	235	14051	94062	1991	74	361	77
K05	0.60	3300	273	15430	114711	2352	75	415	89
K05	0.69	3238	258	16440	108206	2627	89	473	99
K05	0.72	3427	237	15281	90675	2319	83	440	89
K05	0.79	3266	305	13950	158013	2227	70	262	60
K05	0.86	4329	260	14571	104084	2042	78	345	93

Tab. 3. pXRF analyses of percussion drillings in Fajsz-Garadomb (G) and Fajsz-Kovácshalom (K) with sampling per layer. For the position of the drilling see *Fig. 15*. Concentrations are given in ppm.

drilling core	depth below surface (m)	P	Sr	K	Ca	Ti	Rb	Mn	Zn
K05	0.95	2562	259	15549	109845	2233	72	336	61
K05	1.15	3044	252	15016	118568	2096	74	317	68
K05	1.19	3392	202	14687	66434	2151	79	555	110
K05	1.23	2719	222	14888	104293	2428	67	385	60
K05	1.40	896	186	12101	106363	1926	51	235	19
K05	1.70	332	123	9725	72599	1304	41	103	0
K25	0.15	2924	257	15910	127485	2319	85	477	80
K25	0.30	2579	227	14676	115674	2076	81	411	67
K25	0.47	3146	253	15314	118847	2084	85	478	91
K25	0.58	2930	268	13631	133895	1889	73	324	69
K25	0.68	3689	260	15979	120536	2216	86	493	88
K25	0.80	4707	306	15687	121747	2295	81	307	108
K25	0.88	3372	206	16088	80145	2223	77	377	75
K25	0.97	2113	157	16327	66860	2136	73	345	58
K25	1.17	1653	144	15532	62874	2461	67	317	50
K25	1.25	1676	146	13667	74926	1919	62	292	45
K25	1.33	1552	145	12601	83223	1802	58	269	24
K25	1.50	758	141	10819	87443	1873	50	255	0
K25	1.66	728	164	12506	102038	1816	56	273	18
K25	1.85	779	183	12376	111180	2396	54	268	26

Tab. 3. (continued).

The archaeological research of the Sopot culture began rather late in Hungary. The formation of the group probably goes back to the early Vinča period in the western part of its distribution area. The Sopot culture was first identified and described in northern Croatia (Slavonia) and it was considered to be a local facies, a mixture between the Vinča and the Lengyel cultures (Dimitrijević 1968; 1969). The appearance of Sopot pottery and some burials suggested that some groups had migrated from the south along the Danube; their best-known site in the northern Danube area was found at Bicske, Fejér county (Makkay et al. 1996). Following the discovery of Sopot sites in northern Transdanubia (Regenye 1996) and during the fieldwork ahead of motorway construction projects along the southern shore of Lake Balaton (Barna 2017), rich assemblages were found in the Sárköz region at Fajsz and Alsónyék (Osztás et al. 2012; Bánffy et al. 2014: these sites were included in both the ToTL dating projects as well as in the aDNA project mentioned in the introduction). Sopot groups crossed the Drava and moved northward in Transdanubia, as far as the Danube Valley and southern Transdanubia from the south, sometime before the turn of the 6th to 5th millennium cal BC and partly co-existed with the earliest Lengyel culture in Transdanubia (Oross et al. 2016c).

Parts of a large circular ditch, remains of two unburnt Neolithic (probably Sopot) houses, and a Late Bronze Age house along with many settlement pits (quite frequently in multiple superpositions) were uncovered during the Fajsz-Garadomb excavations. The thickness of the Sopot layers amounted to 80 cm in some spots. Three graves with a rather unusual funerary ritual for the Neolithic of the region were also brought to light. The robust skeletons lay on their back in an extended position. In terms of their ancestry, the Preneolithic genetic composition was remarkably high among the Sopot individuals (Szécsényi-Nagy et al. forthcoming). An unusual, secondary burial was also found, carefully deposited in a refuse pit, along with two small clay figurines, one of which had a compound decoration style of the Tisza culture and so may have been imported from the Tisza region (Bánffy et al. 2017). The site was also occupied in later prehistoric periods: during the Baden period and in the Late Bronze Age (Urnfield culture), as well as during the Late Roman / Sarmatian period, indicated by a high number of stray finds. First to be discovered at the site were high numbers of Early Medieval / Avar graves and it was therefore initially reported as an Avar cemetery (Horváth 1972). The assessment of the large amount of pottery and other finds is currently still in progress (for an evaluation of the environmental background, see Kreuz et al. in the present volume).

The magnetic prospections were carried out in two campaigns, on February 19–20, 2013, and November 13–15, 2015 *(Figs 8–10)*. In 2013, the area was prospected with the MAGNETO® MX ARCH 16-channel system. The fieldwork was complicated by ploughed

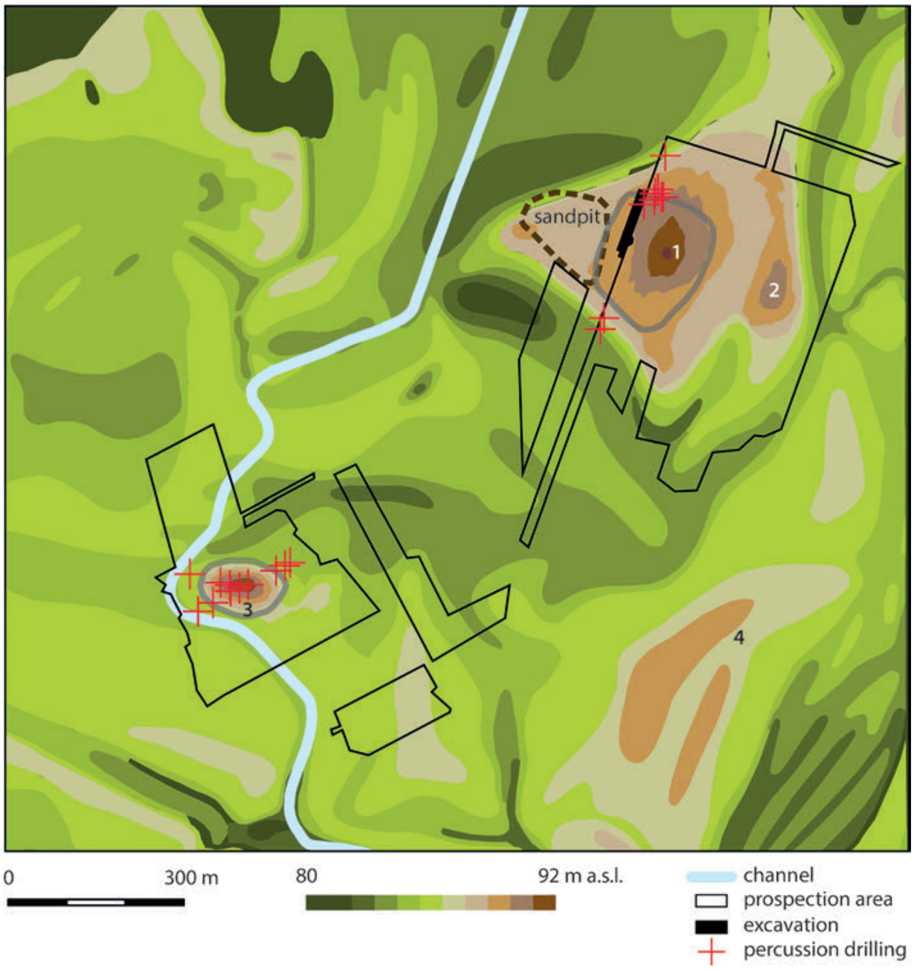


Fig. 8. Fajsz. Digital elevation model (DEM) and the location of the magnetic prospection and percussion drillings. 1 Fajsz-Garadomb; 2 Fajsz-Lipovác; 3 Fajsz-Kovácshalom; 4 Fajsz-Östövér (Wicker et al. 2001, 47 f.). DEM based on the topographic map 1 : 10 000 / Sheet 25 141.

fields and high soil moisture due to intensive precipitation. Nevertheless, in spite of these adverse conditions, data were acquired for approximately 6 ha. The settlement mound (area c. 130 x 80 m) was also fully surveyed. The area that was surveyed in addition to the settlement mound extends a further 200 m to the northwest (Rassmann et al. 2015a). A second campaign was planned for 2015 in order to cover larger areas around the tell and on the flat settlement. Data for an area of around 20 ha were acquired with the MAGNETO® MX ARCH 16-channel system. The settlement mound was prospected again with the same system, involving overlapping areas with the MAGNETO® MX ARCH 5-channel system with different sensor spacing of 25 cm and 50 cm to evaluate the accuracy of the different systems and configurations.

The prospected surface of c. 20 ha covers the complete potential settlement area. The comparison of the digital elevation model (DEM) and the magnetic prospection data allow the reconstruction of the size of the settlement. A large number of circular low magnetic amplitude anomalies – most likely pits – are visible on the magnetic map in addition to a small number of anomalies with higher magnetic amplitudes, presumably the remains of burnt houses. The excavation revealed a variety of archaeological features belonging to different periods, namely the Neolithic, the Bronze Age, the Late Roman / Sarmatian period, and graves of the Early Medieval / Avar period. The interpretation of the circular ditch as the remains of a Sarmatian barrow is very likely (cf. *Fig. 11.1*). The Avar graves were not evident in the magnetic data, but were only discovered during the excavation. While most of the relevant archaeological structures were evident in the magnetic prospection data, this demonstrates that most, but certainly not all relevant archaeological features are detectable through a magnetic prospection survey. The crucial question is the dating of the numerous, more than 2000 less characteristic anomalies evident in the magnetic prospection data that could not yet be directly correlated with the finds of

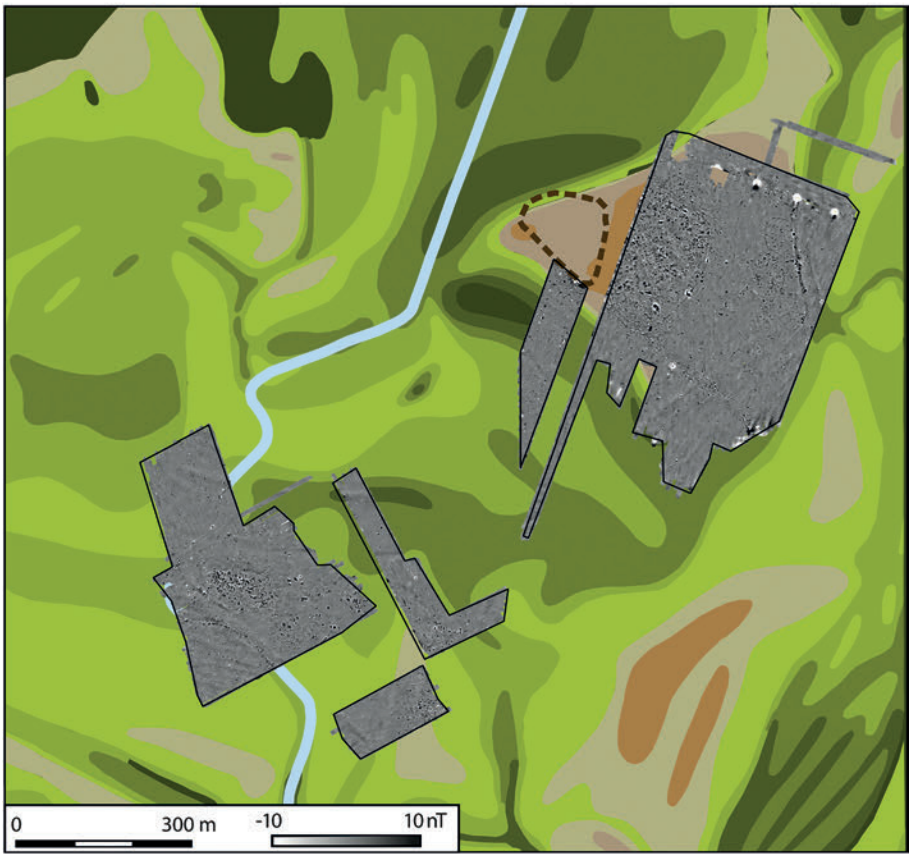


Fig. 9. Fajsz. Overview of the magnetic prospection at Fajsz-Garadomb and Fajsz-Kovácshalom.

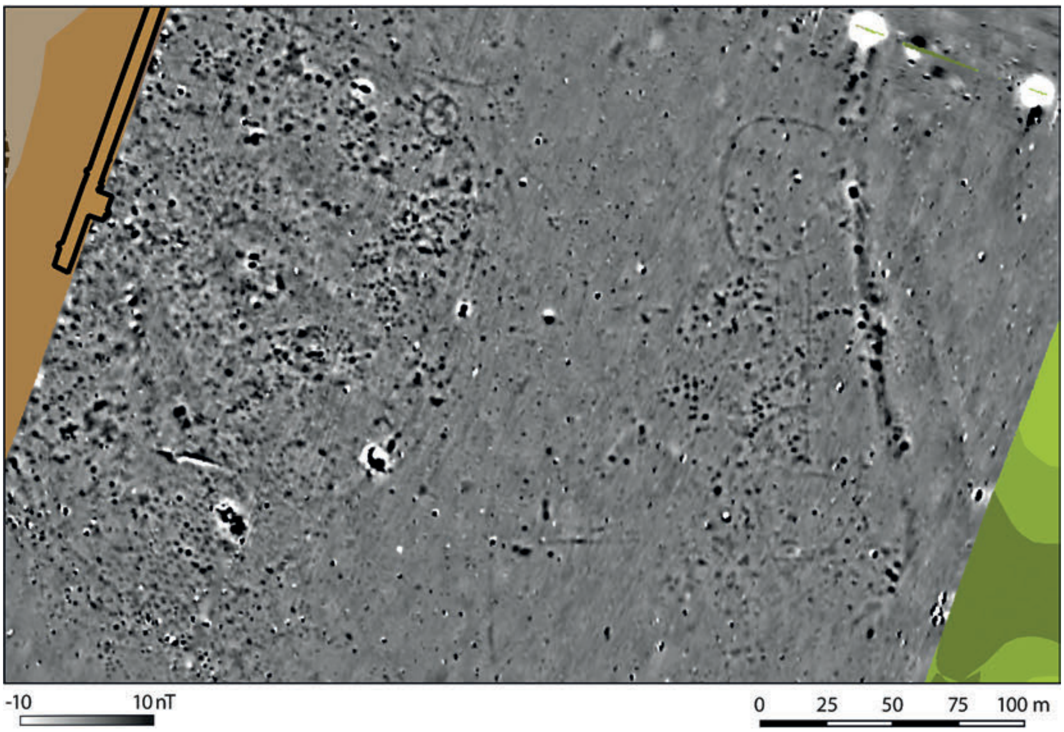


Fig. 10. Fajsz-Garadomb. Result of the magnetic prospection with 16-channel magnetometer with gradiometers spaced at 0.25 m intervals. Interpolation of the raster grid 20 x 20 cm. Scale ± 10 nT.

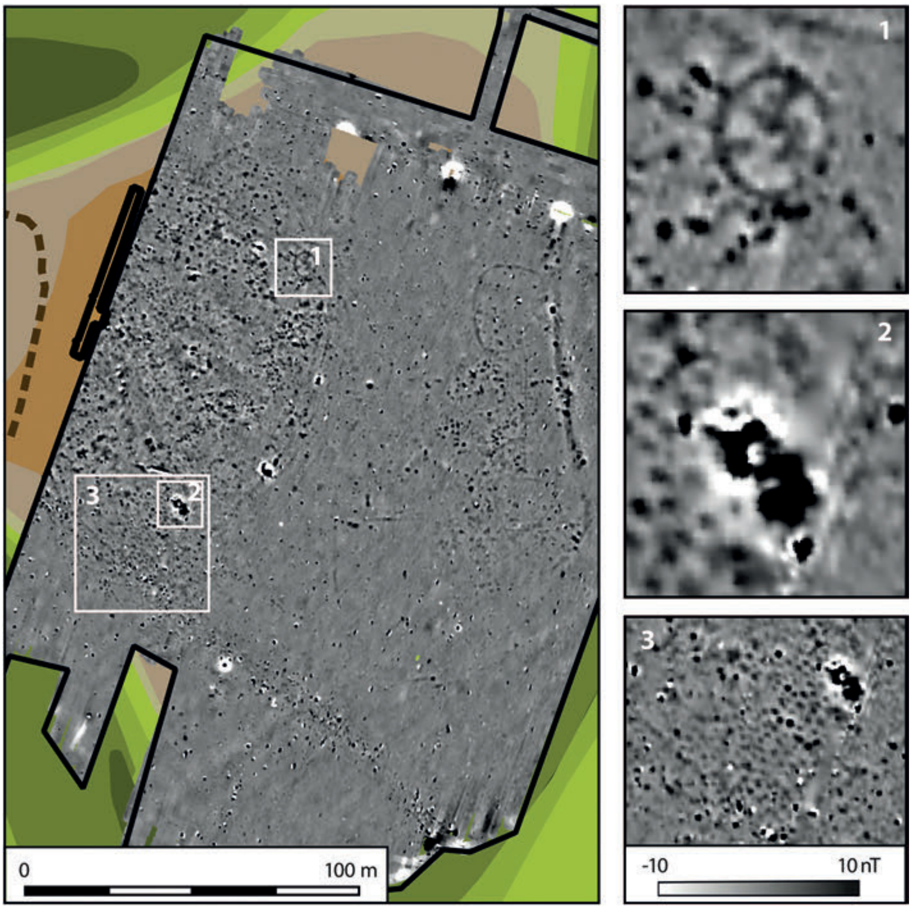


Fig. 11. Fajsz-Garadomb. Significant archaeological anomalies (basic data as in *Fig. 10*).
1 Ring ditch of a Sarmatian grave; 2 Late Bronze Age (?) house; 3 Late Bronze Age (?) house, and a cluster of settlement pits.

the excavations *(Fig. 12)*. To select relevant features, the 2 nT magnetic anomaly contour line was calculated and converted into polygons. By calculating the size of the anomalies, all anomalies larger than 0.5 m^2 were selected by filtering *(Fig. 13a)*.

The filtered polygons were combined with the raster map of the vertical gradient magnetic anomaly data. By using the QGIS-plugin *zonal statistics,* the pixels covered by the selected polygons of the vector layer were analysed. Based on *zonal statistics*, we filtered all objects (anomalies) with amplitudes of less than 20 nT in order to exclude dipole signatures caused by ferrous objects such as modern steel scrap (lost agricultural machinery parts, unexploded ordnance, civilian scrap distributed with manure, etc.) from our map.

For the selected objects, centroids were created. The centroids were then used to perform a kernel density estimation (KDE) *(Fig. 13b)*. The KDE map indicates seven areas with higher density. All these are part of an area enclosed by linear anomalies, presumably a ditch system *(Figs 13a; 14)*. The spatial coincidence of the calculated kernels and the ditches makes an identical chronological background reasonable. One obvious question is how old are these features? To answer this, we have to consider the excavation data. The excavation data suggest a remarkably higher density of Neolithic features in the northern part of the trench. This tendency clearly correlates with the KDE map *(Figs 13b; 14)*. The obvious assumption is to date the majority of nT-anomalies behind the seven 'kernels' to the same time slice. The strong correlation between the kernels and the ditch system is a clear indication that the latter can also be dated to the Neolithic.

A second clear tendency in the excavation data is the prevalence of Bronze Age features in the southern trench. Again, the magnetic dataset indicates a similar tendency (cf. *Fig. 11.3*). In the southern prospection area, we observed a remarkable concentration of circular anomalies with similar size and magnetic amplitudes. Their average diameter is between 1–2 m. Shape, size, and magnetic amplitudes very likely indicate settlement pits. The pit cluster is intersected by the southern ditch *(Fig. 14)*, indicating that these anomalies might belong to different occupation horizons. Considering the ex-

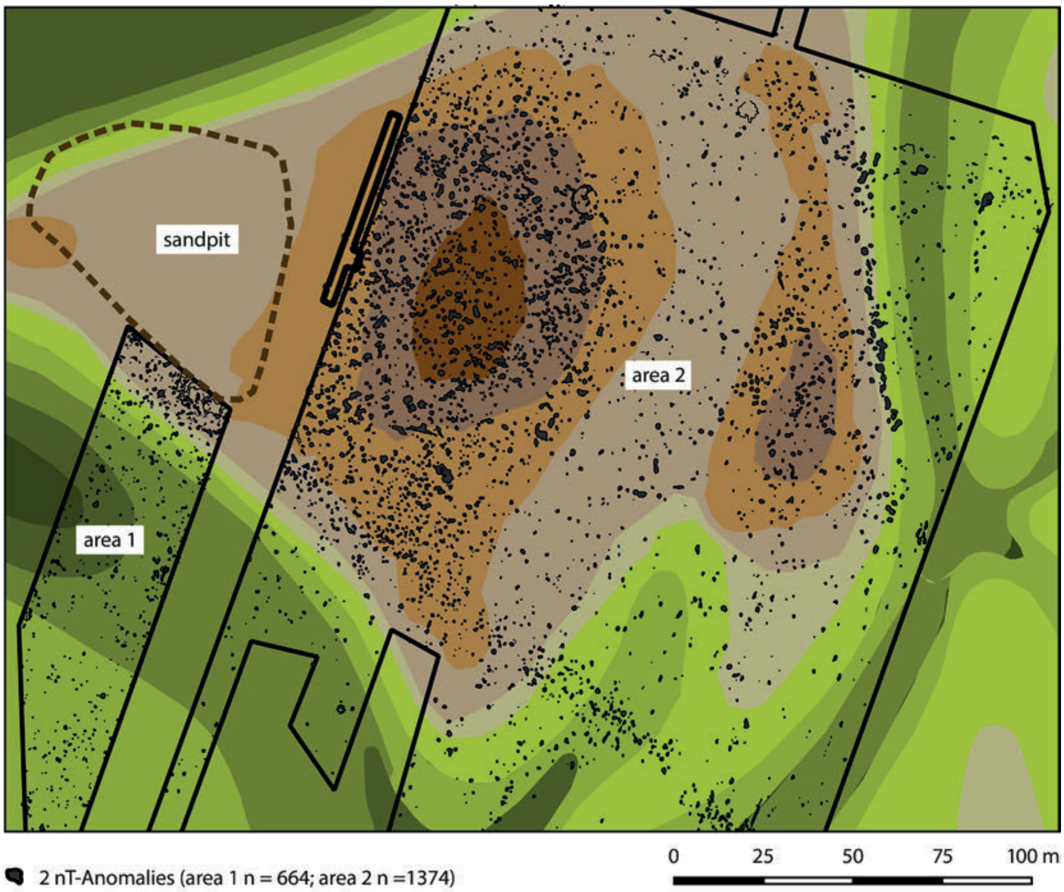


Fig. 12. Fajsz-Garadomb. Map with magnetic anomaly contour lines (polygons) of 2 nT amplitude.

cavation results, the settlement pits likely belong to the Bronze Age occupation, and the small number of house remains might date from the same period. At least, this appears to be much more likely for these features than a Neolithic date.

The KDE map indicates a second activity area eastwards of the flat settlement with clear indications of human activity (cf. *Figs 12–13*). Behind this kernel numerous anomalies resemble the cluster of Bronze Age settlement pits. Their distribution correlates with a slight rise. Indications of houses are not visible. The shape of the ditches does not correlate with the topography and the distribution of the settlement pits. Their interpretation remains open.

In sum, the magnetic data acquired at Garadomb as well as the excavation indicate three main chronological horizons. The majority of the anomalies can be dated to the Neolithic. The settlement pits in the southern part of the area and the burnt house remains date to the Bronze Age, while the circular ditch dates to the Sarmatian period.

The drilling campaign in 2015 focused on the tell settlements of Kovácshalom and Garadomb *(Fig. 15)*. The drilling cores and auger profiles provide information on the sequence of the settlement layers and the sediments in the vicinity of the settlement. All drilling cores from Garadomb indicate a relatively thin settlement layer of up to 1 m. Unsurprisingly, this correlates with the excavation data. In addition to the conventional classification auger profiles, the cores obtained from the percussion drilling pile core sampling and Pürckhauer sampling were investigated by multi-element chemical analysis and magnetic susceptibility measurements. Both datasets clearly indicate the settlement layers by P-values above 1000 ppm and significantly higher magnetic susceptibilities. The magnetic susceptibility of the cores was measured in detail with a sampling distance of 5 cm along the cores. The density of chemical analysis is much lower. We only sampled visually discernible layers.

The multi-element chemical analysis provides additional information that allows the identification of different and additional strata. Not surprisingly, the differences between the various layers that are not discernible visually are also evident in the magnetic susceptibility values. In some layers, the variation of the magnetic susceptibility values is higher than the visual differences. The fact is well known and has been comprehensive-

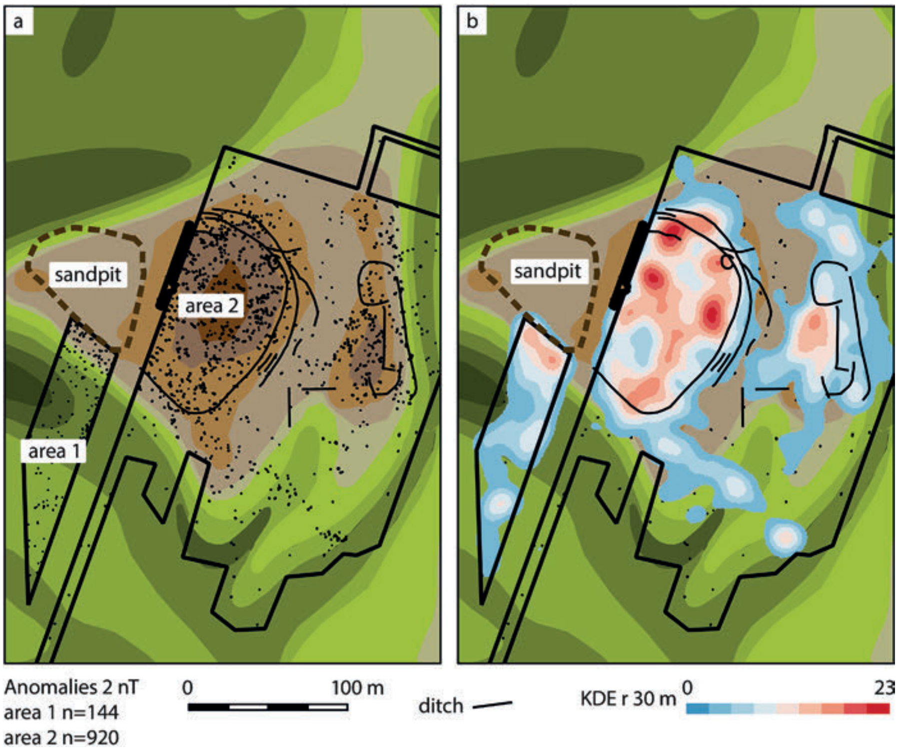


Fig. 13. Fajsz-Garadomb. a Selection of specific 2 nT-magnetic anomalies (criteria: area 0.5–10 m², magnetic mean 2–20 nT). b Kernel density estimation (KDE) map of the centroids of the selected polygons.

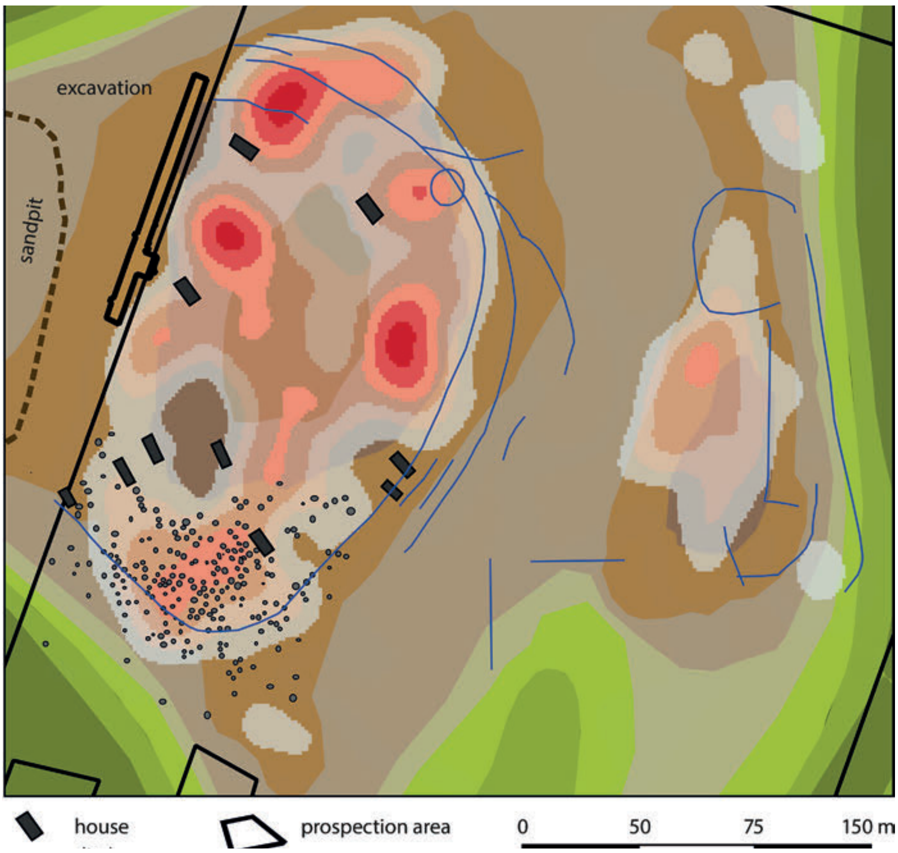


Fig. 14. Fajsz-Garadomb. Kernel density estimation (KDE) map of ditches, Late Bronze Age houses (?), and settlement pits (criteria of anomalies: area 0.4–1 m², magnetic mean 1–4 nT).

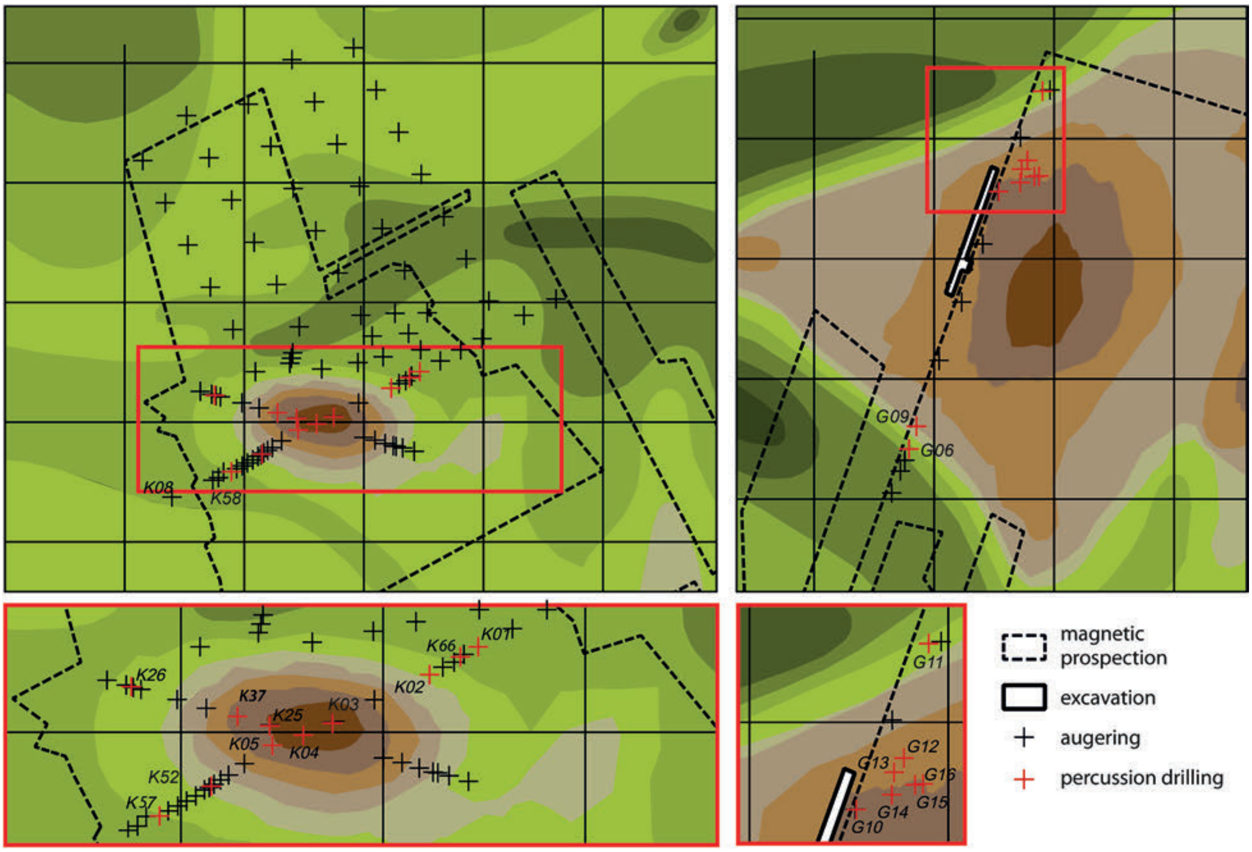


Fig. 15. Fajsz. Overview of the pile core samplings and Pürckhauer auger sampling at Fajsz-Garadomb and Fajsz-Kovácshalom (see *Fig. 8*; measuring grid 100 × 100 m). Only the pile core samplings are marked with numbers.

ly described, *inter alia* by Neubauer (2001, 56) and Frenzel (2014, 11). Therefore, an optimal sampling for chemical analyses should be rather based on a preliminary measurement of magnetic susceptibilities with a small sampling interval along a core than on the visual identification of strata.

The area of the settlement mound is marked by numerous magnetic anomalies *(Figs 16–19)*, belonging to different periods. Few of the anomalies are possibly post-Neolithic – considering the dating of the surface material – presumably of Late Roman / Sarmatian and to a large extent of Medieval date. The former include three clearly visible ring ditches (diameters between 8–18 m). In addition, numerous pit-like anomalies are also evident. Their diameters vary between 2–3 m and some are probably settlement pits. Other pits with low magnetic anomaly amplitudes suggest that they might represent grave pits. Apart from a few dipoles, only two represent layers of burnt daub. The small number of potentially burnt houses is typical for tells, as was the case during prospections at Uivar, Timiş county, Romania (Schier / Draşovean 2004, 151 fig. 3), and Pietrele, Giurgiu county, Romania (Hansen et al. 2004, 95 fig. 18), although there are examples for heavily burnt complete occupation phases, as at Berettyóújfalu-Herpály, Hajdú-Bihar county (Kalicz / Raczky 1984; 1987; Kalicz et al. 2011). One cannot assume that Neolithic features were destroyed by human activity during later periods (e. g. the digging of Sarmatian or Medieval graves). Instead, it can be concluded that burnt houses – at least in the upper settlement layers – were truly a rarity at this tell site. Based on the proximity between the Kovácshalom and the Garadomb sites as well as the Late Neolithic phases of both, physical traces of the assumed communication were investigated. Yet, no evidence of paths or trackways leading to the Fajsz-Garadomb settlement was found. Geological signatures as well as the aforementioned archaeological anomalies provide evidence for the silted backwaters of the Danubian tributaries.

Kernel density estimation (KDE) is used to investigate the general tendency in the distribution of relevant anomalies. The KDE is based on the centroids of anomaly classes defined by 1 nT, 2 nT, and 4 nT magnetic anomalies that were calculated from the data *(Figs 18–19)*. A higher density of magnetic anomalies clearly marks the settlement mound in its entirety. Westward of the settlement mound, a linear agglomeration of anomalies indicates a former river or channel bed. In the eastern periphery, an area with a higher density of anomalies presumably indicates a satellite settlement.

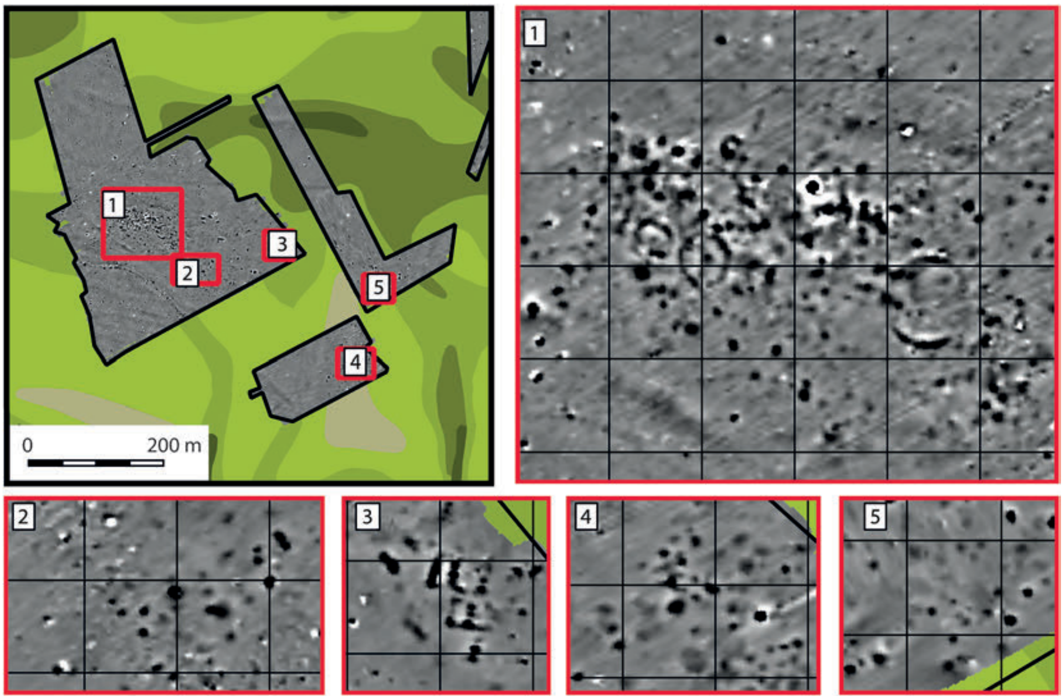
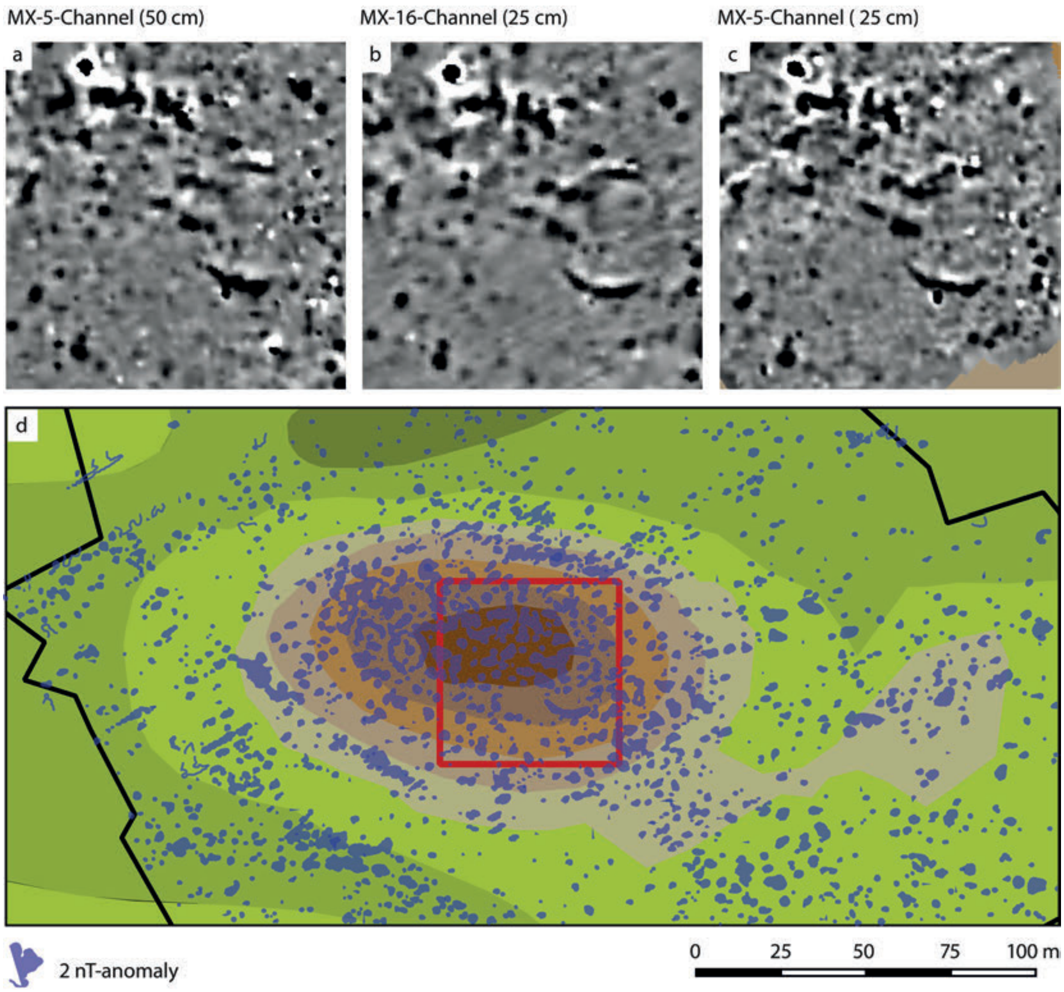


Fig. 16. Fajsz-Kovácshalom. Overview of the magnetic prospection with a selection of the magnetic anomalies of pits and houses. 1 Settlement mound; 2 settlement pits in the southern periphery of the mound; 3 house remains (date ?); 4–5 settlement pits.



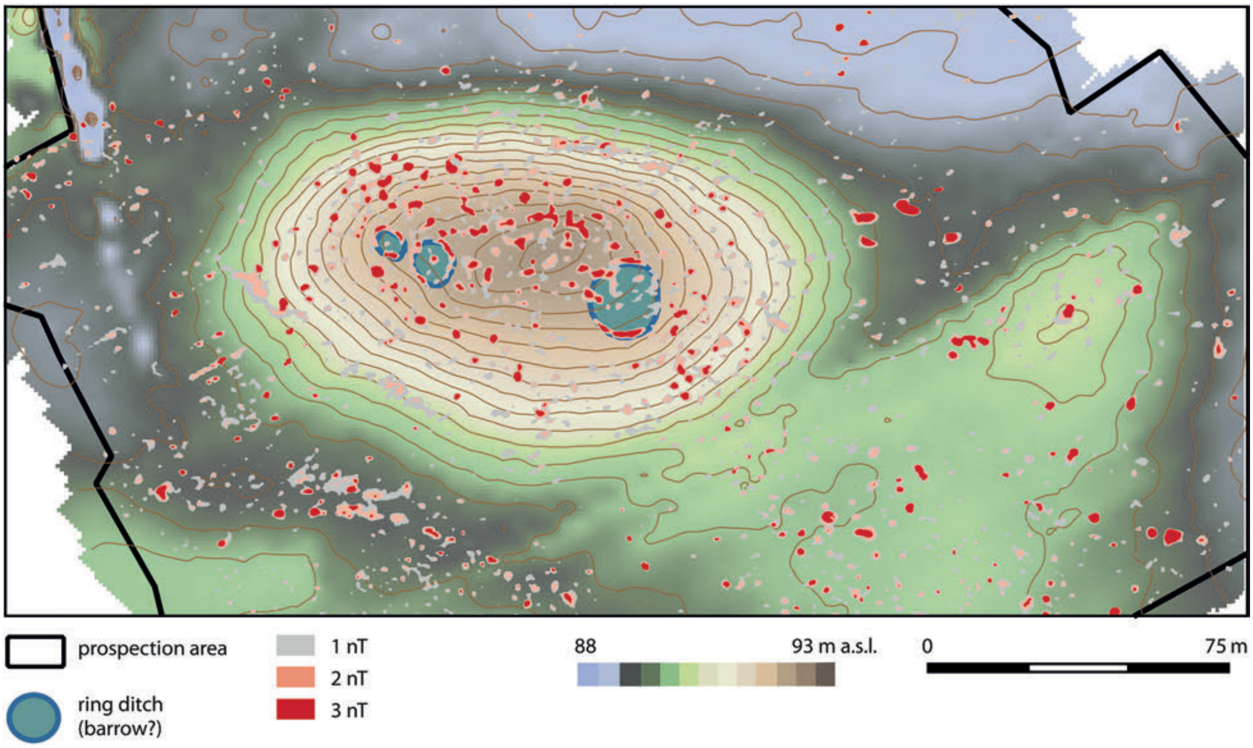


Fig. 18. Fajsz-Kovácshalom. Magnetic anomaly classes: 1 nT, 2 nT, 3 nT *vs.* the digital elevation model (DEM).

The multi-element chemical analysis of the cores provided the data that enable a comparison between the flat settlement Garadomb and the settlement mound of Kovácshalom. The phosphorus values of Kovácshalom are much higher than on Garadomb *(Figs 20–21)*. The highest values of up to 6000 ppm indicate a strong anthropogenic impact. For the majority of the samples, the phosphorus concentrations are in the range between 2000–3000 ppm, a characteristic dimension for settlement layers (Gauss et al. 2013). The lower phosphorus concentrations from Garadomb with values ranging between 1000–2000 ppm are quite remarkable, presumably the result of the lower density of people or buildings per hectare on the flat settlement. At the same time, the magnetic susceptibility values at both settlements are similar, which is quite noteworthy. The soil samples with higher susceptibility generally indicate occupation layers. At the same time, higher magnetic susceptibility values do not directly indicate a stronger anthropogenic impact. The analysis of the overall magnetic susceptibility datasets indicates that susceptibility is a strong indicator, for example, for burnt clay, as may be found in the locations of burnt houses, fireplaces, ashes, ovens, or kilns.

Strontium correlates directly with phosphorus, as shown by the PCA of the XRF analysis data (cf. *Fig.* 7). It is a commonly observed phenomenon (Gauss et al. 2013). Furthermore, the multi-element chemical analysis of cores generally indicates higher calcium concentrations in layers with higher concentrations of phosphorus and strontium.

The A-layer of all cores shows regularly increasing magnetic susceptibility values *(Appendices 1–2)*. In some cores such as in sample K66, we measured high magnetic susceptibility values again in deeper settlement layers, in particular in layers with house daub and burnt clay. Unfortunately, the Bartington magnetic susceptibility metre was only used for the analysis of samples in the laboratory. In the future, we will include *in situ* magnetic susceptibility measurements into our fieldwork as part of our standard operating procedure. We anticipate that for the investigation of prehistoric sites on intensively used agricultural land, susceptibility measurements in boreholes (downhole sensor measurements), and high density grid measurements in vertical and horizontal surfaces beneath the agricultural layer will be of particular value for archaeological investigations. We will continue to use the Bartington MS3 instrument with MS2 sensors

◁ Fig. 17. Fajsz-Kovácshalom. Comparison of different magnetic data from the centre of the settlement mound and filtered anomalies of > 2 nT. a MAGNETO® MX ARCH 5-channel system, sensor separation 50 cm; b MAGNETO® MX ARCH 5-channel system, sensor separation 25 cm; c MAGNETO® MX ARCH 16-channel system, sensor separation 25 cm; d digital elevation model (DEM) and magnetic anomalies > 2 nT.

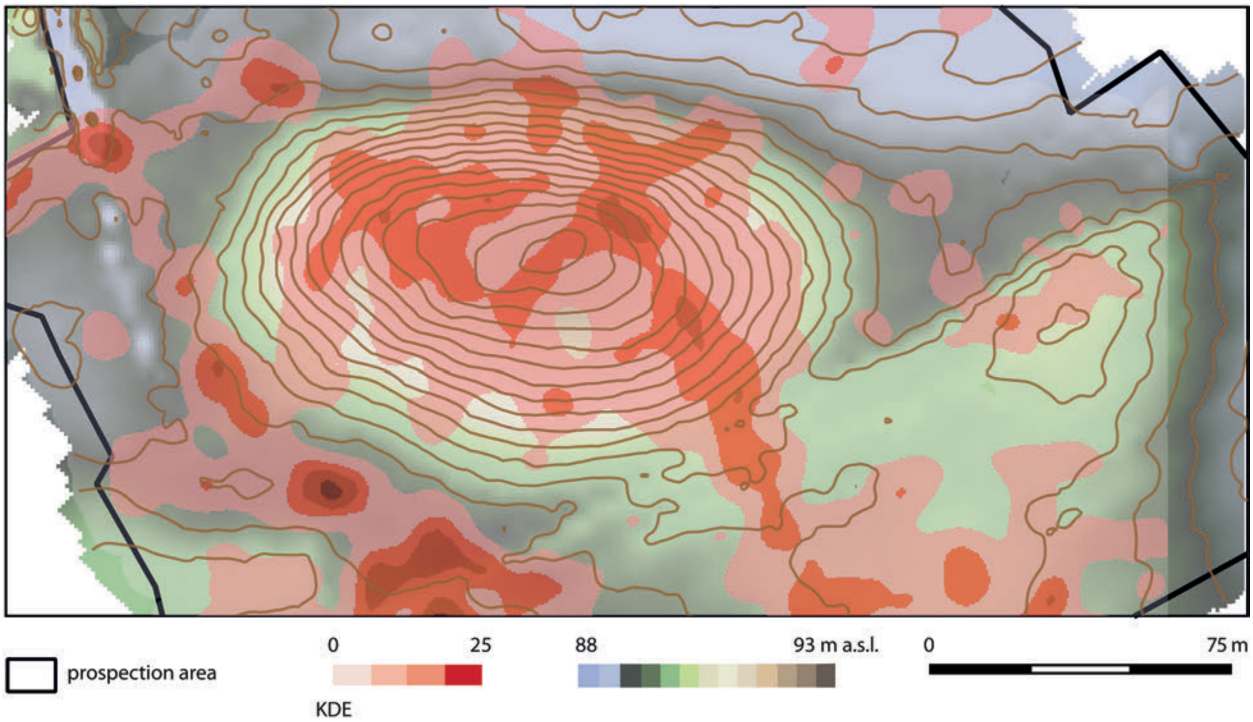


Fig. 19. Fajsz-Kovácshalom. Kernel density estimation (KDE) of the potential pits and house daub (range 10 m) *vs.* the digital elevation model (DEM).

for this task. One option is to measure every borehole with the MS2H downhole sensor. In addition, all cores retrieved by means of pile core sampling should be measured using the MS2C sensors loop configuration for core investigations. Single soil samples should be analysed using the MS2K surface sensor.

The advantage of susceptibility measurements is that only little time is required and that a large number of samples can be analysed in a short time.

Fajsz-Kovácshalom, profile A-A' *(Fig. 22)*

Natural sediments

The central sediments (a) are the basis of the mound. It consists of a moderately fine-grained, moderately silty sand of light-grey to yellow colour and contains oxidised iron compounds *(Figs 22–23)*. Based on qualitative tests using hydrochloric acid, it contains virtually no calcium carbonate and is therefore likely an aeolian sediment, or has been decalcified over time. This is only apparent within the upper 75 cm of the sediment, below which obviously autochthonous layers of silt (b and c) begin to appear. These silt layers as well as some (but not all) of the lower sand layers do react when exposed to hydrochloric acid, and thus indicate a calcium carbonate content. It is likely an alluvial sediment or has been re-deposited through very strong aeolian or fluvial activity.

Both (b) and (c) are deposits that consist of yellow to light yellowish-grey, very sandy silt. Both react strongly to hydrochloric acid, and thus contain carbonate, most likely calcium carbonate. These are classified as alluvial sediments.

Three related, but nevertheless different sediments could be distinguished on the left side of the profile. Sediment (d1) consists of very coarse, light yellowish-grey, very silty sand containing complete shell fragments as well as smaller shell fragments. The upper part of this sediment in Core K7 graded into moderately coarse, moderately silty sand with humic layers, while the upper 20 cm contain a layering of sand and clay.

Sediment (d2) is greyish-brown very silty clay with much humus and shell fragments. In addition, pieces of daub and minute charcoal particles were found in this sediment.

Sediment (d3) represents light yellowish-brown very silty clay with shell fragments.

Deposited on top of these related sediments is sediment (e) which is similar to (b) and (c). Sediment (j) consists of light greyish-yellow, extremely silty sand, with light greyish-yellow, extremely silty clay layers which are fairly thick. The bottom of these sediments shows an erosive transition to the underlying sediments (d1).

A more uniform layering could be observed on the north-eastern side of the mound. The sediments encountered here consist of very silty clay of greyish-brown colour (k) mainly due to humic material. More eastward

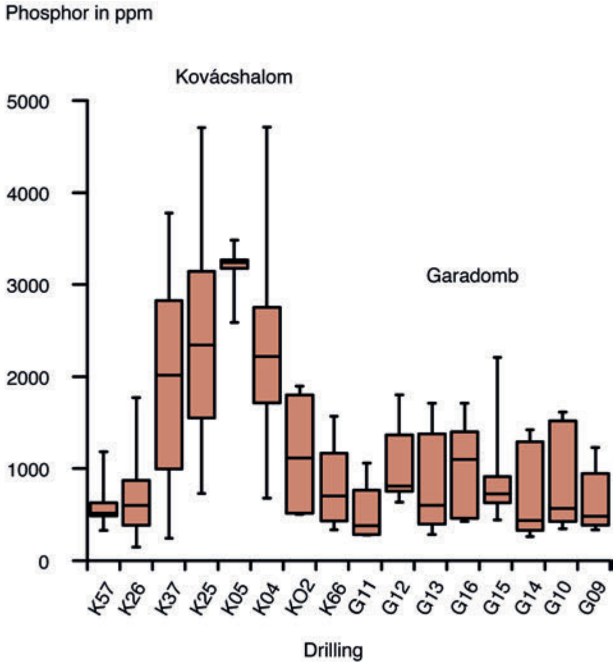


Fig. 20. Fajsz-Garadomb and Fajsz-Kovácshalom. Boxplot comparison of the P-values of the pile core sampling cores.

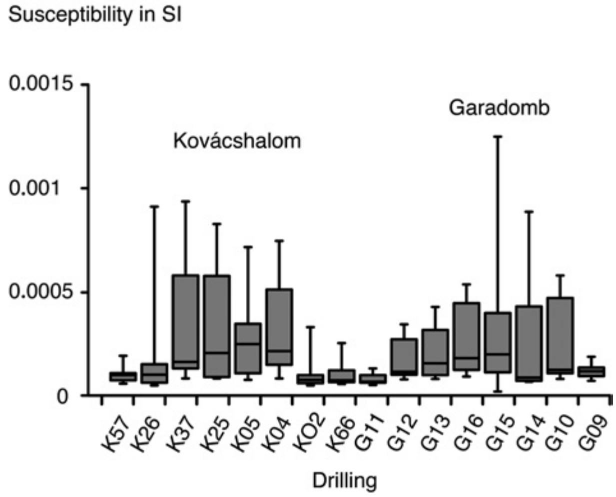


Fig. 21. Fajsz-Garadomb and Fajsz-Kovácshalom. Boxplot comparison of the magnetic susceptibility measurements of the pile core sampling cores.

(Core K20), several thick layers containing large quantities of humic material were observed. Sediment (k2) is also a very silty clay, although it has a dark brown colour, mainly due to high humus inclusions. Overlying is sediment (l) consisting of moderately sandy clay of a greyish-brown colour. Sediment (l2) is also moderately sandy clay of dark brown colour with high humus content. Sediment (l3) has a similar appearance, but contained cultural material in the form of daub and specks of charcoal.

Signs for the presence of a stable groundwater level were observed in cores K20 and GR. Beginning at a depth of 2.5 m below the modern surface, the conditions become reducing with little oxidised iron compounds compared to the upper layers with large quantities of oxidised iron compounds.

Fajsz-Kovácshalom, profile B-B' *(Fig. 23)*

The majority of the features are similar to the ones in profile A-A' (cf. *Fig. 22*). Therefore, see above for descriptions of sediments (a), (b), (c), and (j). Sediment (h2) consists of very sandy clay of dark brown to black colour with large quantities of humus. It contains both a lot of daub and shell fragments, and burnt bone was also identified. It has an erosive transition to the underlying sediment (c). Calcium carbonate concretions have been found in large numbers in the lower parts of this sediment, which might indicate that the erosive contact is natural and caused by fluvial activity. Organisms which live on the bottom of rivers and streams produce calcium carbonate concretions.

Interpretation

Concerning the natural formation, it appears possible that a river dune (a) was covered by floodplain sediments (b) and (c). On the southern side, this was cut by a river arm (called a palaeo-channel in sedimentology) (d) with a fairly shallow riverbed. It is probably indicative of a wider river (a prolonged discharge of large volumes of water). Sediment (k) most likely represents a residual gully. This sediment indicates a water mass that hardly moved and filled up gradually, with some more stable to stagnant phases, which enabled the formation of sediment containing a lot of humus, as evident in Core K20. The layered appearance of these sediments indicates fluctuation in the water intake of the probable basin. Sediment (l) represents the final phase of the residual gully, which apparently had an increase in water velocity, suggested by the sand inclusions throughout the upper part of the sediment. Ultimately, this arm was cut off completely from the river and filled up.

Sediments (h) and (h2) seem to be contemporaneous with sediment (l), although with a large amount of cultural remains in comparison. The sandy nature of the clay sediments (l, l2, h, and h2) is likely to be alluvial, but an aeolian origin is also possible.

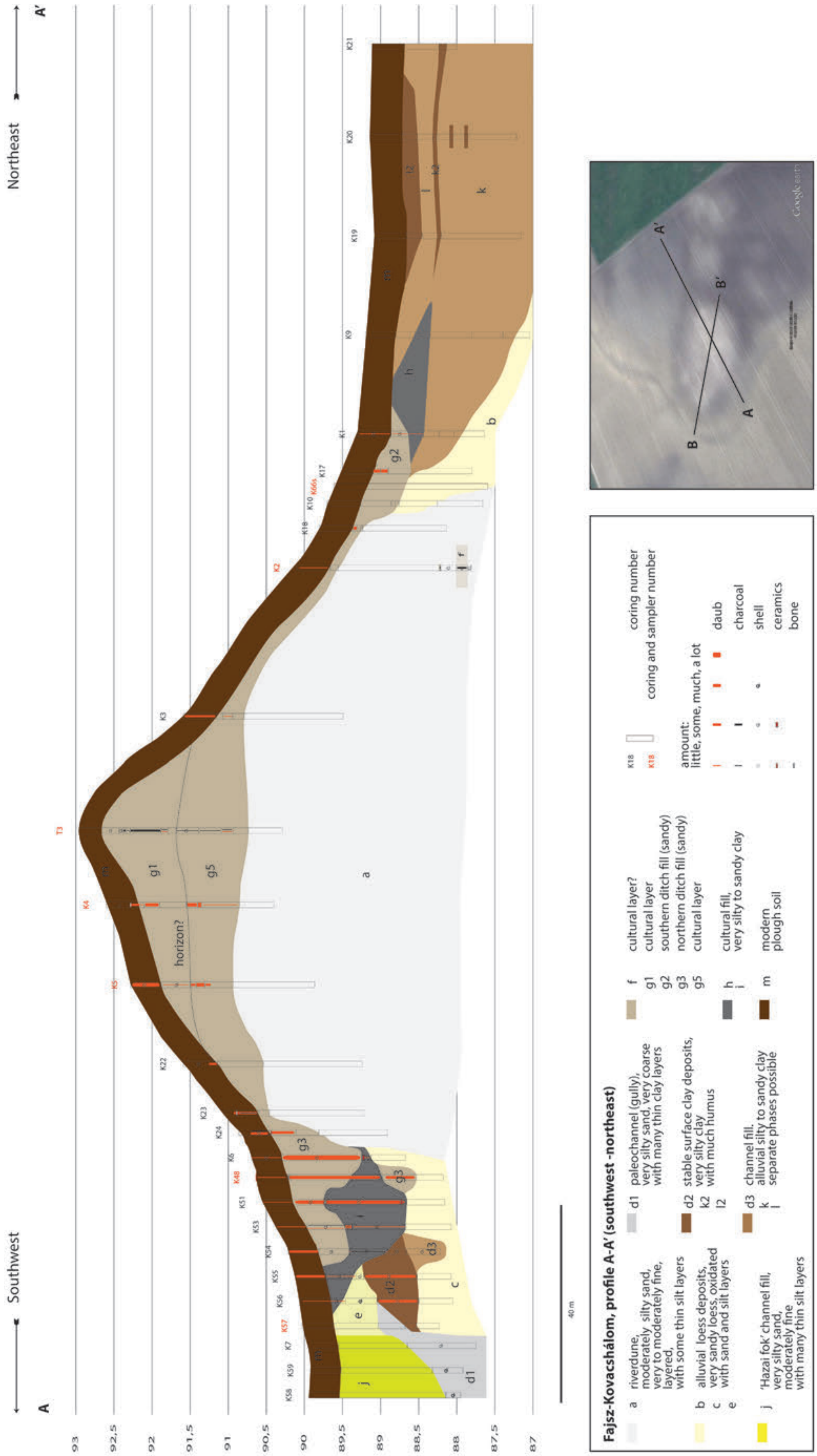


Fig. 22. Fajsz-Kovácshalom. Profile A-A' shows the profile after the interpretation based on the descriptions of the sediments. First, the naturally deposited sediments will be described (even though some have cultural artefacts in them) followed by the description of the cultural layers.

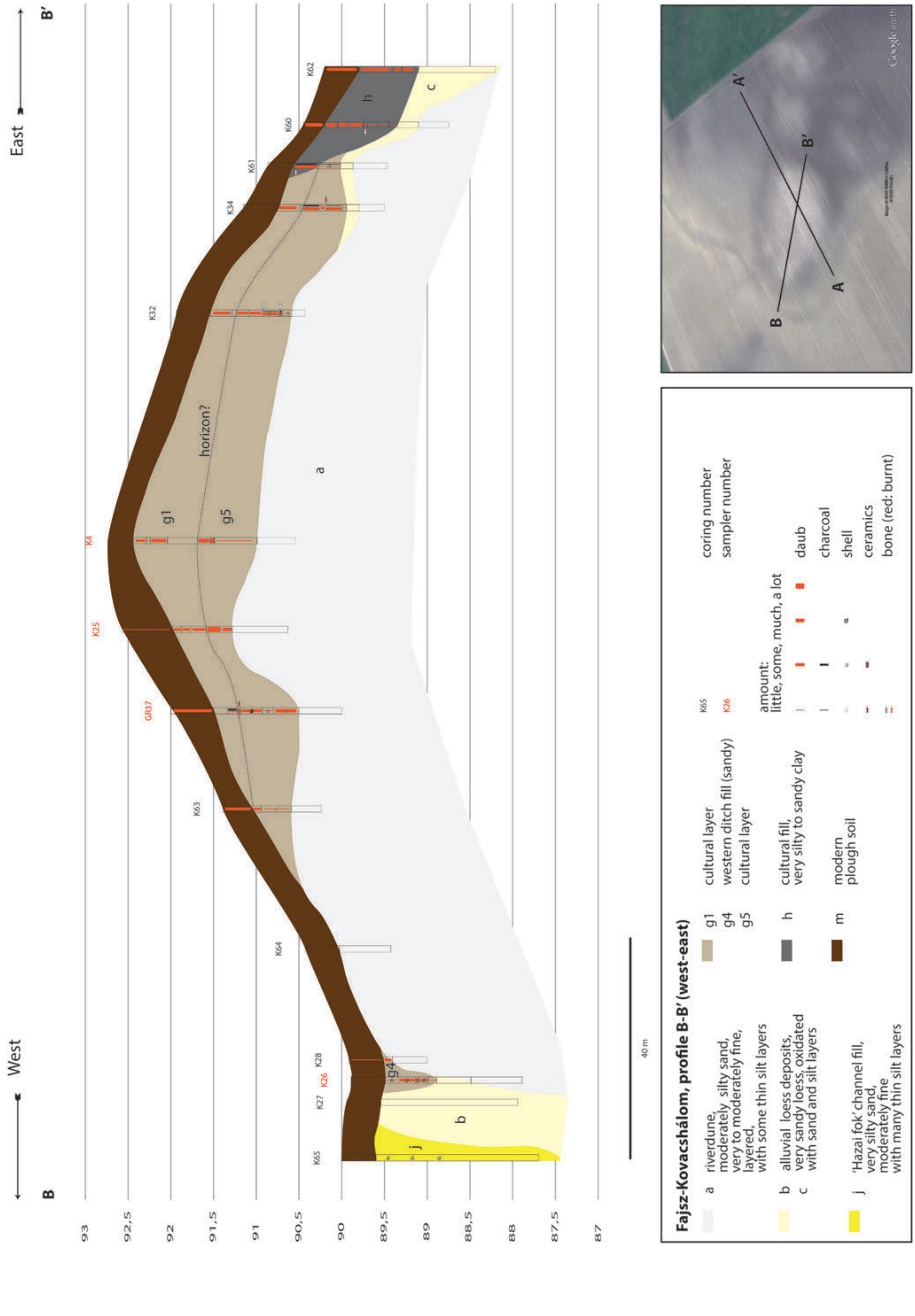


Fig. 23. Fajsz-Kovácshalom. Profile B-B' shows the interpreted profile based on the descriptions of the sediments.

Cultural layers

The potentially oldest layer (f) was found in a single core (K02) at a depth of c. 2.2 m below the topsoil. It appears to represent a layer where a moderate degree of soil formation has taken place. Some charcoal fragments were found in this layer.

It is impossible to reconstruct and qualify the cultural layers at the top of the mound. Due to the number of features that are observed in the magnetic prospection results, it is likely that the observations cannot be properly linked between boreholes. The variety in appearance also gives no indication of comparability. However, a horizon can be postulated between the stages of occupation / utilisation, which is mainly based on a large number of cultural indicators at those depths. Therefore, the description of layers (g1) and (g5) cannot be generalised, despite them consisting mainly of silt and sand.

The natural sediments on the southern flank are culturally interesting because of the possible riverbank (d2 and d3). Here, cultural material is found within the sediment. However, it remains unclear whether these are remains fragmented *in situ* or fluvially deposited materials. On top of the riverbank, natural alluvial sediment (e) is found. This implies that the cultural material represents an early or the earliest phase of the site. After this period, heavy fluvial activity of the Danube covered these remains, after which the area was arable again.

The ditch or trench (i, i2, and g), which could represent a fortification of the mound, had been dug through this accumulated material and gradually filled up since. Initially composed of non-humic greyish-yellow moderately sandy silt (i2), it gradually grades into layer (I). This layer (I) has a very sandy clay fill which, close to the mound, contains large quantities of humus and is dark greyish-brown, but it contains little humus and is light greyish-brown near the outer edge. The accumulation of humus near the mound is likely related to activity on the mound. It contains a lot of debris, daub, charcoal, and (probably) Neolithic sherds as well. The lowest layer (g3), due to its erosive border with the underlying layer, probably represents a rejuvenation of the ditch / trench. This also contains a lot of daub fragments, and (probably) Neolithic sherds were noted immediately below the topsoil.

Layer (g4) in the left part of profile B-B' is most certainly a ditch or trench. It is located on the western side of the mound and is vaguely visible on the geomagnetic image as well. Based on the geomagnetic image in *Figs 16–17*, layers (g3), (g4), and (g5) appear to be contemporaneous, they are connected and form a ditch or moat around the mound. The differing fills can likely be explained by the connection with the gully located on the mound's eastern side. If there was an open access to this main river gully, coarse material would have been deposited closer to the gully, while more fine-grained material would have been deposited farther away from it. The soil colouration in the aerial images also confirms this observation.

Layer (m) is the modern topsoil. It consists of silty sand, sandy silt, or sandy clay depending on the underlying sediments. Around the mound, the soil contains a lot of archaeological debris such as daub, bone material (on the surface and in the sediment), ceramic sherds, pieces of flint (both exclusively on the surface), and shell fragments.

Conclusions

A very complex sediment history mixed with a palimpsest of cultural activity could be noted across the research area. It is likely that all observed sediments were formed during the Holocene, but it remains unclear in which time-frame. Only sediments (a), (b), and (c) might have an older origin. Because of the artefacts on top of this presumed river dune, it confirms the pre-Neolithic origin of the sediments. All other sediments are unlikely to be older than the Neolithic. The mound has a natural origin, but it remains unclear whether this is solely due to fluvial activity or whether aeolian activity also had an impact.

The available information is insufficient for understanding the development of the landscape after the mound was formed. Obviously, the Danube has continually and frequently changed its course. Different sediments ranging from very coarse, very silty sand to very silty clay deposits can be found, reflecting a large variety in sedimentation environments. Gullies with fast-flowing water (d1) to stagnant water-bodies (k) can be postulated, both based on the appearance and morphology of these sediment types. Erosion, sedimentation, and post-depositional alterations have been encountered.

There was open water on all sides of the mound, although it is unclear whether simultaneously or at different moments in time. The humic clay found at a depth of 1 m north of the mound is indicative of a so-called residual gully. While its total extent has not been determined, it appears to have been more than several hundred metres wide. A river-bed was located at some point on the southern side, but it remains unclear how deep and wide this river arm was. It was only identified in the last three cores at the end of profile A-A'.

What makes this situation unique is that it appears to have been buried under a metre of natural sediment. As far as is known, this is unique for the region. A buried landscape could be present not only here, but also in other parts of the region as well.

East of the mound there appears to have been erosion that cut through parts of the mound. Calcium carbonate concretions provide evidence of contact with oxygen-rich water, and it can be postulated on the testimony of these characteristics that parts of the site had been inundated in this area. As can be seen on the geomagnetic images, two smaller mounds lie farther to the east, but these have not been explored so far.

A roughly 1.7 m thick cultural deposit can be found on the top of the mound, which had originally been thicker, although it remains unclear how much thicker. We were told by local farmers about the difficulty of ascending the mound with tractors. They mentioned an attempt to flatten the mound which was stopped when it was identified as an archaeological site.

During this attempt to flatten the mound, many human bones were found, some possibly originating from Sarmatian graves and from the Late Medieval cemetery. As noted above, the estimated depth of the graves of the latter period lay 2 m below the surface, and, thus, it can be assumed that this cultural deposit has already been eroded or removed as shown by these bones. Because of the lack of the dating of the sediments, a precise chronology of events cannot be determined at this point.

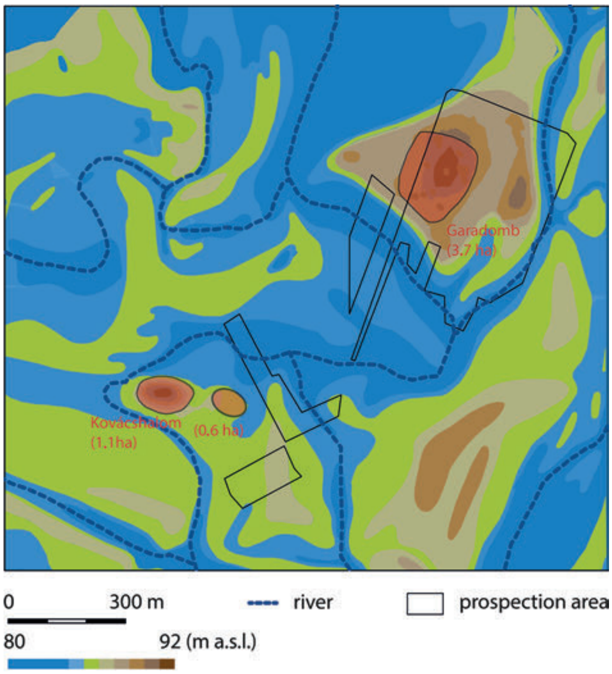


Fig. 24. Fajsz-Garadomb and Fajsz-Kovácshalom. Digital elevation model (DEM). Highlighted in blue are the potentially flooded areas, while the settlement areas are marked in red.

Synthesis

The analysis of different prospection datasets and the integration of the main excavation data revealed general tendencies with respect to the use of both sites over the past 7000 years. These include settlement activities in earlier periods of the Neolithic and Bronze Age and ritual or burial activities in the 1st millennium AD by Sarmatian, Avar, and later Hungarian rural populations. Our prospections enable us to reconstruct the size of the Late Neolithic settlement areas. Fajsz-Garadomb is around 3.7 ha and Fajsz-Kovácshalom around 1.1 ha with a satellite settlement of 0.6 ha.

The settlement area on Garadomb is enclosed by ditches. Some of the ditch anomalies are hardly visible in the magnetic prospection data, an indication that they are presumably shallow. The difference in the visibility of the ditches on the magnetic image might indicate that they are not contemporaneous. Nevertheless, all ditches are enclosed in an area well visible in the digital elevation model (DEM) *(Fig. 24)*. Inside the ditches the KDE revealed significantly higher concentrations of relevant magnetic anomalies. These could indicate small house clusters. A high density of houses as on the Vinča sites such as Stubline, municipality of Obrenovac, Belgrade (Crnobrnja 2011), and Okolište, municipality of Visoko, Bosnia and Herzegovina (Müller et al. 2011), is highly unlikely. The southern area of the Neolithic settlement was again occupied in the Bronze Age. The building density again remained low. The magnetic data most likely indicate seven houses. However, it remains an open question whether all of them originate from the Bronze Age. The high number of Bronze Age settlement pits in the southern area indicates intensive economic activities. As expected, the magnetic data of the settlement mound of Kovácshalom are complicated. A tell site is an accumulation of different regularly overlying settlement layers, resulting in overlapping magnetic anomalies of the overlapping archaeological features. The clear patterns observed at Okolište (Müller et al. 2011) are more of an exception, caused by burnt house remains in the upper layer. The multiple layers at the two investigated sites of Fajsz-Garadomb and Fajsz-Kovácshalom reflect an occupation over different periods. The indication of a small satellite settlement on the western periphery is also a new discovery. The example of the floodplain landscape around Fajsz shows the great value of historical maps. They provide valuable information for the reconstruction of the ancient terrain situation *(Fig. 25)*.

Tolna-Mözs-Községi-Csádés-földek

Location, topography, and previous archaeological research

The prospected area is located south of the small town of Tolna. The route of motorway M6 passes a slightly elevated area west of the present-day town and continues southward over an extensive floodplain with embedded low plateaus *(Fig. 26)*. The remains of a large LBK settlement with an area of approximately 45 ha were discovered on one of these.

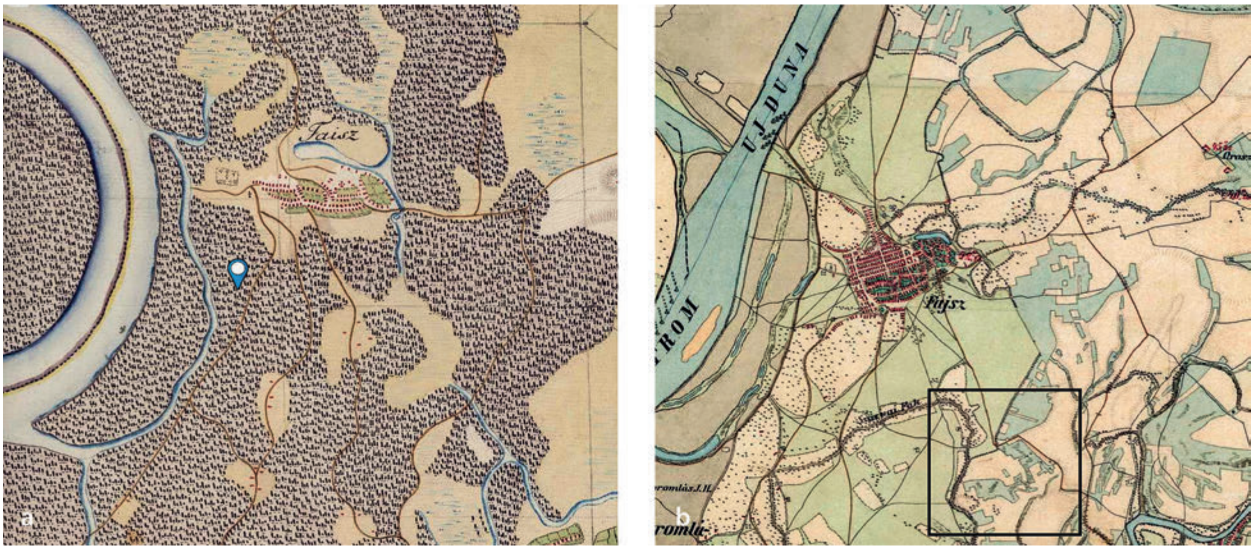


Fig. 25. Fajsz. Sections from maps from a Josephinian cadastre, 1782–1785; b Franciscan cadastre, 1806–1869.

Large-scale rescue excavations were conducted in 2008–2009 by the Institute of Archaeology. The excavation trenches followed the nearly north-south running line for approximately 750–800 m. The width of the investigated area measured c. 70–100 m.

Three spatially separate groups of houses were investigated during this rescue excavation, albeit only partially. To reconstruct the overall extent of the settlement to the east and west better, the team opted, once again, for large-scale geomagnetic prospections (cf. *Figs 33–34*).

Prospection and working conditions

An area of 79 ha within this selected study zone was prospected in two campaigns: in 2011 (November 18–21) and in 2013 (February 21–March 6). As the focal area is currently used for agriculture, we planned to acquire data in the prospection area right after harvesting (and only a minimal ploughing in some areas) in 2013. In spite of excessive rain and soggy soil conditions, the ground was passable.

The prospected area covered nearly the entire plateau, except for the areas covered by the M6 motorway in their central part *(Figs 26–29)*. As at Fajsz, the magnetic prospection was conducted with a vehicle-towed MAGNETO® MX ARCH 16-channel system.

Magnetic prospection: Anomalies, spatial analysis, and modelling

General description of the anomalies (Figs 30–31)

The most common finds revealed by the magnetometer results were the elongated pits flanking obvious LBK houses. These pits appear to have been placed in relation to the house groups that were noted during the excavations. The elongated pits form clusters across the low plateau. Between them are zones without clear evidence of settlement remains. The variation in the building density on the plateau is clearly visible in the magnetic data and was already observed during the excavation.

The elongated pits are obviously in different states of preservation. They are well visible in the south-western and the north-eastern area, whereas they are less clear in the north-eastern part of the area close to the M6 motorway. It could be assumed that the less well-preserved elongated pits associated with houses were partly eroded. Traces of postholes, sometimes observed on LBK settlements (Bihler et al. 2015, 171), are not visible.

The question arises as to how reliable magnetic data are for the reconstruction of the settlement structure and for the estimation of the number of houses, the latter based mainly on the elongated pits. Our interpretation has to consider that not every house is accompanied by two flanking pits, as we know from the excavations at Tolna-Mözs, Alsónyék-Bátaszék, and on other LBK sites in Hungary (Oross 2016b, 125 fig. 2). There is a prevalent pattern of two elongated pits per house, alongside a smaller number of houses with only one elongated pit or, in rarer instances, without any elongated pits. We may therefore contend that the lack of any elongated pits is more of an exception than a recurring variant in regional LBK architecture, even more so because even though elongated pits dug into the prehistoric soil occur most frequently among the archaeological features associated with longhouses, shallow elongated pits can occasionally also be observed. In other words, the lack of elongated pits can in some cases be explained by erosion or by the mechanical topsoil removal preceding an excavation. The results of the rescue excavation are crucial for the

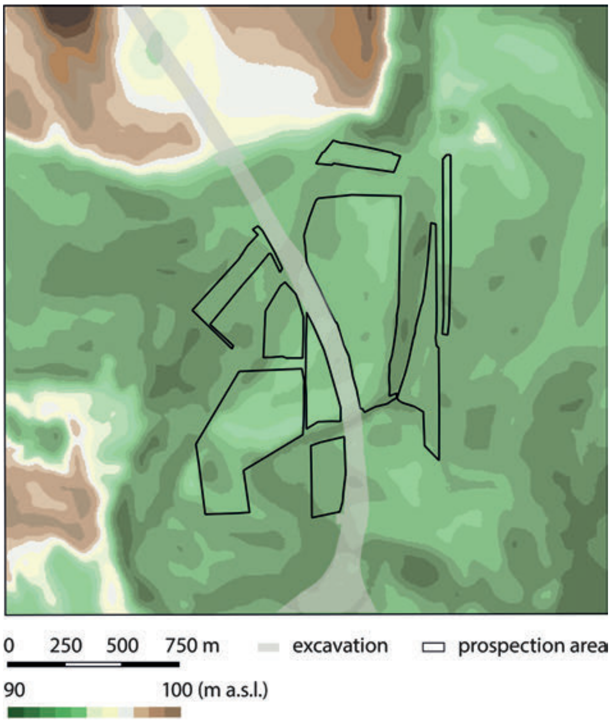


Fig. 26. Tolna-Mözs-Községi-Csádés-földek. Overview of the magnetic prospection areas surveyed in 2011–2013 near the M6 motorway. Digital elevation model (DEM) based on the 1 : 10 000 topographic map / sheets 25 131, 25 133.

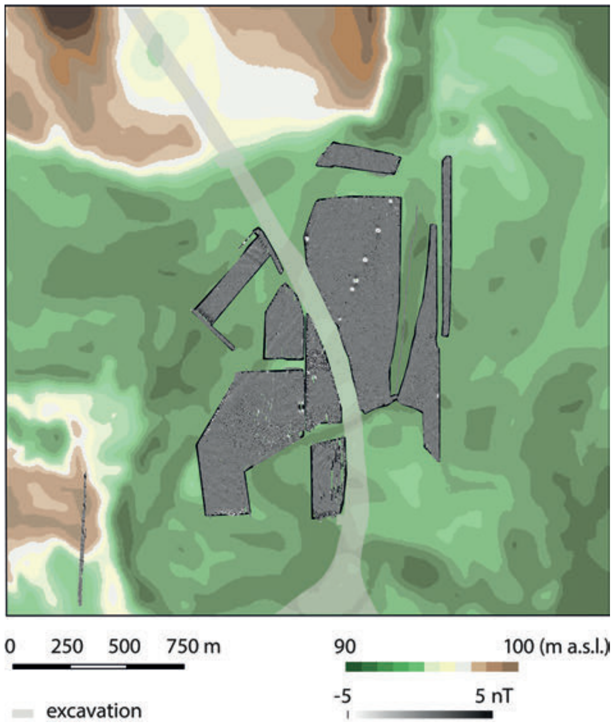


Fig. 27. Tolna-Mözs-Községi-Csádés-földek. Overview of magnetic prospection results from areas surveyed in 2011 and 2013.

Fig. 28. Tolna-Mözs-Községi-Csádés-földek. Overview of magnetic prospection results from the northern area.

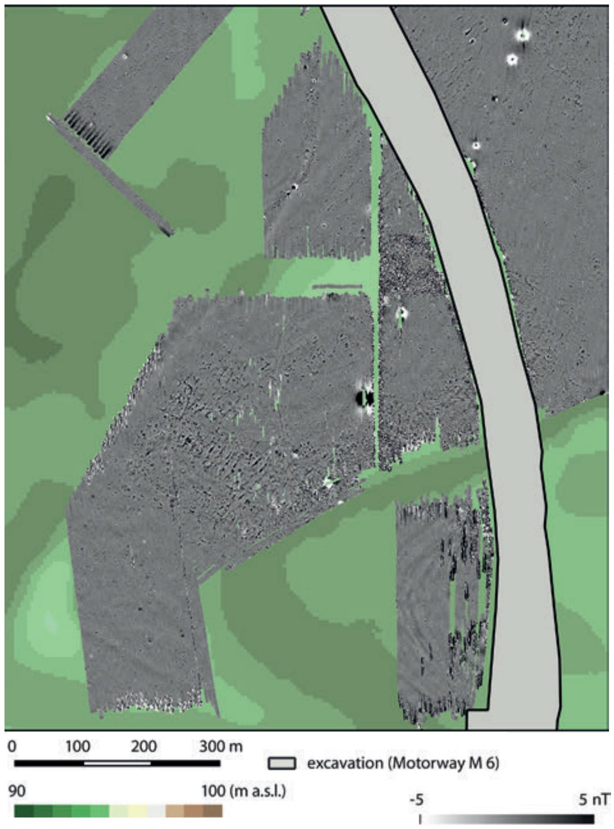


Fig. 29. Tolna-Mözs-Községi-Csádés-földek. Overview of magnetic prospection results from the south-western area.

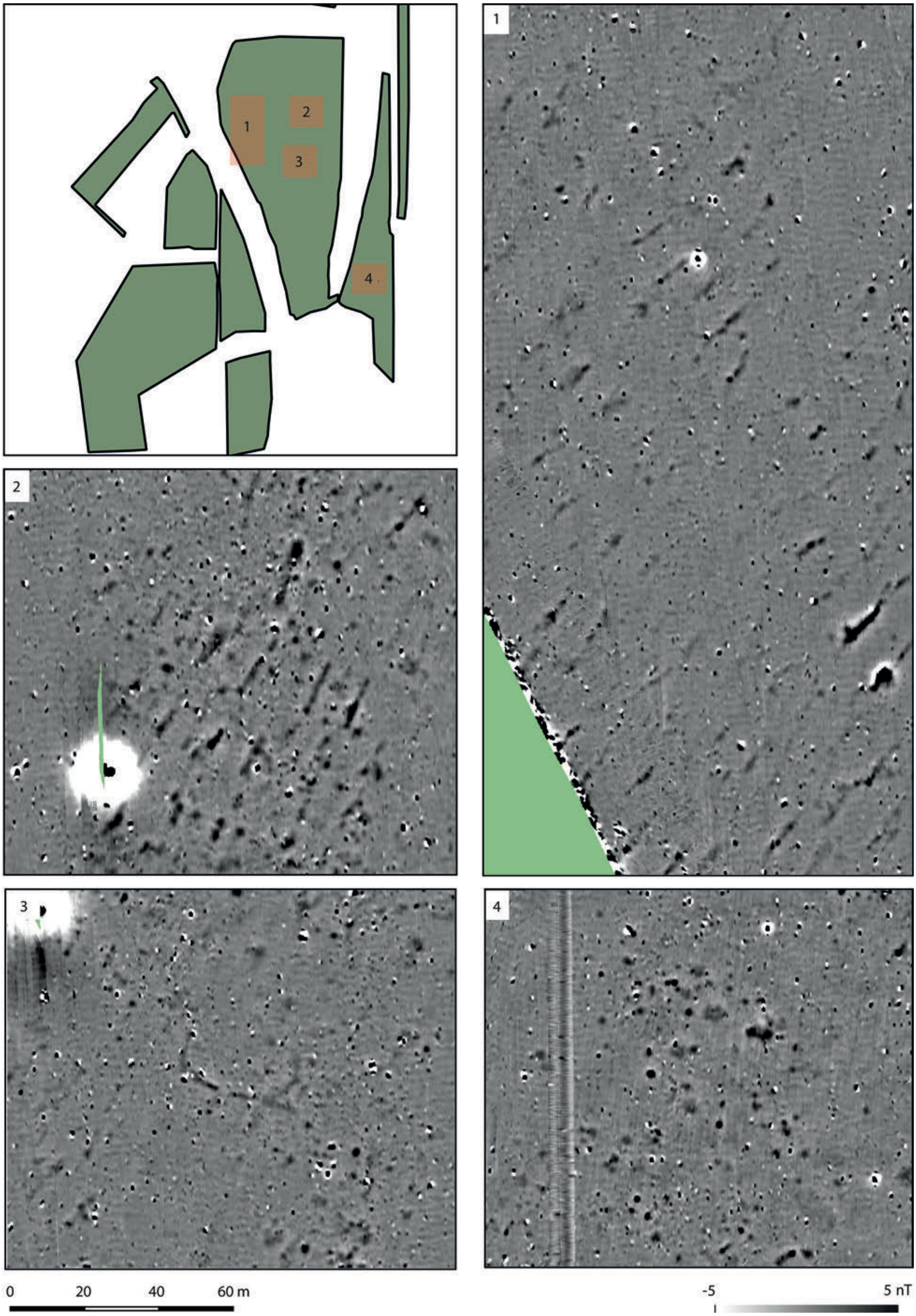


Fig. 30. Tolna-Mözs-Községi-Csádés-földek. Details show elongated pits flanking houses and settlement pits in the north-eastern areas (1–3) and the south-eastern area (4).

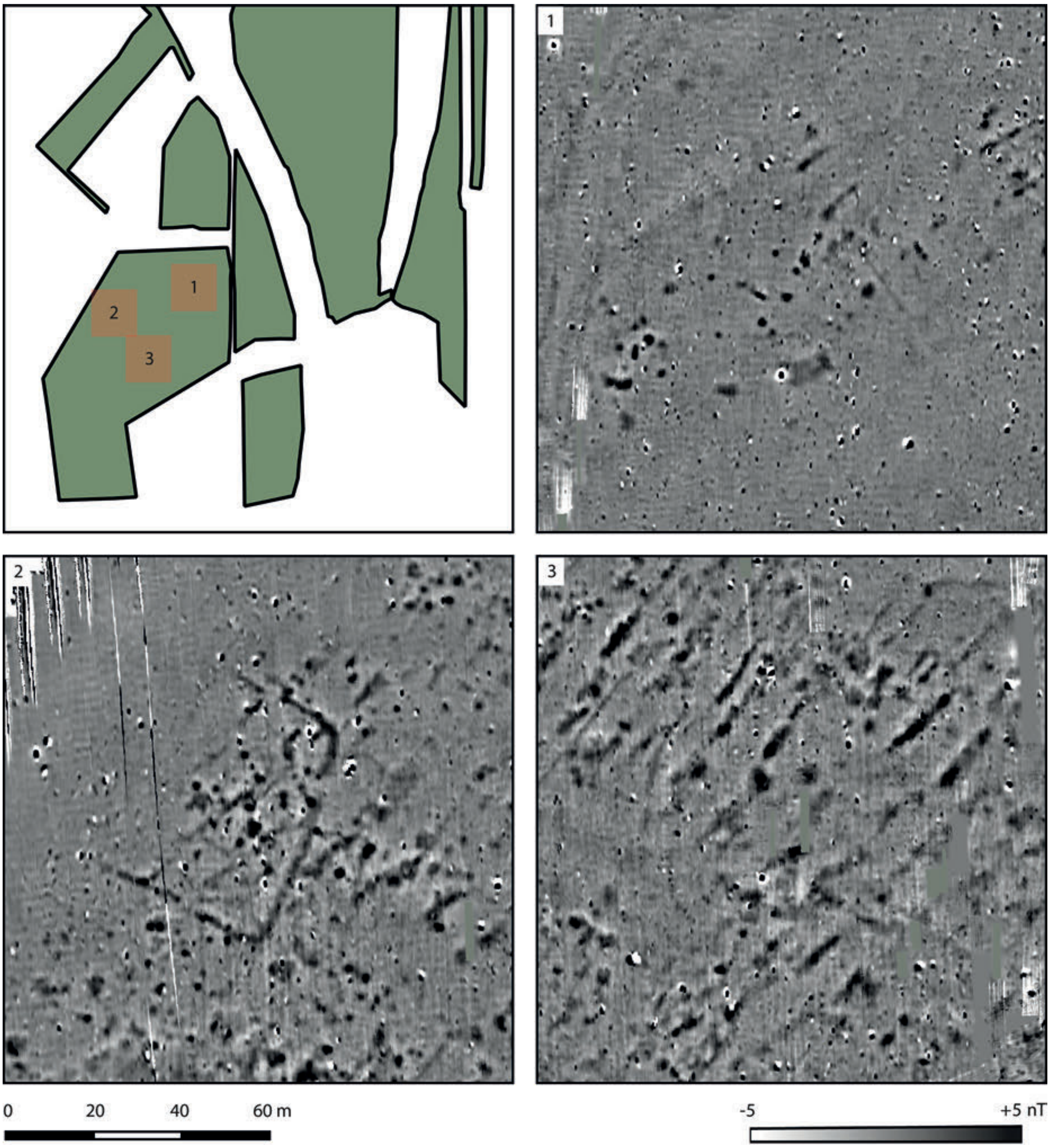


Fig. 31. Tolna-Mözs-Községi-Csádés-földek. Different magnetic anomalies in the south-western area. 1 Settlement pits; 2 ditch enclosure with rounded corners and two entrances and settlement pits; 3 elongated pits.

settlement reconstruction at Tolna-Mözs. Based on these data, we are optimistic that the magnetic data indicate the number of houses and their orientation rather precisely, and thus allow a reconstruction of the settlement structure.

Beside the elongated pits in the southern area, circular anomalies with a diameter of c. 1–4 m are found in clusters. Their distribution clearly differs from the anomalies of the LBK settlement. These anomalies can most likely be dated to the Bronze Age *(Fig. 30.4)*.

Further anomalies of probable settlement pits were found in the south-western area. Traces of a rectangular ditch system are clearly detectable on the plateau's western slope. Their continuation towards the west is not preserved, as it is cut by the slope and very likely eroded. The eastern half is clearly visible, with an entrance in the north-east *(Fig. 31.2)*.

Analysis of the magnetic anomalies *(Figs 32–34)*

As noted above, the magnetic contrast of the elongated pits varies. The 0.5 nT contour line was calculated for their majority *(Fig. 32)*. The main orientation of elongated pits is north-east to south-west with slight deviations. In some areas, the elongated pits overlap, possibly indicating several construction phases. The superposition is limited to larger house clusters and areas with a possibly higher density of houses. The variation in the building density and in the size of the house clusters might correlate with the duration of the occupation in the area.

The kernel density estimation (KDE) method was used for the analysis of the distribution of the anomalies and their density. A radius of 80 m was used to identify the more general structure. A clear tendency is visible in the difference of the distribution of the elongated pits and the settlement pits *(Figs 33–34)*.

Houses and house clusters *(Figs 35–36)*

In the wake of the large-scale excavation and the extensive geomagnetic prospection, some 150 buildings arranged in eleven house groups could be identified during the preliminary assessment of the data. Three of these could be correlated with the three house groups investigated during the excavation. One smaller and two larger house groups lay in the settlement's south-western part, while another house group could be identified west of the excavated area. According to the first model, the settlement's northern part was made up of four other house groups located east of the excavated area (Rassmann et al. 2015a; 2015b).

In the present study, the KDE with a radius of 80 m indicated seven groups, whereas a radius of 60 m leads to a more detailed visualisation of the internal structure of the house groups *(Figs 34–35)*. The house groups in part conform to the groups of the previous model, while others are actually made up of several earlier groups. A total of 186 buildings could be identified *(Fig. 36)*.

The seven house groups are not evenly distributed on the plateau. We assume three larger occupied areas. The largest occupied area on the northern plateau with an area of 19 ha consists of four house groups: The smallest of these is located in the south-east (3.2 ha), which has a single house group, while a third occupation area of 7.7 ha and two house groups can be found in the south-west. The overall size of the plateau is 45 ha, but the settled area is only 30 ha.

The size of the seven house groups varies from 1 ha to 5.6 ha. It can be reconstructed that each house group comprised between 4–63 houses.

The largest group of 63 houses (no. 2) is located in the north and the second largest of 46 buildings lies in the south (no. 7), indicating an occupation of several house generations.

The geomagnetic data can be combined with the excavation results to produce an initial model of the settlement size and its development. The chrono-typology of the ceramic assemblage from the excavation indicates a chronological shift within the houses from south to north (Marton / Oross 2012, 232 f.). The earliest houses (reflecting various late Starčevo traits and the strongest Vinča impact in the pottery) were located in the southern excavated house group. The central excavated house group is generally characterised by Bíňa-Bicske-style finds. Assemblages associated with some of the northern houses included Bíňa-Bicske ceramics, while other house units of that group could be dated on the strength of their Milanovce-style material. Finally, some houses in the same group were erected in the later LBK period as shown by sherds with Keszthely- and *Notenkopf*-style ornamentation.

We can interpolate these observations onto the house groups detected in the magnetic prospection with a certain degree of probability. We conducted several field surveys on the site as part of an ongoing research project focusing on the period's southern Transdanubian communities. Our preliminary findings confirm that the site was a long-lived settlement occupied during several successive generations dating from the final third of the 6th millennium cal BC and that the buildings of the northern settlement section are probably later than some house groups of the southern section. We opened a small sounding in the settlement's northern part in 2016 in a location with a house to clarify its stratigraphy, in the course of which we could also confirm the reliability of the data gained from the magnetic prospection.

The geomagnetic survey results have contributed greatly to our general understanding of the spatial organisation of this LBK settlement. Certainly, cross-comparison with the excavation results will help to draw more detailed conclusions about the structures that were made visible by the magnetics. In the future, the evaluation of the excavation findings, combined with the results of a radiocarbon dating programme, will offer an excellent verification of the geophysical prospections in terms of the temporal structure of these house groups. The fact that the magnetic prospection was conducted over large areas on the periphery of the LBK settlement confirmed our reconstruction. The comparison with the digital elevation model (DEM) indicates a clear correlation (cf. *Figs 35–36*). The settlement area is precisely limited by the flooded area, well visible also on the historical maps: the Josephinian cadastre and Franciscan cadastre *(Fig. 37)*.

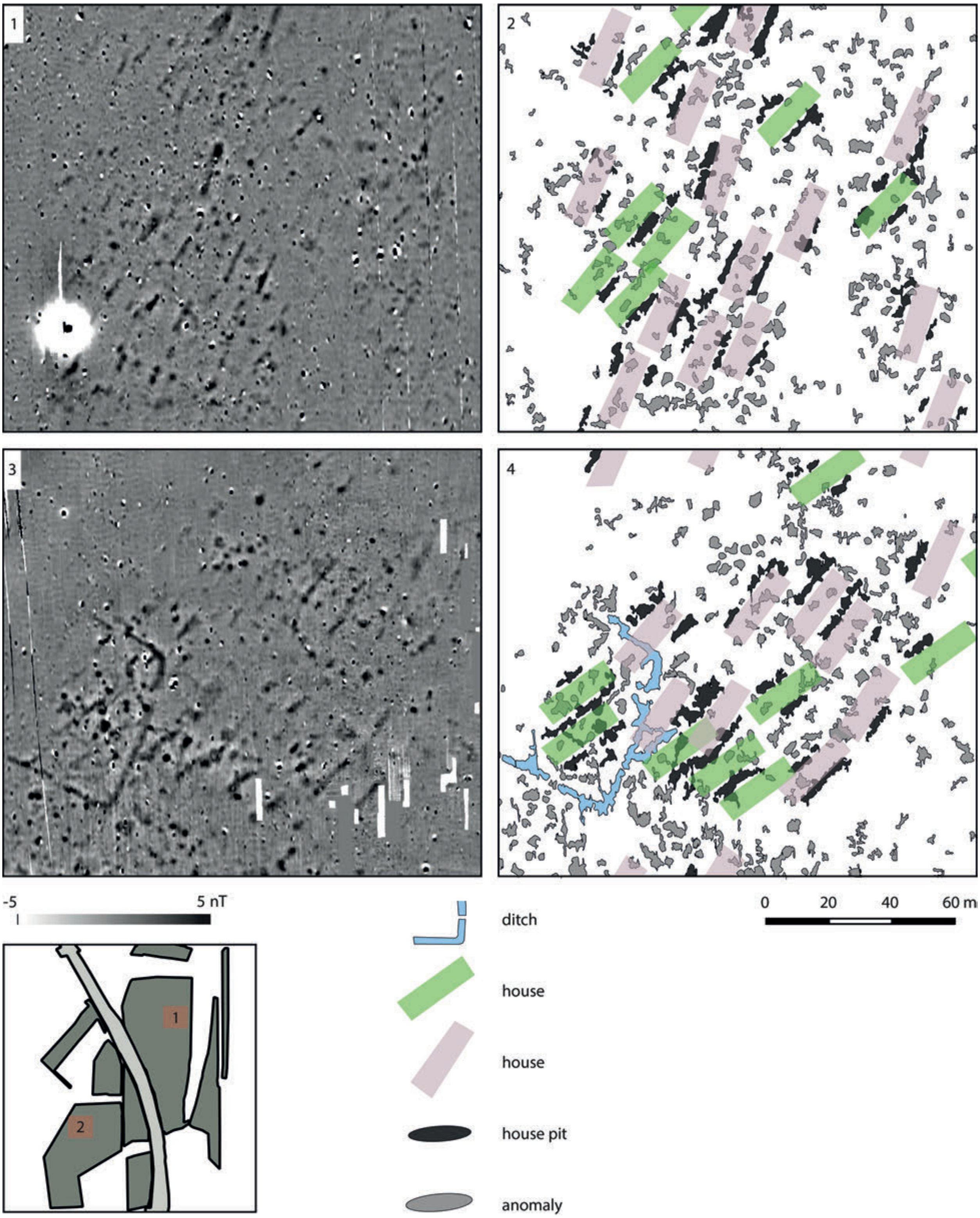


Fig. 32. Tolna-Mözs-Községi-Csádés-földek. Reconstruction of differently oriented houses. 1–2 North-eastern area; 3–4 south-western area.

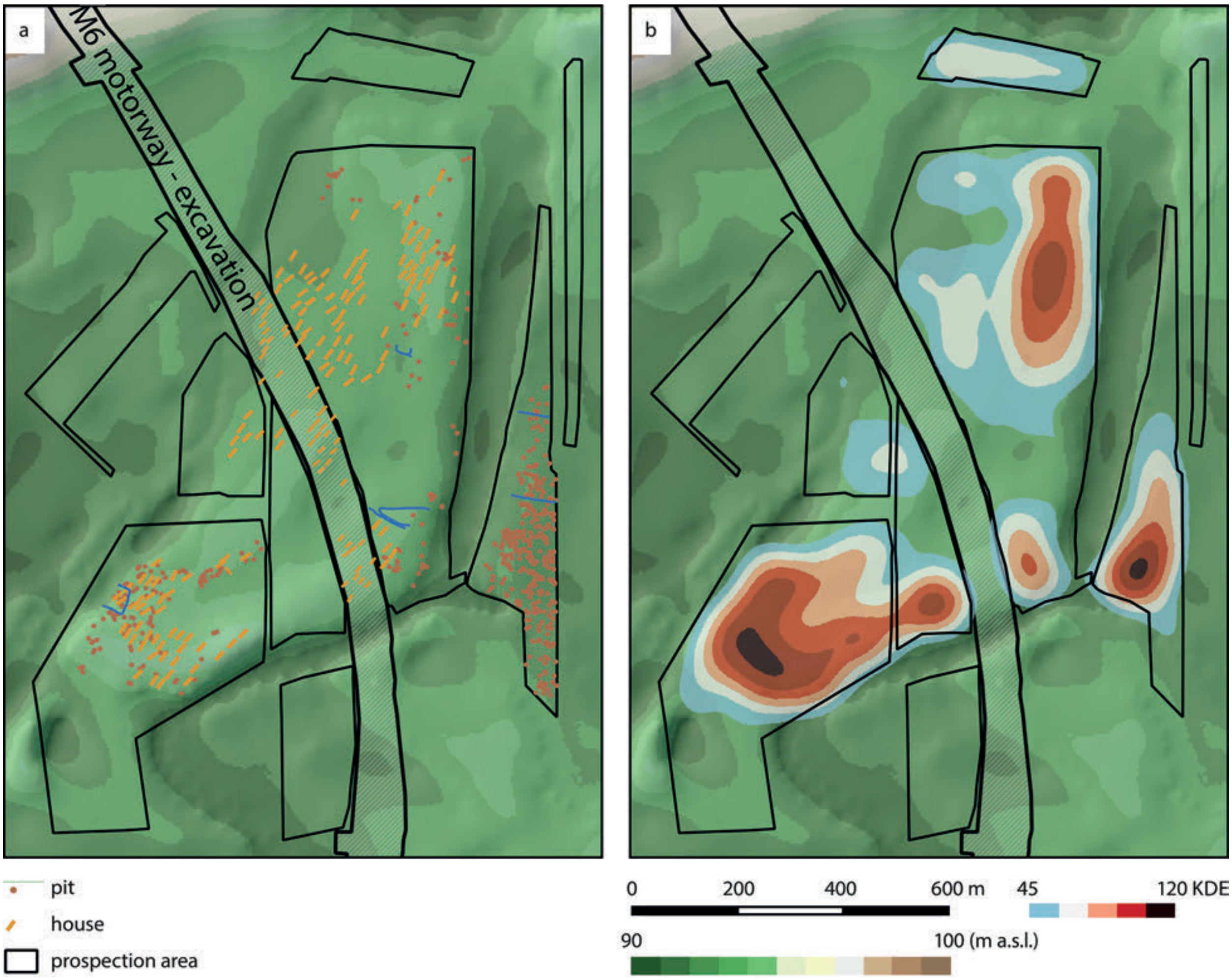


Fig. 33. Tolna-Mözs-Községi-Csádés-földek. Interpretation of the magnetic prospection. a Settlement pits and houses of the LBK settlement revealed by the excavation and magnetic prospection; b kernel density estimation (KDE) (r 80 m) of all magnetic anomalies: size 2–50 m^2; mean 1–10 nT.

The spatial structure of the LBK settlement: An approach from southern Transdanubia

In the previous sections, we deliberately used the neutral 'house group' expression for describing the spatial patterning of the houses and features identified during the excavation and the geomagnetic prospection. For a long time, the independent homestead model (yard model, *Hofplatzmodell*) elaborated for the Rhine region in Germany was the generally accepted model for describing the development of LBK settlements and for establishing the sequence in which the houses were erected (Boelicke et al. 1988; Zimmermann 2012). The settlement row model *(Zeilensiedlungsmodell)* challenging the former model and highlighting some of its contradictions was essentially based on the visual inspection of site plans and lacked detailed chronological confirmation (Rück 2007; 2012). It nevertheless became clear that the independent homestead model could not be applied to certain easterly regions of Central Europe (Lenneis 2012).

We found that on the settlements investigated in Transdanubia, the groups made up of three to seven houses were generally arranged in rows. The term 'house clusters' aptly describes these groups. Although house clusters are not necessarily made up of contemporaneous buildings, they do broadly date from the same period, and some were certainly occupied at the same time.

Several adjacent house clusters form a settlement part, which can be most aptly be described as a 'ward' as defined by Pieter van de Velde in the final report on the LBK settlement at Geleen-Janskamperveld (van de Velde 2007), while one or more wards make up a larger occupation area. One of the major findings of the magnetic prospections conducted at the Tolna-Mözs-Községi-Csádés-földek site is that they provide an outline of the various levels of the site's spatial organisation and that the observations conform to other regional patterns.

The diverse landscape offered prehistoric societies various resources for animal husbandry, farming, hunting, and fishing. However, the availability of arable land on

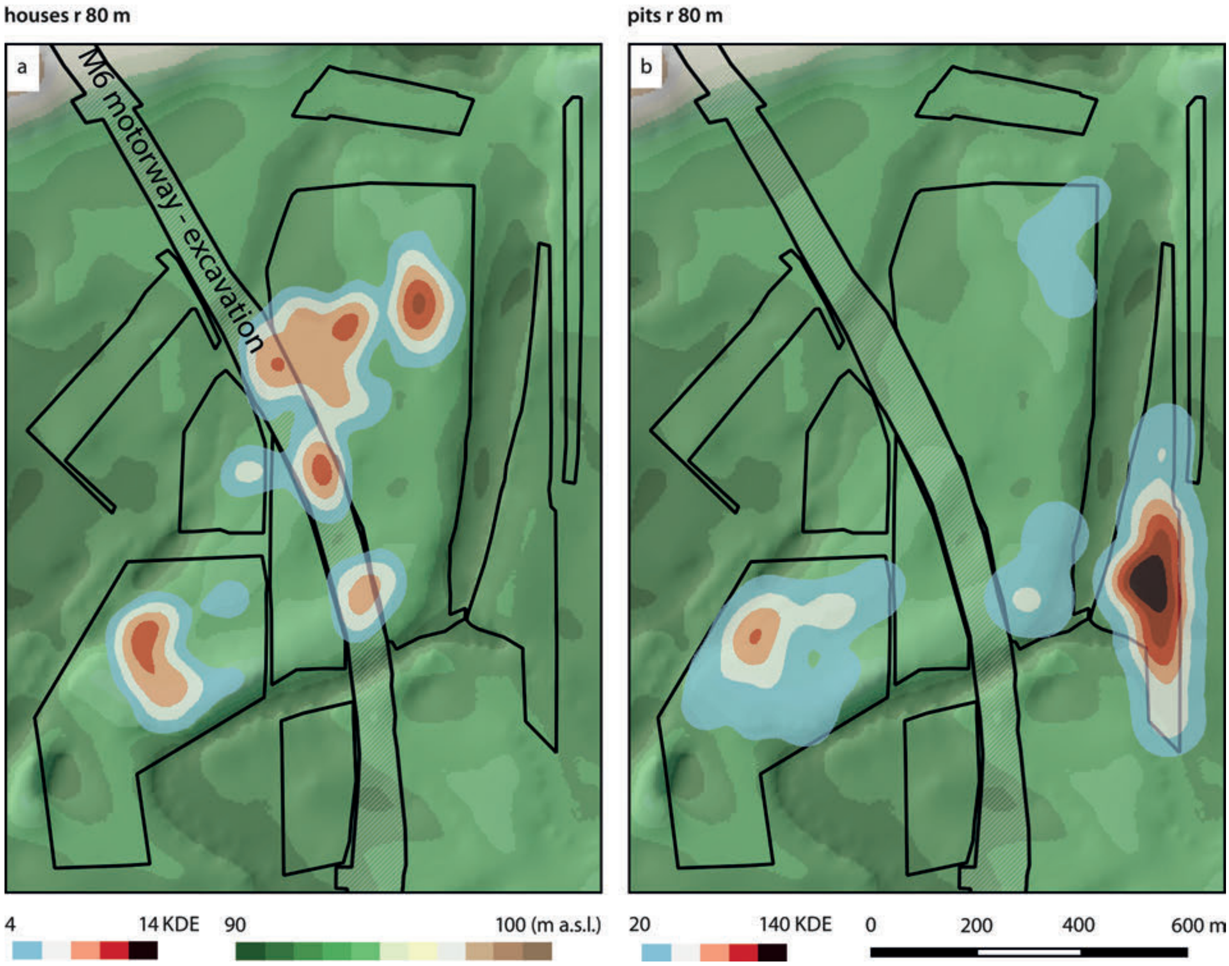


Fig. 34. Tolna-Mözs-Községi-Csádés-földek. Kernel density estimation (KDE). a Houses revealed by the excavation and magnetic prospection (KDE r 80 m); b pits revealed by the magnetic prospection (KDE r 80 m).

the floodplain was limited. This presumption should be investigated in more detail using archaeobotanical data.

Alsónyék-Bátaszék

Location, topography, and archaeological research

Alsónyék-Bátaszék in the Sárköz region, the fourth site investigated within the framework of the joint project of the RGK and the Institute of Archaeology (in cooperation with further institutions), is not a single site, but rather a site complex *(Fig. 38)*. It has a very long sequence of occupation, from the first farmers' settlement in the 58th century BC over the entire span of the Neolithic until the final phase of the Lengyel culture in the 44th century BC. The right bank of the Danube is covered with waterlogged floodplains dissected by oxbow lakes up to the Szekszárd Hills that are often under water in wet periods. Alluvial terraces aside, this was the only land suitable for farming since the lower-lying areas were covered with gallery woods (cf. Sümegi et al. in this volume with further literature).

Similar to Tolna-Mözs, Alsónyék was investigated in the course of the M6 motorway project between 2006 and 2009. Several parts of the site complex, initially considered to be different sites, began to be excavated separately, but eventually the individual segments for the Lengyel period proved to belong to one single huge settlement with an extent of 80 ha. About one-third, 250 000 m^2, of this vast area has been excavated; a series of publications has already appeared and many more are currently in preparation (e. g. Zalai-Gaál / Osztás 2009b; Zalai-Gaál et al. 2012; Bánffy et al. 2010; Osztás et al. 2012; Bánffy 2016 and the entire volume 94 of the Bericht der RGK, published in 2016).

Without speaking of later (scattered) occupation phases, the Starčevo, LBK, Sopot, and Lengyel settlements alone are represented by more than close to 15 000 features and over a million finds. The post-excavation work and especially the evaluation are still ongoing and will last for another few years. Meanwhile, Alsónyék was

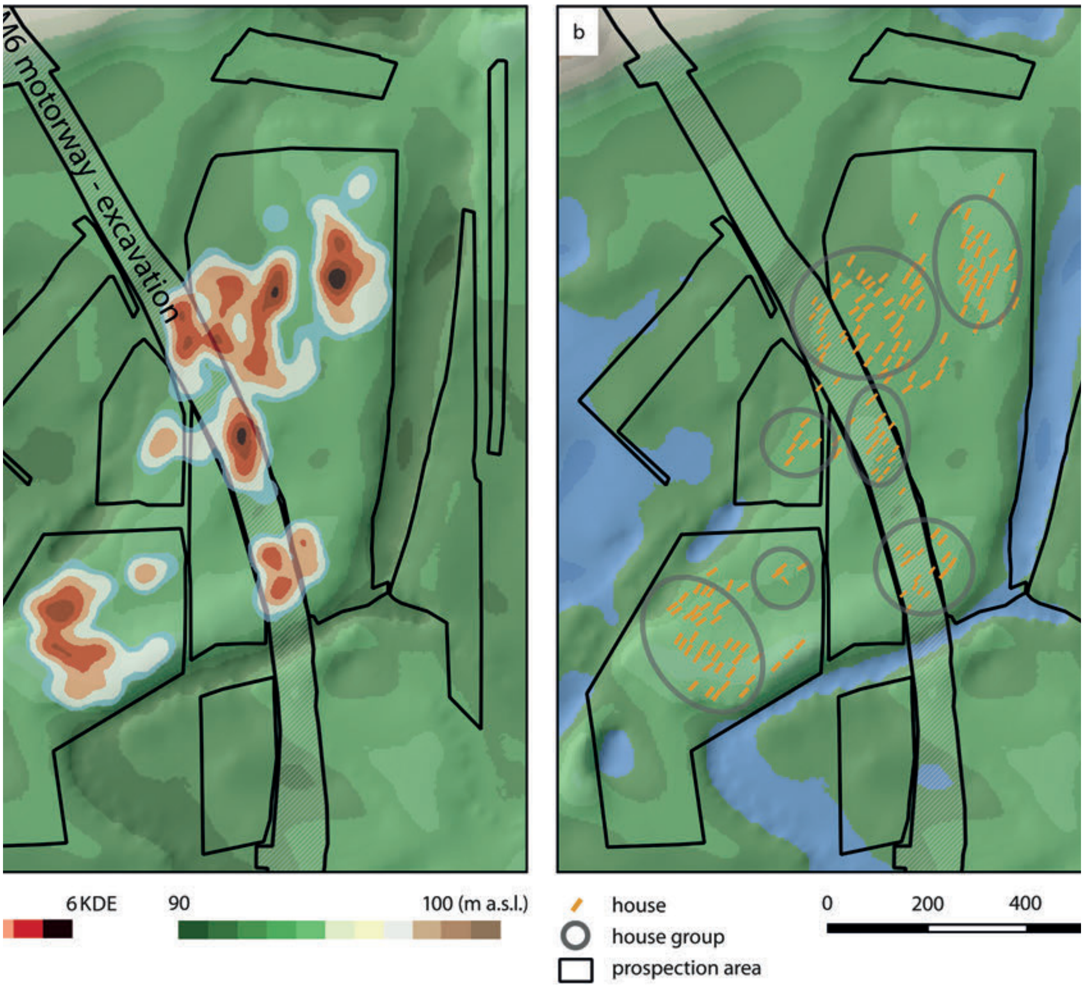
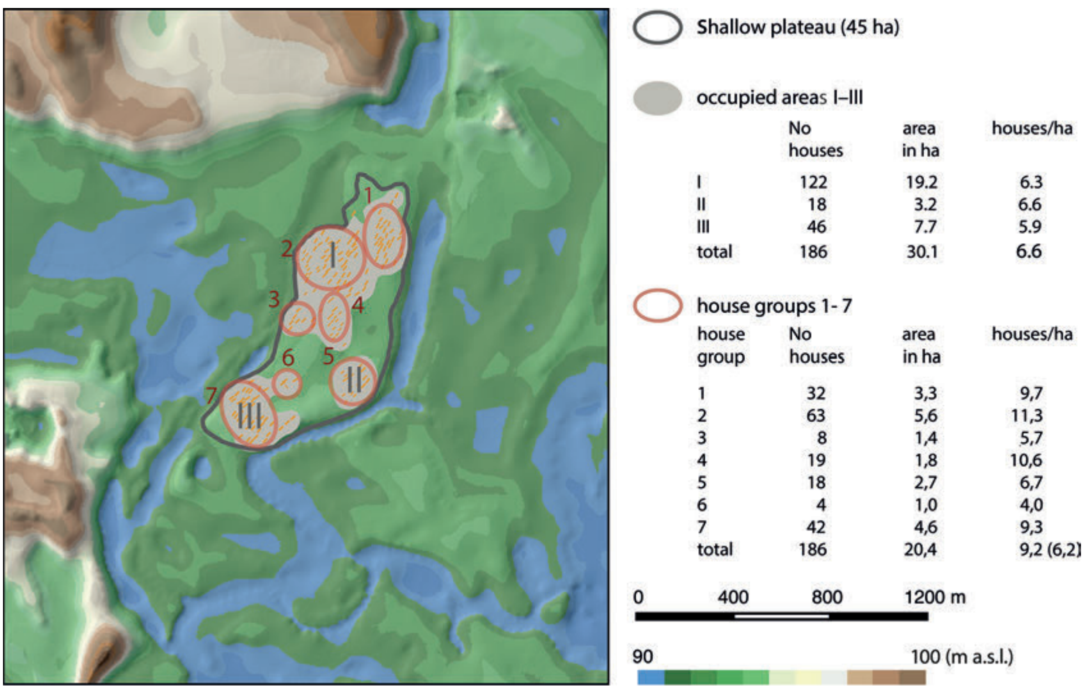


Fig. 35. Tolna-Mözs-Községi-Csádés-földek. Interpretation of the magnetic prospection. a Kernel density estimation (KDE) (r 60 m) of the houses revealed by the excavation and magnetic prospection; b houses and assumed house clusters.



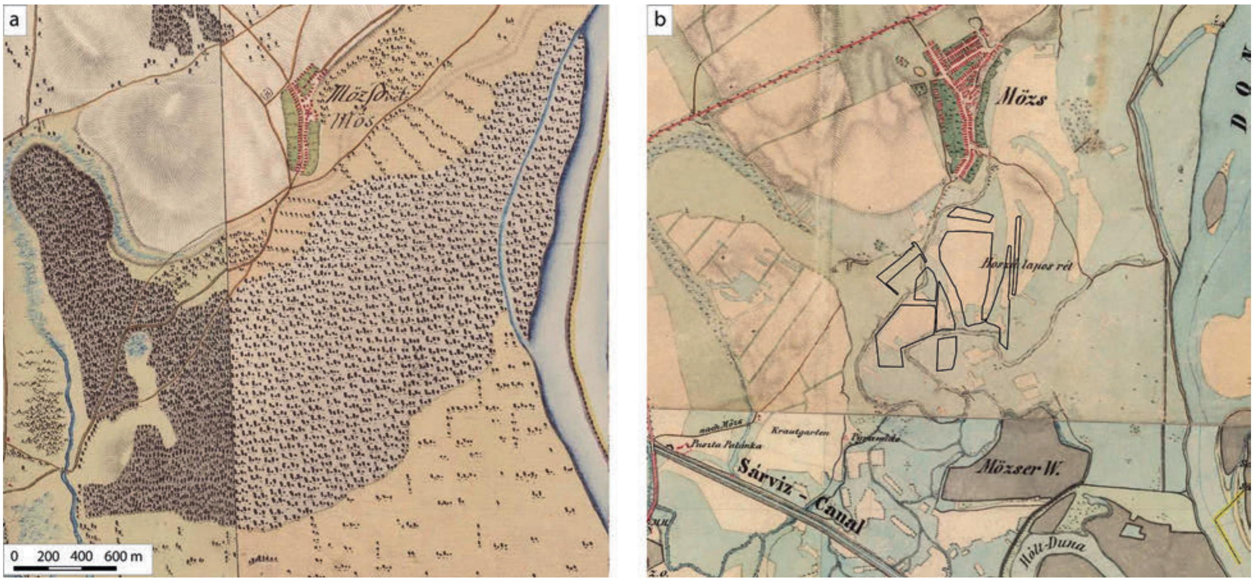
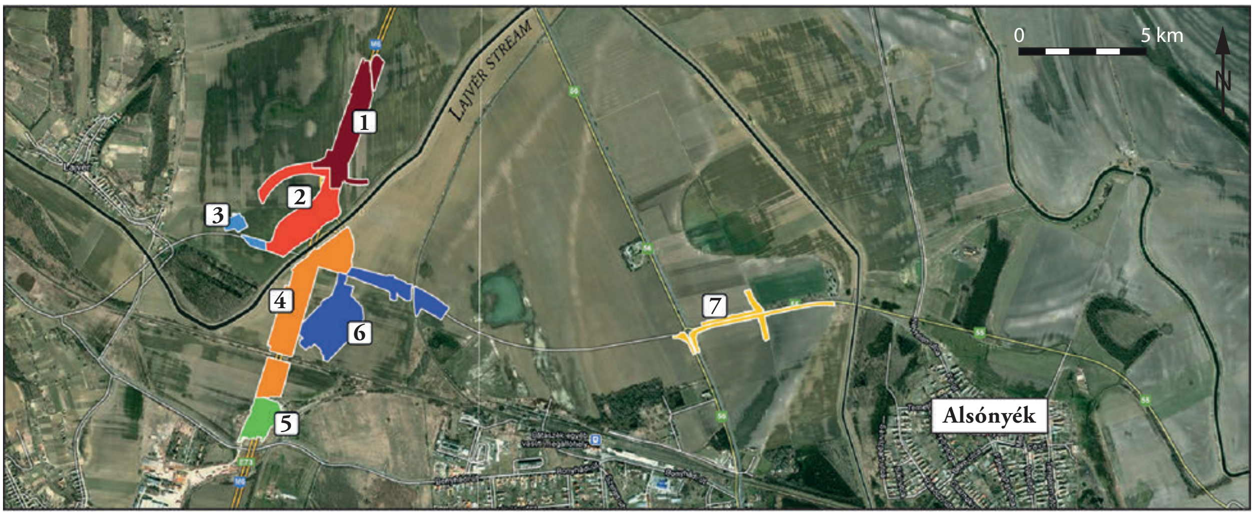


Fig. 37. Tolna-Mözs-Községi-Csádés-földek. Historical maps. a Josephinian cadastre 1782–1785; b Franciscan cadastre 1806–1869 with magnetic prospection areas.



Areas	Subsites	Name of excavated areas	Excavation team
1	10B	Alsónyék-Kanizsa-dűlő (M6 TO 10/B)	Institute of Archaeology of HAS-Archeosztráda Ltd., led by Anett Osztás and István Zalai-Gaál (2006–2008)
2	10B	Alsónyék-Kanizsa-dűlő (M6 TO 10/B)	Ásatárs Ltd., led by Zsolt Gallina (2006–2007)
3	46	Lajvérpuszta (M6 TO 046)	Field Service for Cultural Heritage, led by Vera Majerik (2008–2009)
4	11	Bátaszék-Malomréti-dűlő (M6 TO 11)	Ásatárs Ltd., led by Péter Hornok and Zsolt Gallina (2006–2007, 2009)
5	11	Bátaszék-Malomréti-dűlő Magtár (M6 TO 11)	Field Service for Cultural Heritage, led by Vera Majerik (2008–2009)
6	5603	Bátaszék-Mérnökségi Telep and Bátaszék-56-os út (M6 TO 5603/1)	Institute of Archaeology of HAS-Archeosztráda Ltd., led by Anett Osztás (2008–2009)
7	5603/2	Alsónyék, Hosszú dűlő (M6 TO 5603/2)	Wosinsky Mór County Museum, led by János Gábor Ódor (2008–2009)

Fig. 38. Alsónyék. Plan of the excavations, and the areas and subsites covered by the different excavation teams.

◁ Fig. 36. Tolna-Mözs-Községi-Csádés-földek. Interpretation of the magnetic data. Reconstruction of the LBK settlement. The main groups (I–III) are based on the general structure of the kernel density estimation (KDE) of the houses with a larger radius of 80 m. The smaller house groups resulted from the KDE of the houses with the smaller radius of 50 m.

the focal area of the three research grants mentioned in the introductory part and several MA and PhD theses will evaluate parts of the material.

The earliest Neolithic inhabitants were the early farmers arriving from the northern Balkans. Besides smaller settlement traces (probably 5775–5525 cal BC; 68 % probability), the Starčevo settlement lies in the eastern part (named as 5603), and this settlement section provides the most data for the evaluation. The irregular pits, often large pit complexes, contained not only vast amounts of pottery and animal bones, but also over 2 t of burnt daub, many with imprints of the timber structures of the houses. Lying among these features were some 30 burials, some placed in niches into the side walls of pits. This rich skeletal material became the basis of scientific analyses, including pathology, isotope analyses (Depaermentier et al. submitted), and DNA.

The only gap in the Neolithic sequence at Alsónyék is before the LBK occupation. The most probable reason for this is that the culture's formative period is attested north of the Sárköz (Bánffy 2004); accordingly, the start of the Alsónyék LBK occupation represents the early, but not the earliest LBK phase (start: Alsónyék LBK settlement, probably 5335–5280 cal BC; 68 % probability). The entire LBK settlement comprises a total of 50 longhouses with flanking pits located in the centre of the excavated area. Notably, the Alsónyék LBK site is not only one of the most southerly settlements of this phase, but the material is imbued with early Vinča elements, a phenomenon that deserves a special attention (see Jakucs et al. 2016; 2018).

The Sopot phase at Alsónyék reflects the heritage of a migrant group arriving from the northern Balkans with somewhat different burial customs and material culture (probably 5095–4750 cal BC; 68 % probability). Very interestingly, as was demonstrated in the 2016 report on the absolute chronological position of the Sopot occupation, the Sopot settlement appears to have been synchronous with the latest LBK houses and was located fairly close to the earliest Lengyel feature. This chronological position of the Sopot group largely confirms the archaeological evidence that the early Lengyel culture stems mostly from the late LBK, although it evolved under strong southern impacts. The Sopot occupation at Alsónyék is east of the central excavated area and its discovery was due to the construction of a slip road leading to the motorway. The small excavated section yielded some burials, remains of an enclosure of four parallel ditch sections and also a well, while the complementary geomagnetic prospections revealed much of the occupation pattern.

The Lengyel settlement and cemetery, spanning the earlier 5th millennium BC (from c. 4800–4600 cal BC to until c. 4400 cal BC in some areas), proved to be not only the largest and most intensive occupation phase at Alsónyék, but also by far the most extensive Lengyel site as well as one of the largest Neolithic sites in Europe. The excavated part of the site brought to light 122 robust houses and more than 2300 burials. Lengyel features dotted the eastern, Starčevo part of the site; the southern part was also occupied, but the most intensive part of the settlement is in the north called 10B *(Fig. 38)*. Typically, the humus layers also contained features, and thus the upper layers had to be removed by the machines twice. The graves formed clusters in various parts of the settlement, ranging from a few dozen burials to nearly a hundred. The grave goods shed light on an extremely broad exchange network extending across Europe: obsidian knives from the Tokaj-Zemplén Mountains, Spondylus jewellery from the Mediterranean, jadeite axes from the western Alps, and flint raw materials from nearly all directions (Biró et al. 2017; Szilágyi 2019). Even copper items were found in the latest graves. Some of the richest burials revealed a unique, unparalleled feature, a 'house of the dead' erected over the grave, with four robust timber posts at the corners. In the light of these unique phenomena, it was an exciting challenge to see how the non-invasive methods would enrich the information on the unexcavated areas of this extraordinary site. The present report focuses on the areas that lay beyond the motorway track, and thus remained intact.

Magnetic prospections on the site complex of Alsónyék-Bátaszék

Diagnostic fieldwork and large-scale excavations were carried out at Alsónyék-Bátaszék by the Institute of Archaeology, in cooperation with the Tolna County Museum. These archaeological investigations covered both the main route of the M6 motorway as well as the slip roads north of the village of Bátaszék. Settlement remains and graves from different historic periods were discovered in the road construction area.

The largest excavations took place along the M6 motorway at Alsónyék-Kanizsa-dűlő (areas 1 and 2), Lajvérpuszta (area 3), Bátaszék-Malomréti dűlő (area 4), and Bátaszék-Mérnökségi Telep (area 6). The north-western excavation site of Alsónyék Kanizsa-dűlő (areas 1 and 2) was dominated by remains of the Lengyel culture (Bánffy et al. 2014; Osztás et al. 2016a; 2016b), while numerous features of the Starčevo culture and the LBK were excavated in addition to the remains of the Lengyel culture at the south-western excavation site of Bátaszék-Malomréti dűlő (area 4) and Bátaszék-Mérnökségi Telep (area 6). A settlement of the Late Neolithic Sopot culture was discovered at a distance of c. 1.5 km from Alsónyék, Hosszú dűlő (area 7; *Fig. 38*).

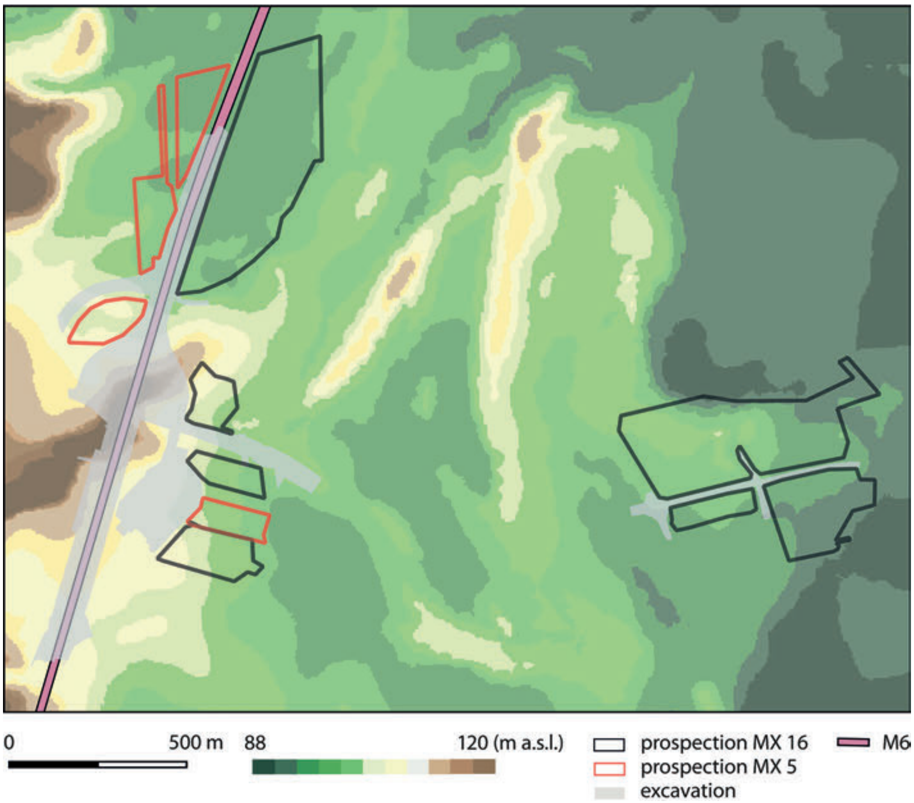


Fig. 39. Alsónyék. Overview of geomagnetic prospection areas examined between 2011 and 2014. Base map DEM.

The overall investigated area of both excavation areas follows the road construction. It opens a valuable transect on prehistoric sites of different periods in the region. While the large-scale excavations enriched our knowledge of the Neolithic and Late Neolithic in western Hungary, some questions have remained unanswered such as, for example, the crucial one of how far the settlement areas continued into the unexcavated areas. Further research in the peripheral areas of the rescue excavations is needed to answer the latter question. Large-area magnetic prospection was used to enrich our knowledge in this respect.

The magnetic prospection in Alsónyék was organised in the context of our investigations in Tolna-Mözs and Fajsz. It was conducted from November 15 to 17, 2011, on March 7, 2013, and from February 4 to 6, 2014 (Serlegi et al. 2013; Rassmann et al. 2015a; 2015b). Our prospections provided data for the periphery of both excavation areas (nos 1–7; *Figs 38–41*) and covered almost the entire periphery of area 7 in the east. Regarding the surroundings of the excavation on the M6 motorway (areas 1–6; *Figs 38–39*), the magnetic data are representative of the eastern and north-eastern periphery of the excavation area. There is still a gap south-westward of the M6 motorway excavation *(Fig. 39)* due to the fact that we did not have access to the fields.

The prospections in 2011 and 2013 using the 16-channel system covered 40 ha in total. When we returned in 2014, we operated with the 5-channel equipment on smaller areas of around 7 ha *(Fig. 39)* in the north-west and on the northern periphery. The magnetic data revealed numerous archaeological features (e. g. a ditch – *Fig. 41.1*) correlating with the excavated ones.

The Starčevo settlement at Bátaszék-Mérnökségi telep (area 6)

The southern portion of the rescue excavations brought to light numerous pits that can be dated to the Early Neolithic Starčevo culture (Osztás et al. 2016a, 12 f. fig. 4; Oross et al. 2016a, 102 fig. 5). The settlement features of the Starčevo culture are concentrated in clusters. Numerous features consist of burnt clay, especially of oval ovens (Bánffy et al. 2010, 42 fig. 6). Archaeological features of burnt clay are usually easily detectable in magnetic prospections. In the course of the present work, we opened four windows onto the southward lying area in addition to the excavations *(Fig. 40)*. The size of the prospected areas ranges from 1.5 ha to 2.8 ha. The southern prospection area of 2.8 ha is immediately adjacent to the excavated Starčevo settlement. Inside

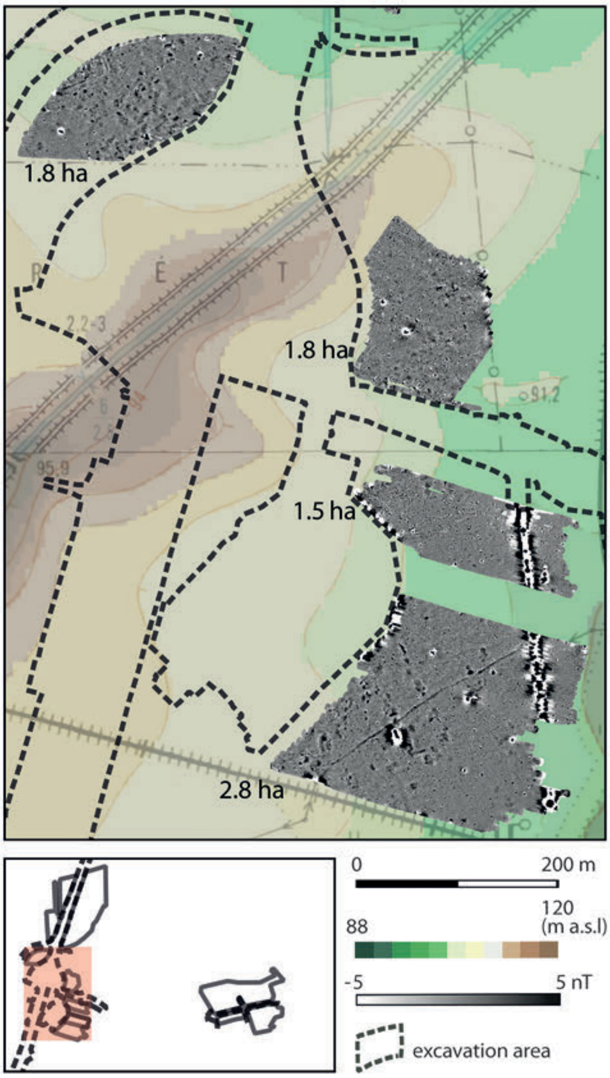


Fig. 40. Alsónyék. Alsónyék-Kanizsa-dűlő (area 2), Bátaszék-Malomréti dűlő (area 4), and Bátaszék-Mérnökségi Telep (area 6). Overview of the eastern prospection areas showing anomalies mainly connected to the LBK (north) and the Lengyel culture (south). Base map DEM.

this prospection area, more than 1000 anomalies can be interpreted as archaeological features *(Figs 41–42)*. The majority of these features can be assigned to the Early Neolithic with a high probability.

Irregularly shaped anomalies with higher magnetic amplitudes (nT) have the highest probability of belonging to the Starčevo culture (c. 3–15 nT). The excavation on the Starčevo settlement brought to light many structures such as the above-mentioned ovens and indefinable house remains of burnt clay (Bánffy et al. 2010, 38 fig. 1). The analysis of the burnt structures, specifically of the burnt daub, is part of an ongoing research project (Bánffy / Höhler-Brockmann accepted). There are indications that some of the daub came from houses. However, the form and layout of the houses remain to be clarified. The distribution of the architectural features in the excavation is largely uneven. There are some indications for paths (linear corridors without archaeological features) and clusters of obviously archaeological features. Similar patterns can be discerned in the magnetic data. Irregular, large anomalies with a size between 2 and 20 m^2 are the most characteristic. These anomalies are characterised by a mean magnetic amplitude of 3–5 nT *(Fig. 42c–d)*, the maximum often surpassing 8 nT.

A linear ditch is clearly visible in the prospection area. The ditch is interrupted by a small gap *(Fig. 41.1)*. The gap is accompanied by a semi-circular ditch. Both elements indicate an entrance. There are three other circular anomalies in the same area. At first glance, the distribution of the circular anomalies does not appear to have any spatial order. However, a kernel density estimation (KDE) revealed two concentrations and one area with a higher density around the entrance *(Fig. 42c–d)*. A correlation might indicate they are contemporaneous with the ditch.

The fact that the ditch crossed the anomalies of the Starčevo culture directly indicates a later, Lengyel period date for this structure (Osztás 2019).

One crucial question that might be answered by the magnetic prospection concerns the size of the Starčevo settlement. Considering the noise in the data and the uncharacteristic distribution of the anomalies, the spatial analysis by KDE is obvious (cf. *Fig. 42*). Therefore, we used the standard workflow as applied to the data from Fajsz and Tolna (cf. *Fig. 6*). By processing the 1 nT polygons, we count 983 anomalies with an area upwards of 1 m^2. When using the centroids of these objects for the KDE, two concentrations become evident. The KDE was calculated using all filtered anomalies on the map as shown in *Figure 42*. The KDE used a radius of 40 m and was weighted by the size of the magnetic anomalies. One small area with high density is located around the entrance of the ditch and a second one in continuation of the excavated Starčevo settlement.

The well visible area with the higher density of anomalies is precisely in the continuation of the excavated Starčevo settlement. The picture becomes clearer by mapping selected polygons larger than 2 m^2 and maximum magnetic amplitudes higher than 5 nT. We can note a clear correlation between these anomalies and the KDE map. Obviously, the majority of the filtered anomalies correlate with the settlement area of the Starčevo culture *(Fig. 42)*. The magnetic data allow for an optimised reconstruction of the settlement area. When integrating the excavation data and the results of the magnetic prospection, the size of the settlement area can be estimated as 5.8 ha.

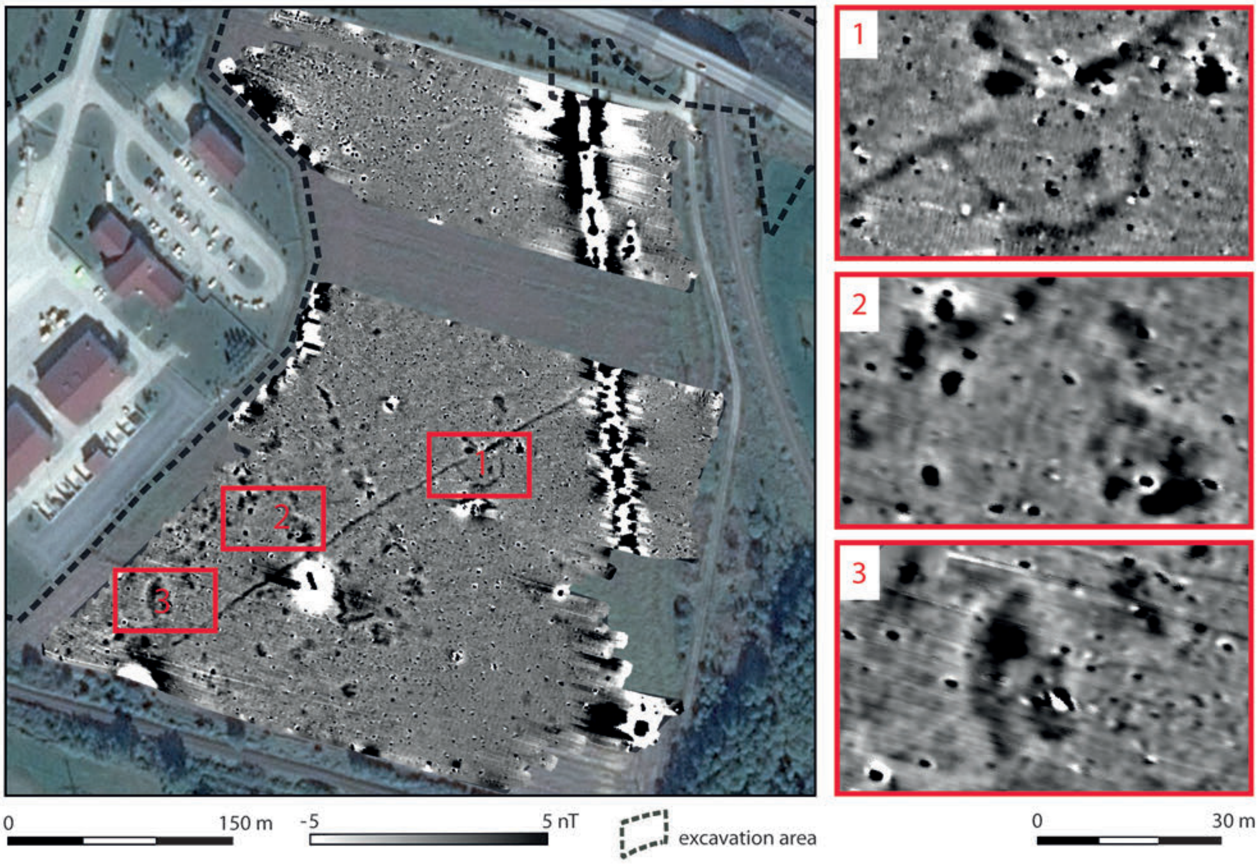


Fig. 41. Alsónyék-Bátaszék-Mérnökségi Telep (area 6). 1 Linear magnetic anomaly and an entrance-like feature; 2–3 irregular magnetic anomalies, presumably features of the Starčevo culture, possibly caused by burnt clay.

The magnetic data are too noisy for answering any further questions on the internal spatial structure of the settlement. However, there is a potential to gain a greater insight by the use of other non- or minimum intrusive methods such as soil chemistry in combination with drillings and geophysical methods such as ERT (electrical resistivity tomography) and GPR (ground penetrating radar). These are useful methods for which an appropriate excavation and fieldwork design should be developed.

The Linearbandkeramik (LBK) settlement near Alsónyék-Kanizsa-dűlő (area 2) and Bátaszék-Malomréti dűlő (area 4)

Numerous LBK features could be identified in the central part of the rescue excavation on the M6 motorway construction site (Oross et al. 2016b, 124–130) as shown by the overview map *(Fig. 43)*. The settlement remains of the LBK extend from area 2 and in the northern part of area 4. The excavation revealed a large number of elongated pits originally flanking the long sides of the timber framework of the LBK houses. Altogether, 50 of these could be reconstructed, whose majority (46) were found in area 4. Beside the elongated pits, numerous other features were excavated, in part belonging to other periods. Only some postholes correlating with the elongated pits were excavated.

The 46 houses in area 4 formed different clusters consisting mainly of two to four houses (Oross et al. 2016b, 124). One key observation for the reconstruction of the area of the LBK settlement is the remarkable concentration of 90 % of the houses in area 4. The density of LBK features in area 2 is much lower.

The magnetic data from areas 2 and 4 are very noisy. Unlike at Tolna-Mözs, significant structures such as houses or elongated pits are not visible. There are 964 anomalies with an area of 1 m^2 and an amplitude of more than 1 nT. When selecting polygons larger than 2 m^2 and magnetic maxima below 20 nT, only 234 objects remain. However, all of them are uncharacteristic. The methodological challenge is to find indications for the boundary of the LBK settlement in the noisy data. We tried KDE based on the 934 1 nT anomalies, but did not find any significant patterns. Our interpretation of

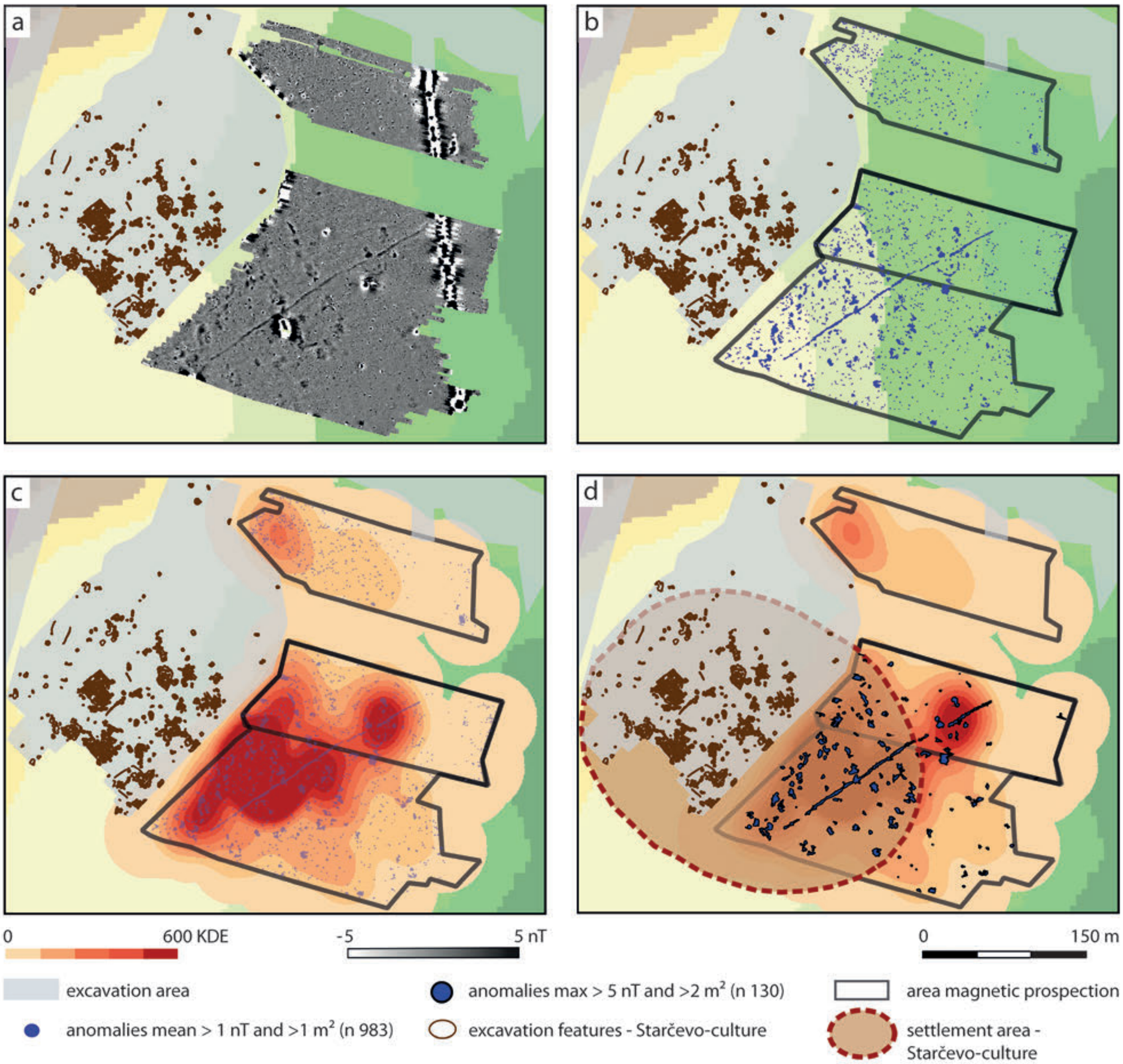


Fig. 42. Alsónyék-Bátaszék-Mérnökségi Telep (area 6). Prospection and excavation data in the south-eastern area showing settlement features of the Starčevo culture and a linear ditch with an entrance. a Excavated settlement features of the Starčevo culture and magnetic data. b Excavated settlement features of the Starčevo culture and the generated anomalies following the 1 nT contour line. c Excavated settlement features of the Starčevo culture and the generated anomalies following the 1 nT contour line and a kernel density estimation (KDE) based on the centroids of the 1 nT anomalies > 1 m^2. d Excavated settlement features of the Starčevo culture and the generated anomalies following the 1 nT contour line with an area > 2 m^2 and maximum magnetic amplitudes > 5 nT, and the estimated area of the Starčevo settlement.

this indefinable picture is that it reflects the overlap of numerous anomalies from different occupation periods from the Early Neolithic to the Medieval period.

In conclusion, there are some uncertainties in our estimate for the size of the LBK settlement area. The lack of elongated pits in the magnetic data might indicate that these areas were one part of the LBK settlement. Based on this assumption, an estimate of around 10 ha is very optimistic, but a much smaller one is more realistic as we can see from the concentration of house remains in the southern part of the excavation area *(Fig. 42)*. A specific weighing of the distribution of the house clusters in the excavation area might lead to a settlement size of 3–6 ha.

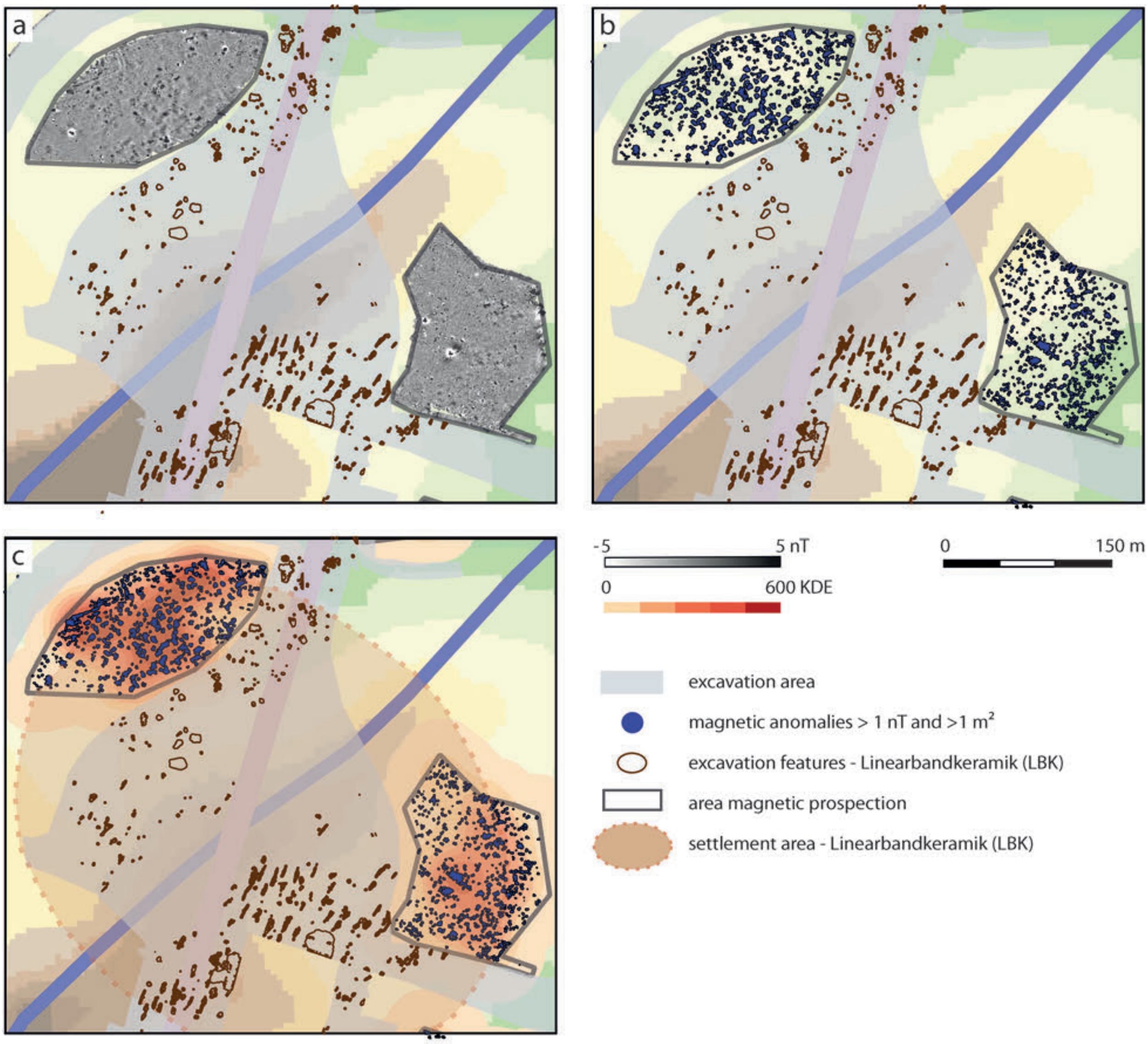


Fig. 43. Alsónyék. Alsónyék-Kanizsa-dűlő (area 2) and Bátaszék-Malomréti dűlő (area 4). Overview of the excavation and the magnetic prospection results of the LBK settlement area. a Overview of the magnetic prospection; b magnetic anomalies with 1 nT and higher with an area > 1 m^2; c kernel density estimation (KDE)-calculation of the magnetic anomalies in comparison to the excavation features of the LBK.

The Lengyel settlement at Alsónyék: Alsónyék-Kanizsa-dűlő (areas 1 and 2), Bátaszék-Malomréti dűlő (area 4), and Bátaszék-Mérnökségi Telep (area 6)

The 15 000 features uncovered during the excavation are dominated by the 9000 features of the Lengyel culture. The richness of settlement features is indicated by the 122 houses whose timber framework is marked by postholes and the nearly 2300 burials of the same period (Osztás et al. 2016b). The majority of the settlement features can be found in the northern part of the excavation area at Alsónyék-Kanizsa-dűlő (areas 1 and 2), Bátaszék-Malomréti dűlő (area 4), and Bátaszék-Mérnökségi Telep and Bátaszék-56-os út (area 6). The magnetic prospection investigated larger areas on the north-eastern and north-western periphery of the Lengyel settlement. Whereas the density of relevant archaeological anomalies is low in the western prospection area, it is high in the north-eastern area.

House remains are clearly visible in the magnetic prospection data *(Figs 44; 45.1–2)*. Their size and shape indicate similarities to the 122 excavated houses. Obviously, the internal structures are much less detailed in the magnetic prospection data, particularly the postholes found in large numbers during the excavation, which

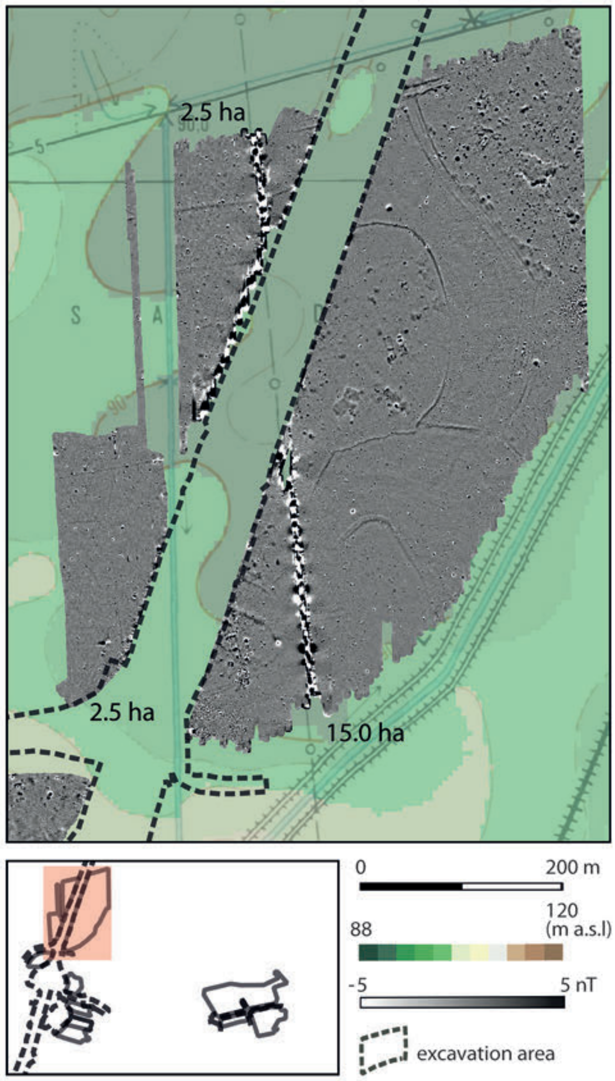


Fig. 44. Alsónyék. Alsónyék-Kanizsa-dűlő (areas 1 and 2). Overview of the magnetic prospection in the north-western areas showing anomalies mainly dating to the Lengyel culture and later periods (Middle Bronze Age?). Base map DEM.

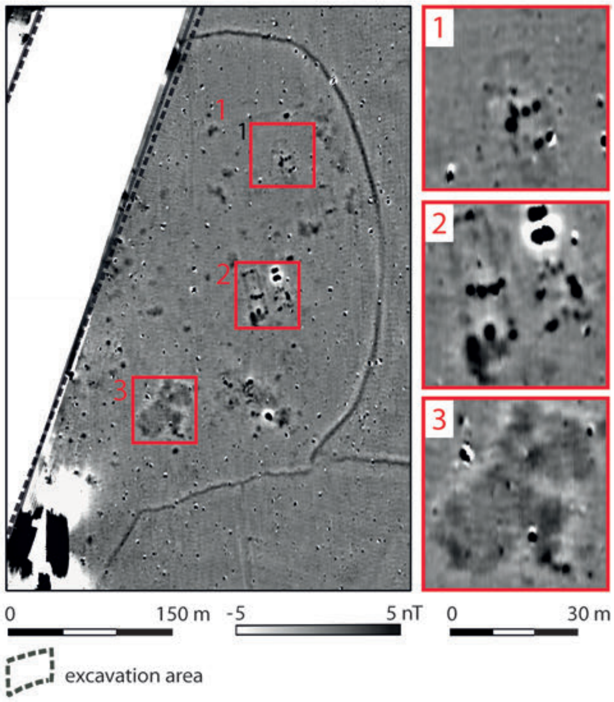


Fig. 45. Overview of the prospection in the north-eastern areas with ditches, house remains, and pits. 1–2 House anomalies; 3 a large structure, possibly a pit for clay extraction.

rarely showed up in the magnetic data *(Fig. 45.1–2)*. Besides the small number of postholes, indications for ovens and linear structures aligned to house walls are visible in the magnetic data. These indicate rows of postholes (Osztás et al. 2016b, 194 fig. 9). Large pits with a diameter between 1.5–1.8 m are clearly visible in the middle of the houses. Their size and position inside the house are similar to the excavated houses (Osztás et al. 2016b, 194 fig. 9).

Further relevant features are indications of pits for clay extraction *(Fig. 46)*. An extraordinarily large structure is visible in the southern part of the north-eastern prospection area *(Fig. 45.3)*. Smaller, similar structures are unevenly distributed. The magnetic contrast is low, some of them are framed by the 0.5 nT contour line. On this level, there is also a lot of indifferent noise *(Fig. 46.1)*. Therefore, the precise identification of the clay extraction pits is difficult, it is more likely for structures larger than 6 m^2 (cf. *Fig. 43c*). Despite some uncertainties, they are clearly more frequent than the houses. An optimistic interpretation of the magnetic data in the north-eastern prospection area allows the reconstruction of a larger number of houses. The number of possible pits for clay extraction is probably more than twice that number. In some areas, we observed a specific correlation between house remains and the occurrence of larger pits *(Fig. 46.1–3)*. In some areas in the north, more pits than houses are evident, the latter observation suggesting that only a part of the house remains are visible in the magnetic data (cf. *Fig. 48* below*)*, and that their real number must be higher.

An exceptionally high number of Lengyel burials were brought to light during the rescue excavation along the M6 motorway (Osztás et al. 2016b, 182 figs 2–3), making the assemblage one of the most important in the European Late Neolithic because of the large number of well-preserved skeletons. The human bodies were buried mainly in grave pits and very rarely in settlement features independent of the houses. Their sizes vary between 2.5–4.0 m^2. Around 2300 graves clustered in 92 burial groups were found (Osztás et al. 2016b, 184). The grave pits contain the skeletal remains and grave inventories, which, however, do not result in a detectable contrast in the magnetic data. Only the refilling of the grave

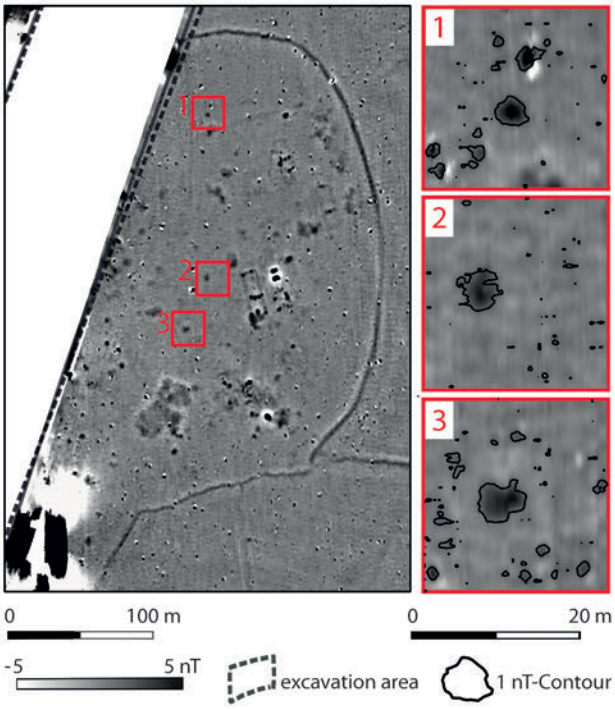


Fig. 46. Overview of the prospections in the north-eastern areas. 1–3 The highlighted areas might indicate clay extraction pits.

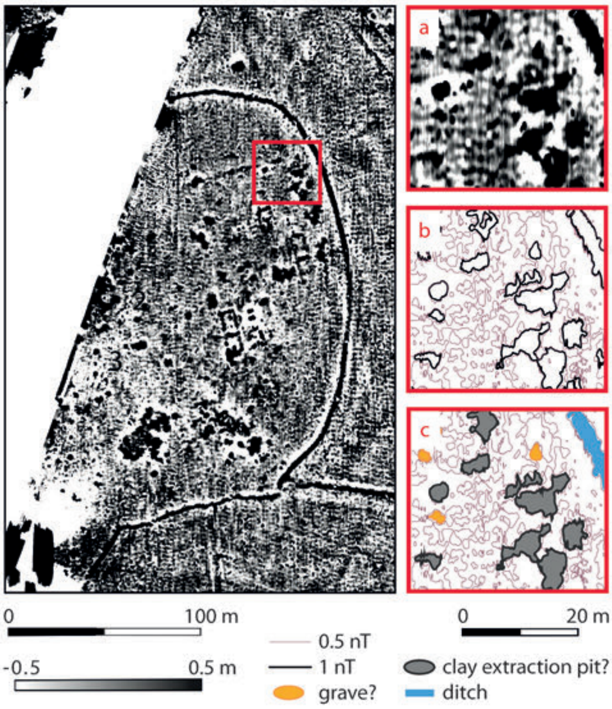


Fig. 47. Overview of the magnetic prospection in the north-eastern areas. Anomalies interpreted as pits. a Magnetic data; b calculated contour lines 0.5 and 1 nT; c interpretation of the anomalies.

pits – sometimes after the later robbing of the graves – might cause a contrast, probably in a similar range of between 0.5–1.0 nT as the clay extraction pits.

Taking the low magnetic contrast features into account, we calculated two contour lines with 0.5 and 1 nT. The 0.5 nT contour line presumably revealed relevant archaeological features. However, these are embedded in a noisy set of more than 30 000 features, which are dominated by indeterminable features reflecting largely extended disturbances of the SUV. This noise is evident as a ripple-line pattern in the data *(Fig. 47)*. It is obviously caused by vertical movements of the magnetometer array or low-current inductions in the magnetometer system. Of higher relevance is the 1 nT contour line. The 1 nT line framed as above reveals large clay extraction pits as well as possible grave pits *(Fig. 47.a–b)*. The latter are much smaller, with a size ranging between 3–6 m^2. There is a small number of c. 30 anomalies inside the ditch. The magnetic contrast is low, with around 1 nT. The difficulties of filtering relevant features from the north-eastern prospection area is evident when considering the relation of the total of around 30 000 anomalies to the number of only about 23 houses, c. 40 clay extraction pits, and c. 30 pits that might classify as grave pits.

Ditches enclosing the house clusters are easier to recognise in the dataset. This might be an indication that the ditches can be dated to the same occupation period, but they may as well date to the Bronze Age.

We may conclude that the house remains in the prospection area are a continuation of the houses observed in the excavation area and that the houses are surrounded by the large ditch. The ditch enclosing the settlement narrows towards the south *(Fig. 48)*.

Analysis of the magnetic anomalies

The features described above as house remains and clay extractions pits are clearly visible in the magnetic data. In order to calculate the area of Lengyel culture settlement, the information acquired with the magnetic prospection and the excavation has to be set into context. Based on the prospection alone, it remains uncertain whether the features can be dated to the Starčevo or the Lengyel settlement phase. The ditch might belong to the Lengyel culture. As a matter of fact, inherent to the magnetic data are uncertainties with respect to dating them. Despite these uncertainties, broad reconstructions are possible.

The graves and the settlement remains indicate different patterns in the excavation area along the M6 motorway. Some of these differences might reflect the specific conditions of the rescue excavation and should be discussed in more detail in the future. However, with respect to the reconstruction of the general spatial pattern, it might be negligible.

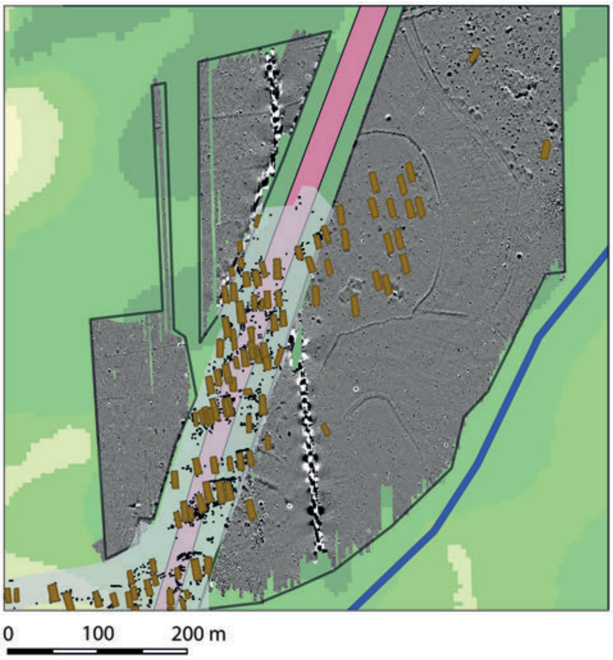


Fig. 48. Alsónyék-Kanizsa-dűlő (areas 1 and 2). Overview of the magnetic prospection in the northern areas showing anomalies mainly from the Lengyel cultures. Base map DEM.

The kernel density estimation (KDE) of the grave centroids indicates groups in the south at Bátaszék-Malomréti dűlő (area 4) and Bátaszék-Mérnökségi Telep (area 6). In the north, at Alsónyék-Kanizsa-dűlő (areas 1 and 2), there is only one large concentration *(Fig. 49a)*[10]. Outside these areas with a high density of graves, some further graves were found during the excavation, but the latter were of a considerably lower density. When evaluating the KDE of the grave centroids, we have to bear in mind that no data from the magnetic prospection were considered. Therefore, the KDE map only provides information based on the distribution in the excavation area.

For house remains, data from both the excavation and the magnetic prospection were processed *(Fig. 49b)*. The house remains of the Lengyel culture are widely distributed in the excavation area. However, in the magnetic data they are only evident in the north (cf. *Fig. 48*). The area with a high density is limited to the northern part at Alsónyék-Kanizsa-dűlő (area 1; *Fig. 49b*).

The differences in the general spatial distribution of graves and houses are clearly evident. Additionally, the KDE map can be used to estimate the general distribution of graves in both settlement areas. The question marks indicate areas around the excavation on the M6 motorway where no magnetic prospection data were available *(Fig. 49c)*.

Based on the KDE for both datasets (graves and house remains), the size of the Lengyel site could be roughly estimated despite some persistent uncertainties. The graves and settlement features are distributed unevenly in clusters. The size of the territory covered by the graves and the settlement is roughly 23.5 ha and 24.0 ha, respectively. Bridging the gaps between the clusters, the Lengyel culture is distributed at least over a total area of c. 47.5 ha. The overall territory might be larger because of the gap in the magnetic prospection data in the southwest.

Undated, presumably Middle Bronze Age features in the north-east

Interestingly enough, no settlement remains were observed in a c. 50 m wide zone in the outer periphery of the ditch *(Fig. 50)*. Besides the clear indications of settlement remains, wide areas without any evidence for archaeological features are visible. The absence of clear settlement features indicates the boundary of the Lengyel settlement eastwards of the excavation area. Behind a double line feature, we found an area with a higher density of circular anomalies, presumably pits, which might originate from the Middle Bronze Age.

The pits are of different sizes *(Fig. 50.1)*, the largest of which is approximately 5 m in diameter, suggesting an interpretation as a storage pit, while the high contrast possibly indicates a secondary function as a refuse pit for settlement waste.

Similar to the area of the Lengyel settlement, some large indifferent and irregular anomalies can be identified as possible pits for clay extraction. More significant are the remains of two houses *(Fig. 50.2–3)*. As in the Lengyel settlement, the house forms are outlined by the bedding trenches. Their internal structure and the distribution of postholes differ from the buildings of the Lengyel settlement. The dating of the house features remains unclear at this time. An argument against their context in the Lengyel culture is their location far beyond the ditch of the Lengyel settlement.

The area around the eastern slip road of the M6 motorway at Alsónyék, Hosszú dűlő, area 7

1.2 km east of the prospection area along the main route of the M6 motorway, approximately 30 ha of farmland were prospected along the eastern slip road *(Figs 51–52)*. Rescue excavations brought to light several ditches and graves of the Sopot culture (Oross et al. 2016c). The

10 A recent analysis of the Lengyel settlement pattern modifies some statements of this KDE analysis (Osztás 2019).

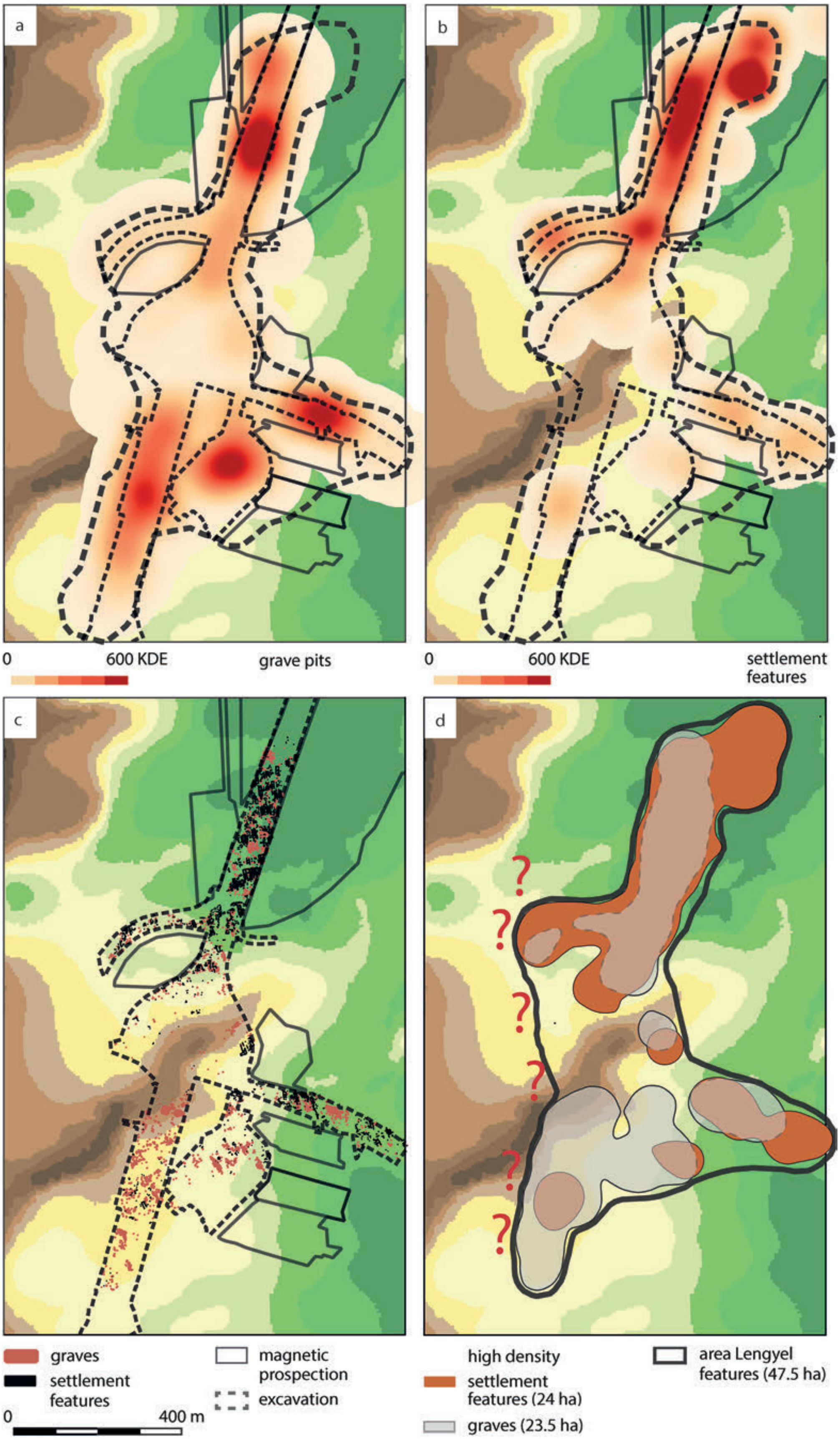


Fig. 49. Kernel density estimation (KDE) of the Lengyel culture houses and graves. a KDE of grave centroids from the excavation; b KDE of the house remains of the excavation and magnetic prospection; c overview of the graves and the settlement features in the excavation area; d generalised model of the grave and house clusters of the Lengyel culture based on the KDE contour map. Base map DEM.

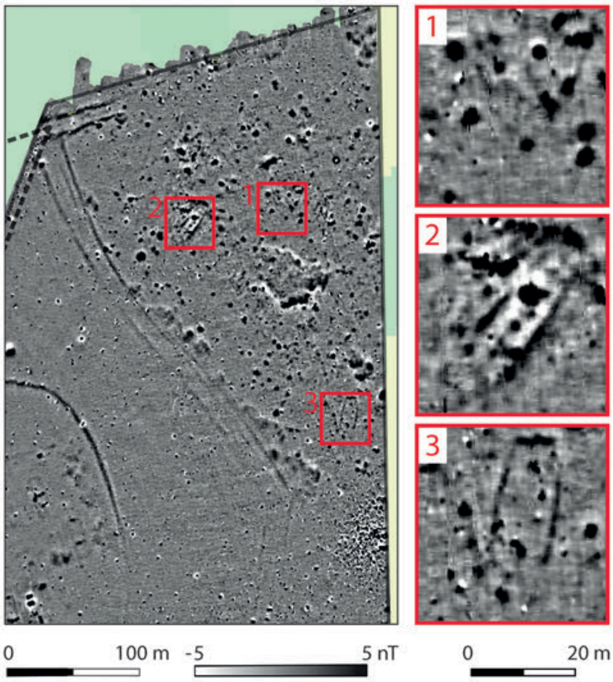


Fig. 50. Alsónyék-Kanizsa-dűlő (area 1). Overview of the magnetic prospection in the north-eastern areas showing anomalies mainly from the Lengyel cultures. Base map DEM.

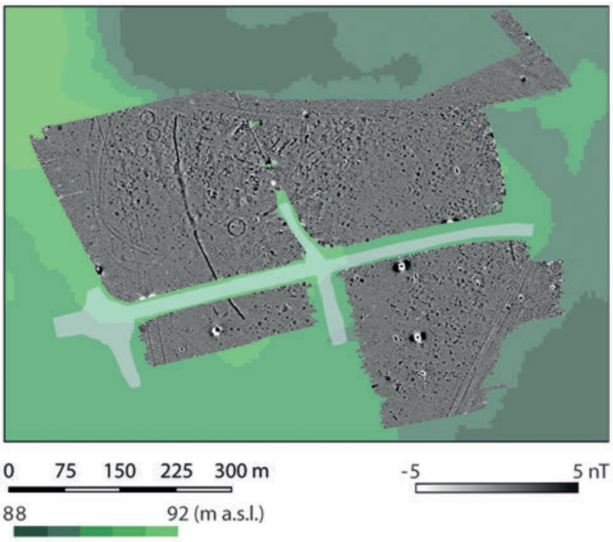


Fig. 51. Alsónyék, Hosszú dűlő (area 7). Overview of the eastern prospection areas showing settlement features of the Sopot culture and later prehistoric, probably Iron Age barrows. Base map DEM.

magnetic prospection investigated the area north- and southwards of the rescue excavation and revealed a high density of anomalies that was remarkably higher than in the western area close to the M6 motorway. The magnetic anomalies indicate a wide range of archaeological features such as ditches, various pits, house remains, and circular ditches / barrows. The data clearly show settlement activities and the existence of a burial ground. The different types of pits and house remains reflect activities in different periods. On the one hand, the clear evidence from the rescue excavations highlighted the presence of the Sopot culture, while on the other hand, some of the features might date to the Late Bronze Age. The larger number of pits in the eastern and south-eastern area remains to be investigated through further research.

The site lies in a characteristic topographical location on a flat elevation surrounded by a former riverbed, virtually forming a peninsula as we know from the maps from the 18th and 19th centuries (cf. *Fig. 57a–b*).

Permanent access to the plateau was probably available only from the west. Exactly in this zone, the magnetic prospection revealed a ditch perpendicular to the peninsula. The size and the shape of the ditch varied. The topography and the ditches indicate that the location was chosen for its potential for defence against intruders.

The linear features *(Fig. 52, nos 1–7)* differ in magnetic contrast, shape, and size. The linear features nos 3–6 can probably be associated with the Sopot settlements. The double linear feature (no. 2) most likely indicates an old road clearly visible on the Josephinian cadastre *(Fig. 57a)*. The double line feature (no. 7) in the south-eastern part of the prospection area might be considered as an additional road *(Fig. 52)*. The linear features nos 3 and 4 with a much lower contrast than no. 1 are precisely parallel, as often observed in the case of Lengyel enclosures, for example at Sormás (Barna / Pásztor 2010, 119 f.). They curve eastwards, but here they are overlapped by a circular ditch of an Iron Age (?) barrow. Close to the rescue excavation, the magnetic signature is only partly visible, but still strong enough to see it connected to the ditch line of the magnetic prospection with the evidence of the excavation. Farther to the east, one weak linear anomaly indicates the final course. Despite the gaps between the ditch segments, the magnetic data clearly allow the reconstruction of the general structure of the ditch system. The existence of the two double ditches nos 3–4 and 5–6 and their counterparts in the excavation indicate at least two phases. At present, only a single radiocarbon date is available for a single grave from ditch 211 (no. 4 in the magnetic data). A more precise evaluation of the ditches and their chronology remains a task of future investigations.

Besides the linear ditches, circular ditches enclosing Iron Age barrows can be identified *(Fig. 53)*. They are of the same size and shape as a structure found at Fajsz (cf. *Fig. 11.1*). The barrows are completely eroded. Only the ditches around the former barrows are preserved and evident in the magnetic data. The ditch of the largest barrow with a diameter of 22 m *(Fig. 53.2)*

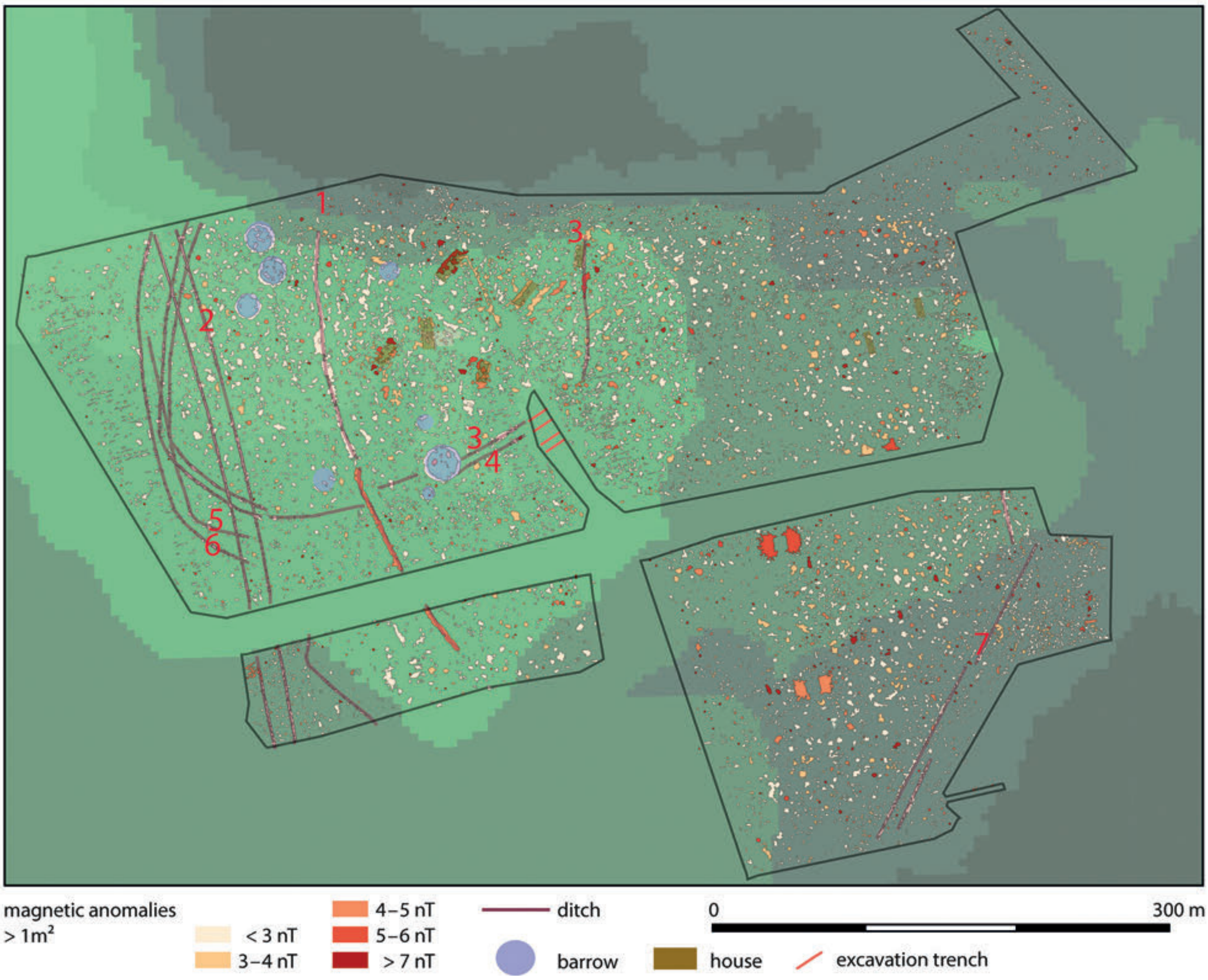


Fig. 52. Alsónyék, Hosszú dűlő (area 7). Interpretation of the magnetic data of the eastern prospection areas showing settlement features of the Sopot culture and later prehistoric, probably Iron Age barrows. Base map DEM.

is better preserved than the small round ditches in its neighbourhood to the north-west and south-west. These three smaller ditches with diameters between 15–17 m *(Fig. 53.1)* indicate a similar stage of preservation. The correlation of visibility, magnetic contrast, and preservation (?) might be explained by the use of the ditch as source of material for the construction of the barrow and its subsequent slow refill with material with a higher magnetic susceptibility. Generally, it can be assumed that a smaller barrow has a shallower ditch, whereas a larger one has a deeper ditch and a larger volume of material with a higher magnetic susceptibility, resulting in better visibility in the magnetic prospection data.

Several houses are revealed by the magnetic prospection in the northern prospection area (no. 7). Five of them are located within ditch 3 *(Figs 52; 54.1–3)*. The houses are different in size, orientation, layout, and internal structure. Four houses were identified within the prospection area on the basis of the post structures. Interestingly, each of these houses was oriented differently. The largest one can be estimated to have been 20 m long and 8 m wide *(Fig. 54.2)*.

Some of the differences might be caused by the different stages of preservation of the house remains or the process of the house's destruction. The houses might belong to the Sopot culture, but this needs to be verified by excavation with at least small test trenches.

Two house remains were found on the eastern periphery of the Sopot settlement *(Figs 52; 56)*. The dating of these houses is uncertain. We might assume that they belong to the same chronological horizon as the numerous pits in their neighbourhood (Late Bronze Age?).

The majority of archaeological features uncovered during the excavation were burials of the Sopot culture (Oross et al. 2016c). Taking the information of the excavation into account, we expect a weak magnetic contrast for graves. It is a similar situation as the one for the graves of the Lengyel culture discussed above. By

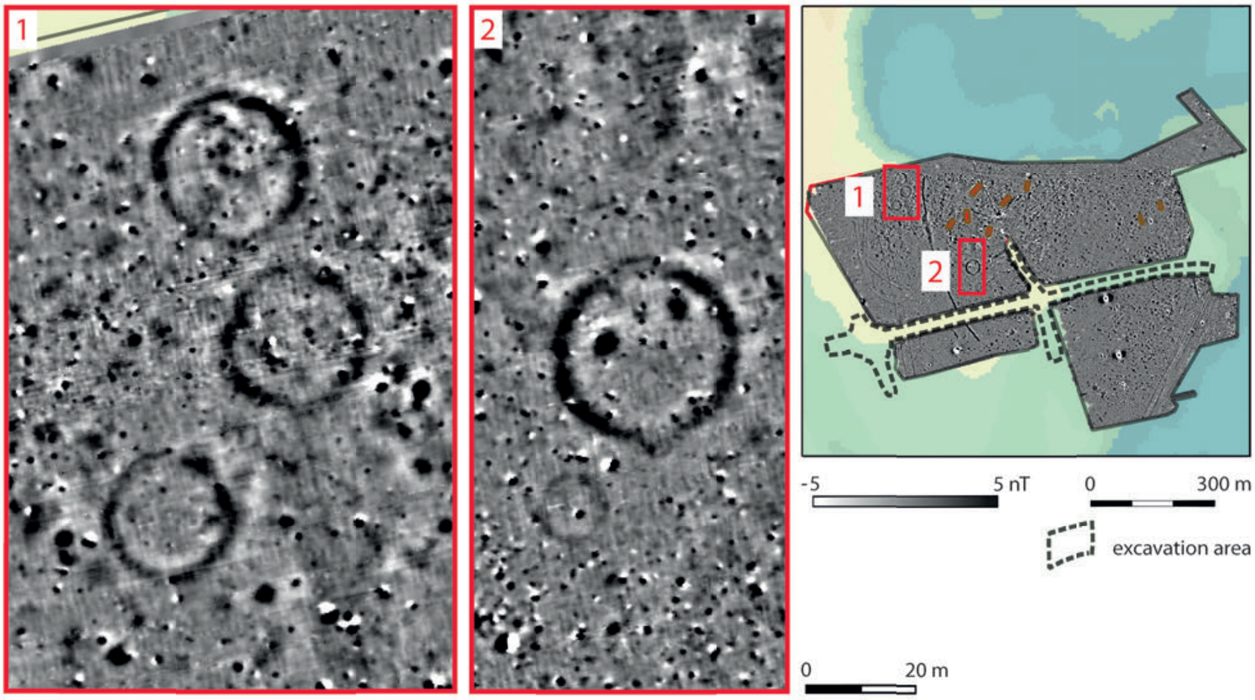


Fig. 53. Alsónyék, Hosszú dűlő (area 7). Details of the eastern prospection areas showing probable Iron Age barrows. Base map DEM.

calculating the polygons of the 1 nT contour line with an area larger than 1 m^2, over 7500 objects were calculated. Based on these data, a filtering of all objects within an area of between 2–6 m^2 resulted in more than 2500 objects. Hidden in this noise cloud of polygons, we also assume a large number of grave pits of the Sopot culture, but the reliable dating of pits based solely on the magnetic data is impossible.

A large number of settlement pits were revealed by the prospection in the eastern prospection area. Because of the uncertainties with respect to the differentiation of grave pits from small settlement pits, we selected all polygons with a magnetic amplitude of more than 3 nT and larger than 3 m^2. We assume that the majority of pits over 3 m^2 might be classified as settlement pits. By this we filtered 1399 anomalies larger than 3 m^2, up to 18 m^2. The anomalies are distributed in classes as follows: 3–6 m^2 = 1037; 6–9 m^2 = 174; 9–12 m^2 = 54; 12–15 m^2 = 39; 15–18 m^2 = 62. The pits are of varying magnetic contrast, with 50 % of them having a mean peak amplitude of < 4.4 nT *(Fig. 55)*.

The pit anomalies seem to have an even spatial distribution. We tested it again by kernel density estimation (KDE). The KDE highlights four areas with a higher density. The largest of these areas in the north-west is fairly big and enclosed by ditches 3 and 4 of the Sopot culture. There are four houses in the centre of this cluster. The spatial coincidence indicates an internal coherence and date in the Sopot culture. By this, we are able to reconstruct the boundary of the Sopot settlement, which only partially covered the elevation. The area enclosed by ditches 3 and 4 covers an expanse of 4.8 ha. The three other areas of higher density of anomalies might be contemporaneous with the settlement pits in these areas. Our hypothetical dating to the Late Bronze Age has to be proven by further research. Ditch 1 extended across the western plateau and might be seen in this context *(Fig. 56)*. Its function was very likely to control access from the west.

Implications. The 6th and 5th millennium BC on the basis of geomagnetic prospections at Alsónyék: From the Starčevo to the Lengyel period

The multi-period site Alsónyék lies in a diverse landscape that can be called liminal or marginal. To the west, the Szekszárd Hills with an elevation of up to 250 m a.s.l. mark the western boundary of the floodplain of the Danube and its tributaries. The different archaeological sites are located a little above the floodplain, around 92–94 m a.s.l. The area on the western boundary of the valley might be used as arable land, whereas the landscapes on the floodplain and in the Szekszárd Hills were suitable for animal husbandry in different seasons (Depaermentier et al. submitted). The maps from the late 18th and the earlier 19th century illustrate the diversity

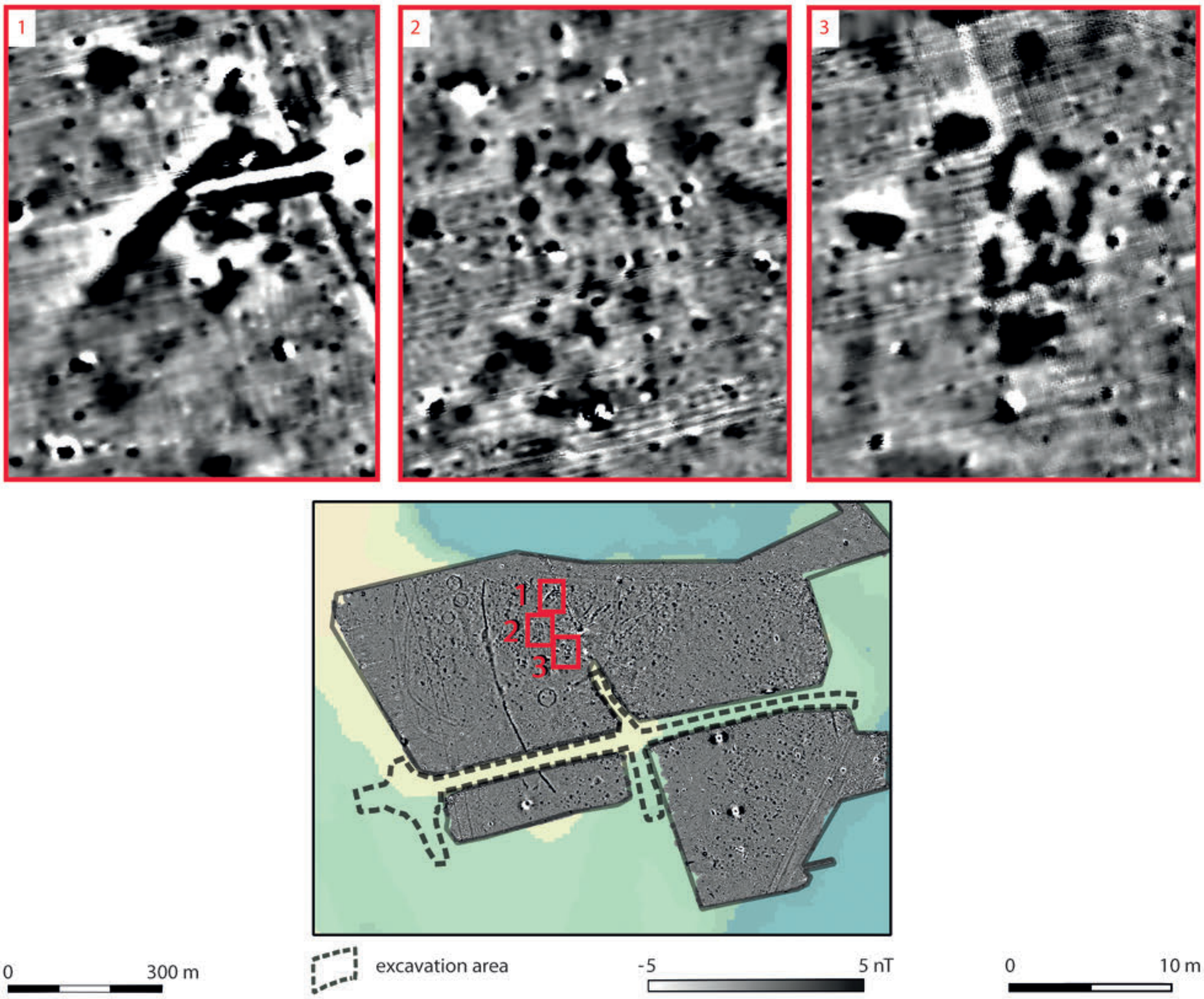


Fig. 54. Alsónyék, Hosszú dűlő (area 7). Details of the eastern prospection areas showing magnetic anomalies of houses.

and the changes in the landscape as discussed above (see Bánffy / Sümegi 2012; cf. Sümegi et al. in the present volume).

The magnetic data revealed numerous archaeological features from prehistoric periods until recent times. One of the latest features are the remains of a road visible on the Josephinian cadastre, whose course shifted decades later, as evident from the Franciscan cadastre 1806–1869 *(Fig. 57)*. The earliest features can be dated to the Starčevo culture.

The settlement remains mark the beginning and early period of human occupation in this landscape (cf. *Fig. 59*). The magnetic data revealed different concentrations of settlement remains. The combination of excavation and magnetic data can be used to reconstruct the total area of the Starčevo settlement of around 5.8 ha. The Starčevo occupation can be dated to between 5775 cal BC and 5525 cal BC (cf. *Fig. 59*). The next occupation horizon by LBK communities started around 5340 cal BC after a gap of some 200 years and lasted until 4915 cal BC (68 % probability).

The LBK settlement was located more northwards, although at a distance of less than 100 m. This might indicate an intention not to use the location of the previous Starčevo settlement. It is always an intriguing question, if this was indeed the case, to what extent people of later centuries recognised their forebears' settlement remains and, if so, what their attitude towards those remains might have been. Was this merely a practical matter to avoid bothering with the immense amount of burnt remains (which still weighed more than 2000 kg in the 21st century)? Or did it have something to do with respect, imposing certain constraints? A rather clear case for the first scenario could be noted at the Transdanubian site of Szentgyörgyvölgy-Pityerdomb, when a group of the more developed LBK phase returned to the heavily burnt remains of the settlement dating from the initial, formative LBK phase after some 150 years, perhaps

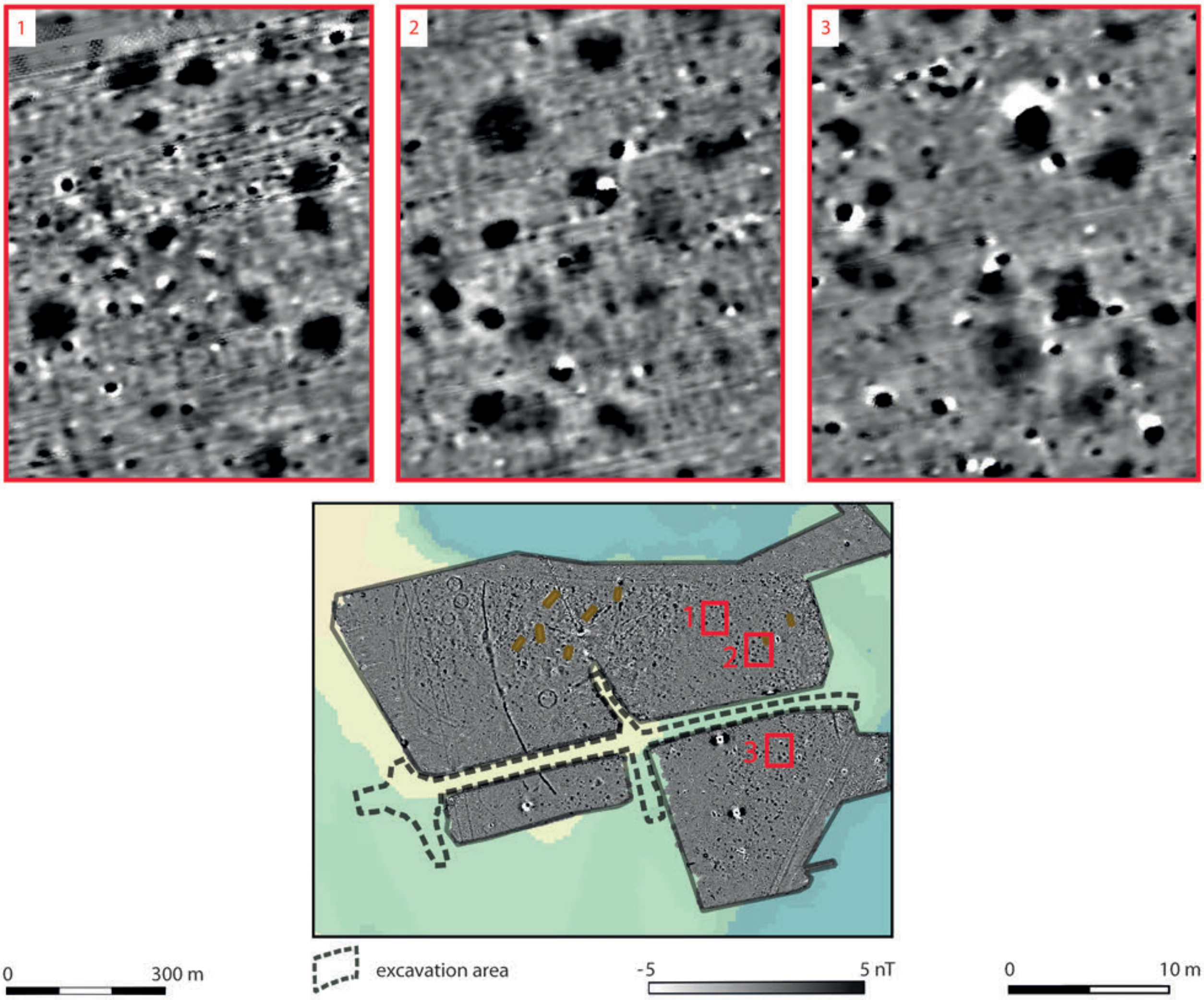


Fig. 55. Alsónyék, Hosszú dűlő (area 7). Details of the eastern prospection areas showing magnetic anomalies of settlement pits.

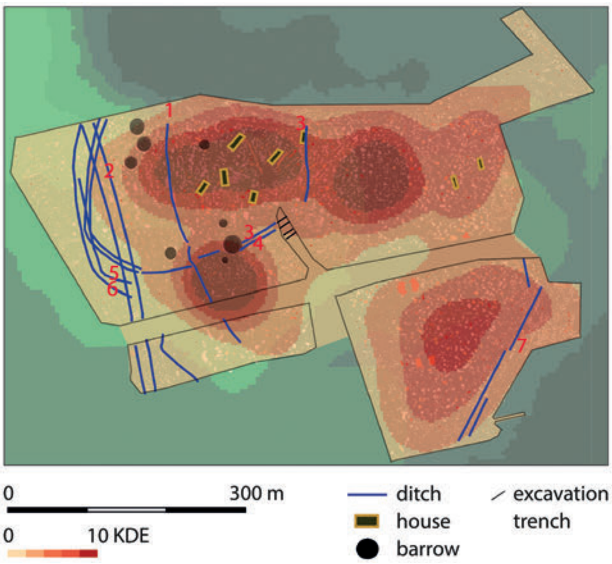


Fig. 56. Alsónyék, Hosszú dűlő (area 7). Kernel density estimation of anomalies > 3 nT and an area > 3 m².

around the late 54th to 53rd centuries BC (Bánffy 2004; Jakucs et al. 2016), and spent some time at the place, although without establishing their own settlement with longhouses. The time-gap is similar to the Alsónyék case. Judging from the rich surface finds it seems highly probable that at Pityerdomb the later LBK people, perhaps even distantly related to the first farmers, were aware of what they had found. These short visits to places that were obviously still visible may have been part of the process of constructing collective memories. This is but one possible explanation; however, the issue of avoidance *vs.* overlap between distinct periods of the Alsónyék occupants implies that this question needs to be raised separately for each case.

The archaeological features of the LBK are more widely distributed than those of the Starčevo culture. The rich excavation data for the LBK houses indicate a concentration at subsite 11 (Oross et al. 2016b, 124; 125 figs 1–2). Outside this area, the distribution of LBK

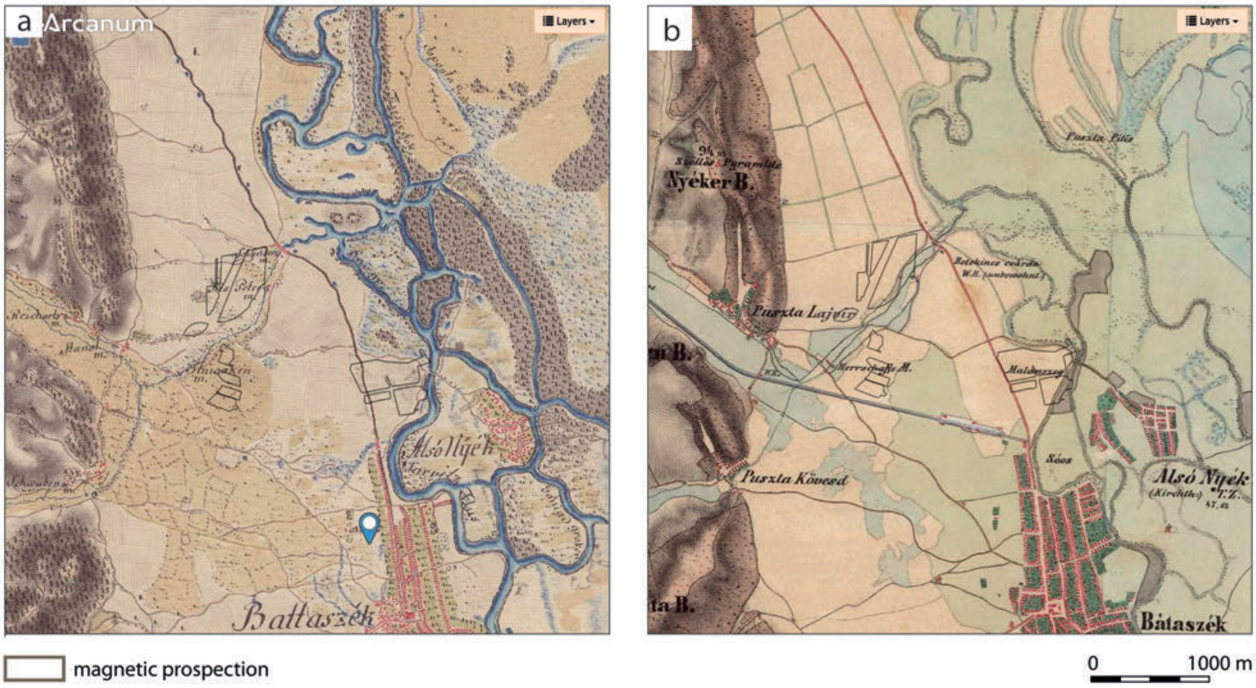


Fig. 57. Alsónyék, Alsónyék-Bátaszék. a Josephinian cadastre, 1782–1785. b Franciscan cadastre, 1806–1869. Both showing the prospection areas between the Szekszárd Hills and the floodplain.

features is less dense. Between the areas with some LBK features are large gaps without any evidence of an LBK presence. The majority of the houses are concentrated in the south (subsite 11). Taking the magnetic data into account, we are able to reconstruct the outer boundary of the LBK settlement and confirm the uneven distribution of LBK features. Very likely, the reconstructed 10 ha for the LBK settlement only marks the overall territory with LBK features, while the houses are actually distributed over a much smaller area of only 5–6 ha. If only the house areas are taken into account, the LBK settlement has a roughly similar size as the Starčevo settlement.

The next occupation phase was marked by the Sopot culture. In contrast to the relation between Starčevo and the LBK, there is no chronological gap between these occupation horizons. The overlap between the LBK and the Sopot culture is clearly evident. The Sopot culture began around 5060 cal BC and ended around 4750 cal BC (with 68 % probability) *(Figs 58–59)*. In contrast to the change from Starčevo to LBK, the new settlement was not established in the neighbourhood of the previous one. The two settlements lie at a distance of more than 1 km *(Fig. 58)*.

The final occupation at Alsónyék started with the Lengyel culture around 4800 cal BC. The settlement features and burials of the Lengyel culture are most widely distributed over an area of some 50 ha *(Fig. 58)*. The settlement features and burials indicate a clear overlap (cf. *Fig. 49*), but there are also some differences. The highest density of settlement features is in the northern area at Alsónyék-Kanizsa-dűlő (areas 1 and 2). The radiocarbon dates indicate an earlier beginning for the Lengyel occupation in the south and in the north, roughly around 4800 cal BC (Osztás et al. 2016b, 223 fig. 25). Taking these results into account, the circular ditch around the Lengyel settlement was not constructed at the beginning of the Lengyel occupation, but some three or four generations later.

The uneven distribution of the archaeological features of the Lengyel culture might be interpreted either as a shift of the settlement, or as the contemporaneous existence of different house clusters. The fact that the area with the highest density of houses is the place with the shortest occupation period of less than 50 years, whereas the areas in the south-east with low building density are characterised by an occupation lasting nearly 350 years, has implications for the calculation of settlement size and the calculation of the population change. Here, the magnetic prospection possibly raises more questions than giving answers. The probable dissolution of the converse estimations will be hopefully resolved in the dissertations focusing on Lengyel settlement patterns and buildings at Alsónyék. Most probably, an intra-site population shift should also be taken into consideration, certainly at around 4730 cal BC when the northern, 10B part of the Alsónyék Lengyel settlement (cf. *Fig. 38*) suddenly began to grow, until the aggregation reached a previously unobserved size, with some 50 times as many people moving to

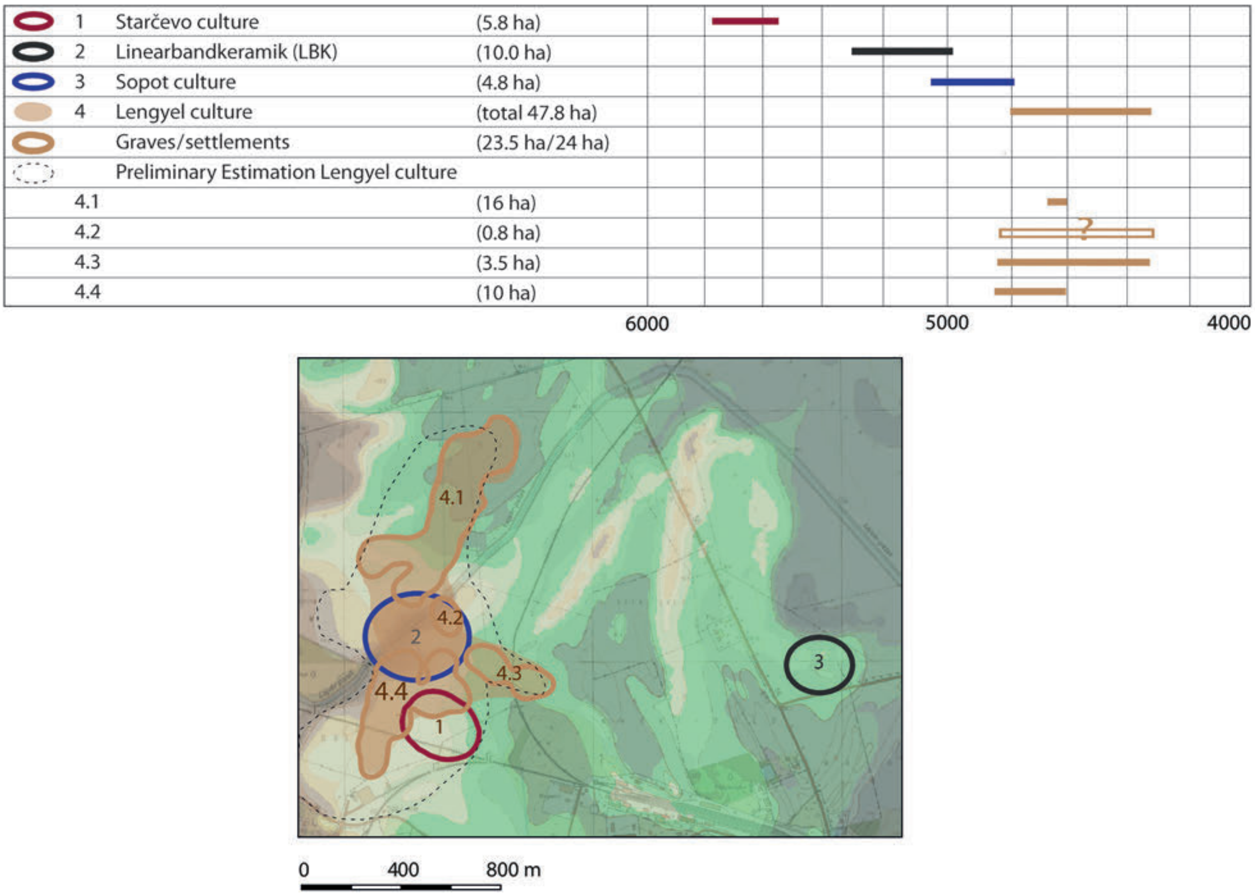


Fig. 58. Alsónyék. Overview of the sizes of occupation areas and a generalised chronological model of the occupation horizons. Starčevo culture; LBK, Sopot culture; Lengyel culture.

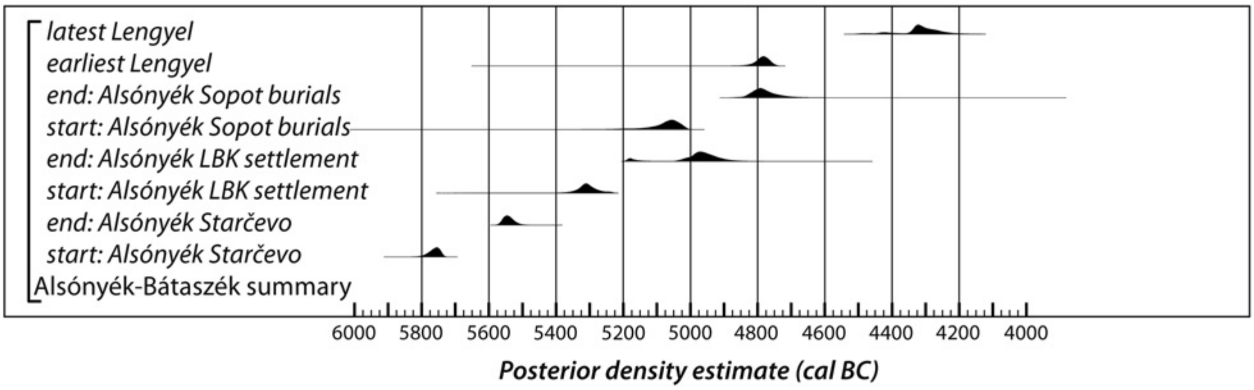


Fig. 59. Probability distributions for the start and end of the settlements of different cultural groups in the Alsónyék landscape.

the area than in the earlier phase of the Lengyel settlement (Bánffi et al. 2016). However, even the excavations record might prove insufficient for pinpointing the causes underlying this aggregation. Nevertheless, the overarching study that takes other early and synchronous Lengyel sites into consideration sought to find at least some answers for the population shift and aggregation (Regenye et al. 2020).

A comparison of the three micro-landscapes with the sites of Fajsz-Garadomb, Fajsz-Kovácshalom, Tolna-Mözs, and Alsónyék highlights certain differences. The Starčevo and the LBK settlements at Tolna and Alsónyék lie on a fault line between the Szekszárd Hills area and the floodplain, while the Sopot settlement is located on slight elevations within the floodplain both at Fajsz and Alsónyék.

In terms of their sizes, the same or very similar dimensions are apparent in the case of the Starčevo settlement at Alsónyék, the LBK settlement at Tolna-Mözs and Alsónyék, and also regarding the Sopot settlements at Fajsz-Garadomb and Alsónyék. The smallest site is Fajsz-Kovácshalom with 1.2 ha, but this is a tell mound, making Kovácshalom less comparable with the others that are all horizontal sites. By far the largest settlement is that of the Lengyel period at Alsónyék. The preliminary estimate of 80 ha might be necessary to be corrected. The general territory covered is around 50 ha (without the prospection of the southern part), although there are a few more densely settled areas within this area. The Bayesian modelling of the radiocarbon dates sheds light on the fine chronology of the Lengyel phases, which also provided answers to the question of how many houses may have been contemporaneous. Based on these studies (Bánffy et al. 2016, 304 fig. 11), the highest population (perhaps in the entire European Neolithic) can be found on the Alsónyék Lengyel settlement, at least for a few generations' time.

The circular ditches of the Sopot culture can be compared given that they were found both at the Alsónyék and the Fajsz-Garadomb settlement. The fact that both groups settled on small elevations rising above the floodplain and mostly surrounded by marshland might indicate the deliberate search for a topographic location with good conditions for the possible defence of the settlement. Not much information is available about the social structure and the possibly hostile behaviour of Sopot groups from other communities, or perhaps even their own groups may have competed with each other. The fact that the construction of ditches around settlements becomes fairly common over the entire territory of southern Transdanubia in the early 5th millennium BC might be an indication of the appearance of conflicts (cf. Zalai-Gaál 1990; Bertók / Gáti 2011; Barna et al. 2016; 2019; s. a. Literski / Nebelsick 2012). The archaeological evidence also speaks for the rise of inequality and the emergence of elite social groups (Osztás et al. 2012; Bánffy et al. 2016). The two observations corroborate each other.

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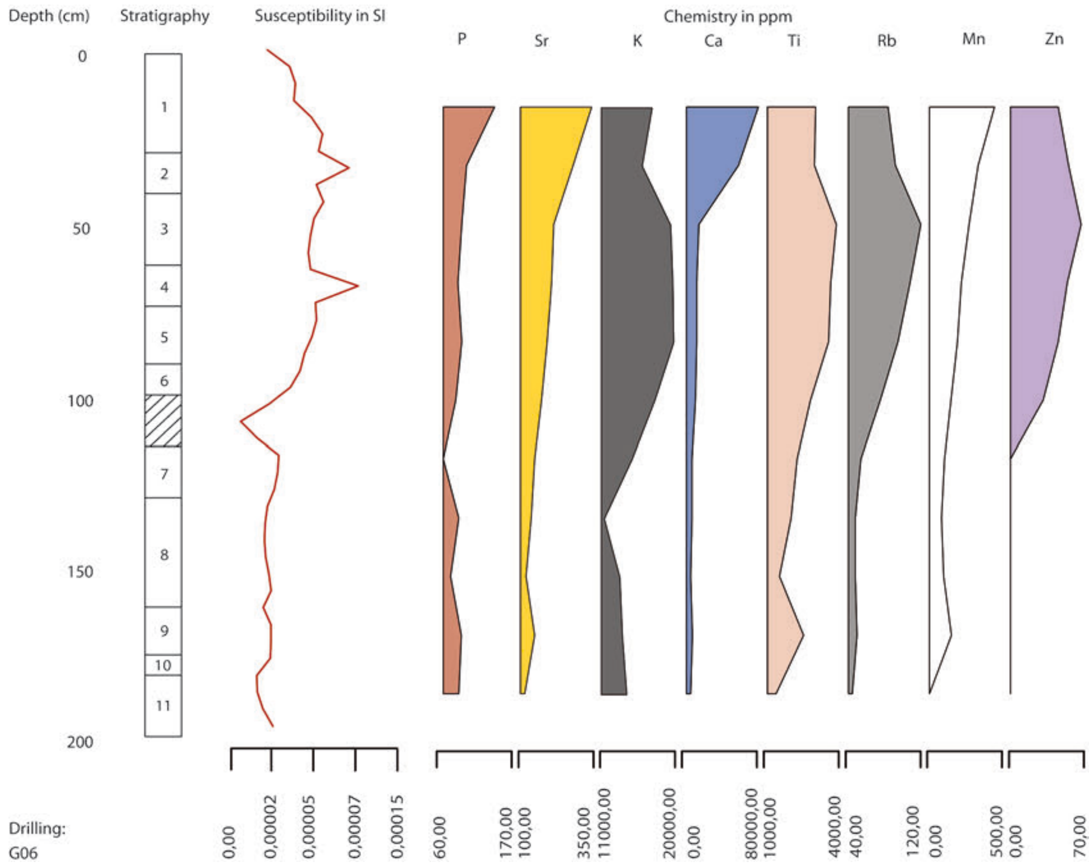
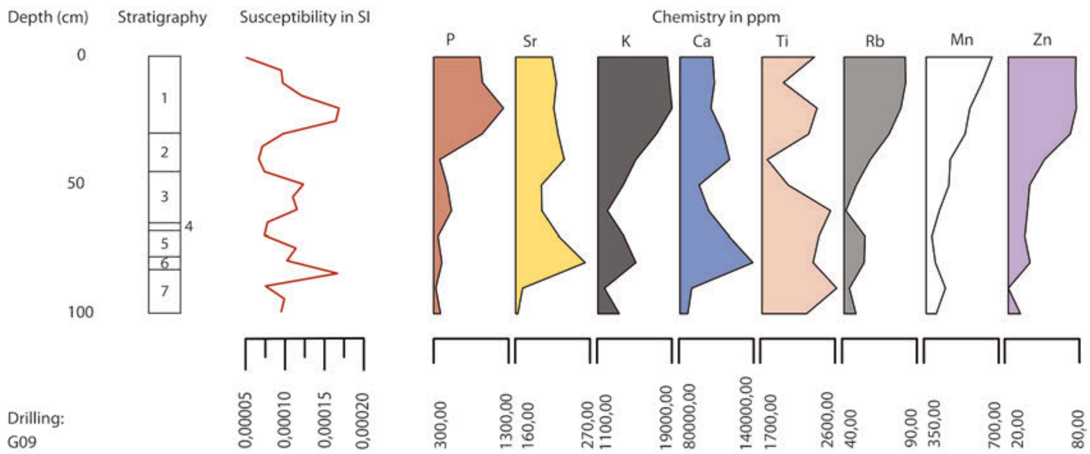
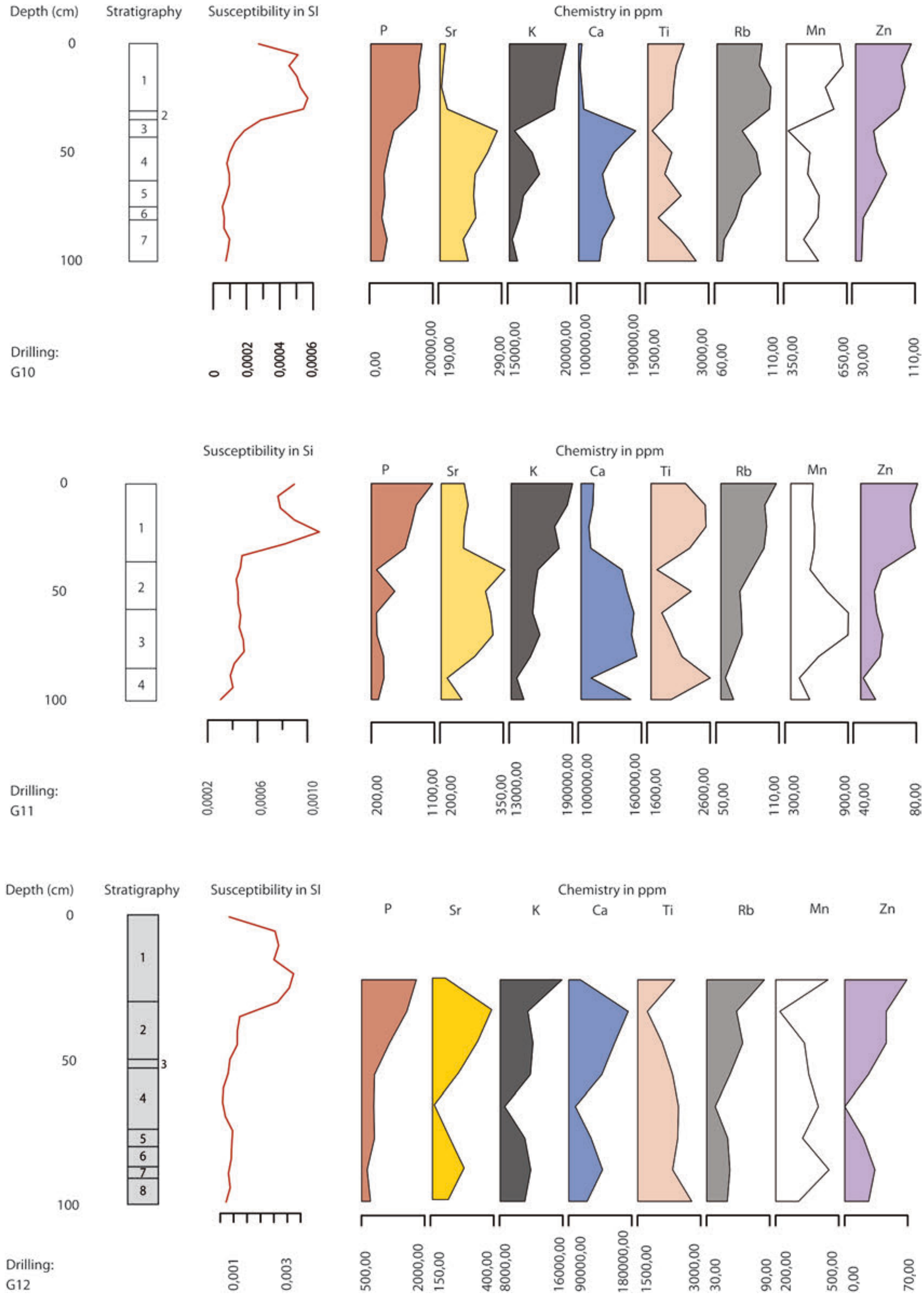
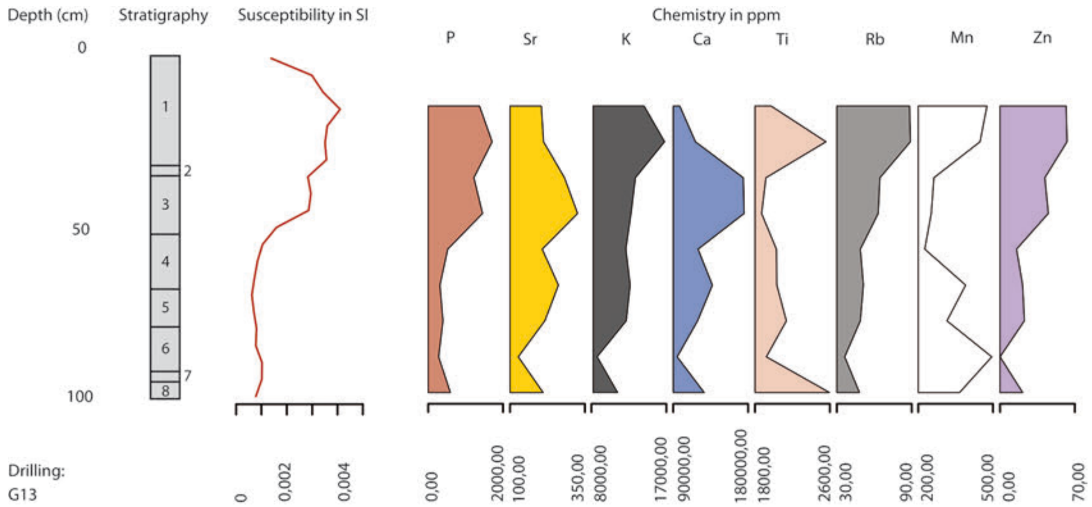
Appendices

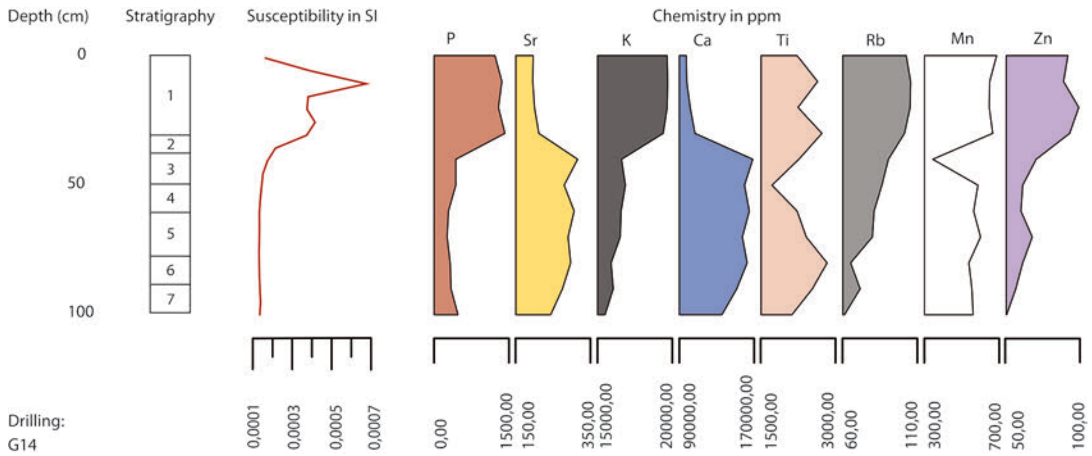
Appendix 1. Fajsz-Garadomb. Magnetic susceptibility and multi-element chemical analysis results of Cores G06, G09–G16.

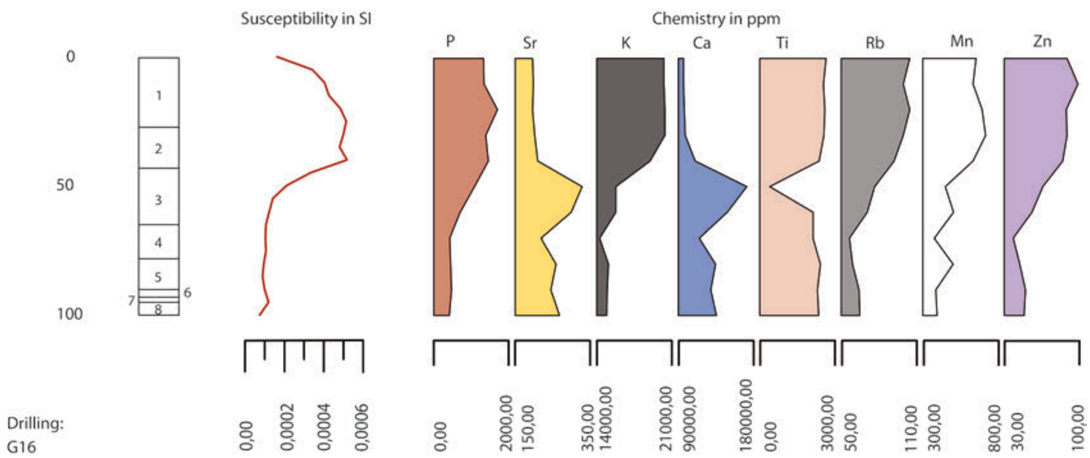


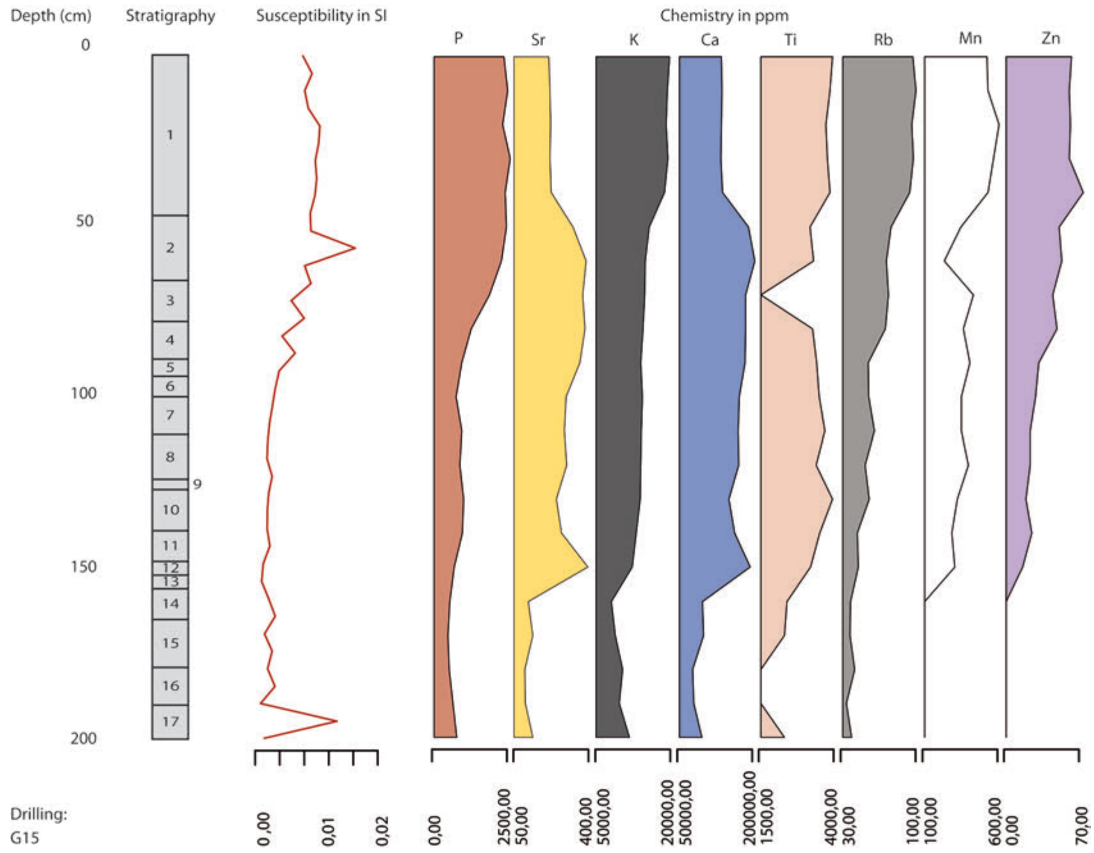



Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
Drilling:
G10
0
0,0002
0,0004
0,0006
0,00
20000,00
190,00
290,00
15000,00
20000,00
100000,00
190000,00
1500,00
3000,00
60,00
110,00
350,00
650,00
30,00
110,00
Susceptibility in Si
Drilling:
G11
0,0002
0,0006
0,0010
200,00
1100,00
200,00
350,00
13000,00
190000,00
100000,00
160000,00
1600,00
2600,00
50,00
110,00
300,00
900,00
40,00
80,00
Drilling:
G12
0,001
0,003
500,00
2000,00
150,00
400,00
8000,00
16000,00
90000,00
180000,00
1500,00
3000,00
30,00
90,00
200,00
500,00
0,00
70,00

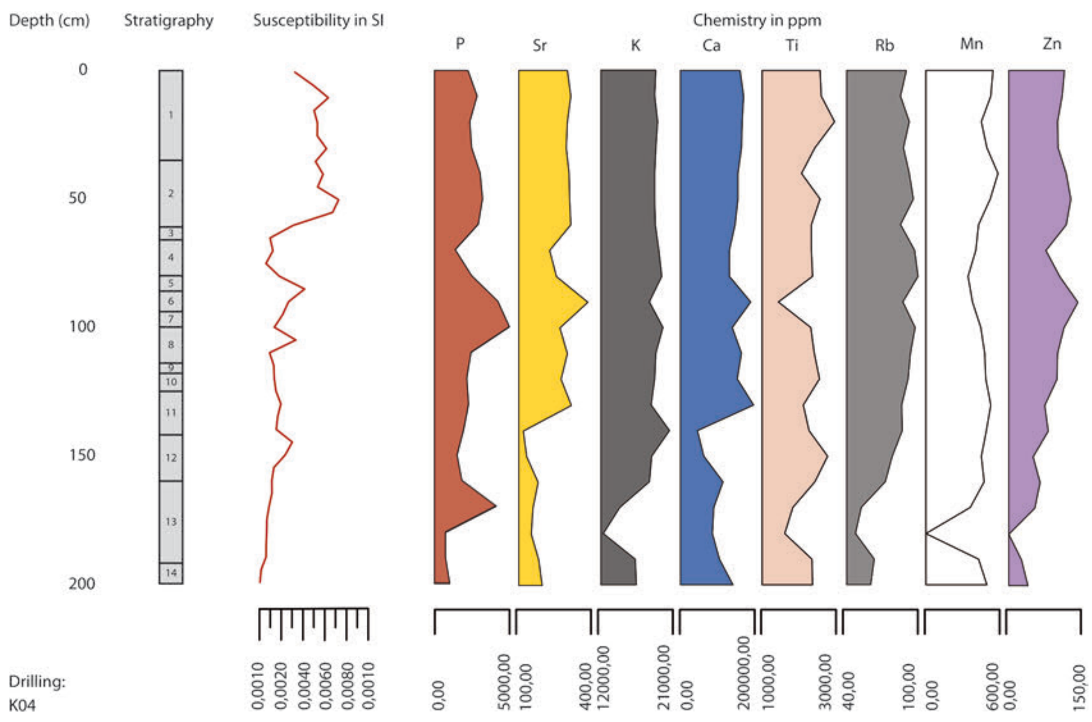

Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
1
2
3
4
5
6
7
8
Drilling:
G13
0
0,002
0,004
0,00
2000,00
100,00
350,00
8000,00
17000,00
90000,00
180000,00
1800,00
2600,00
30,00
90,00
200,00
500,00
0,00
70,00

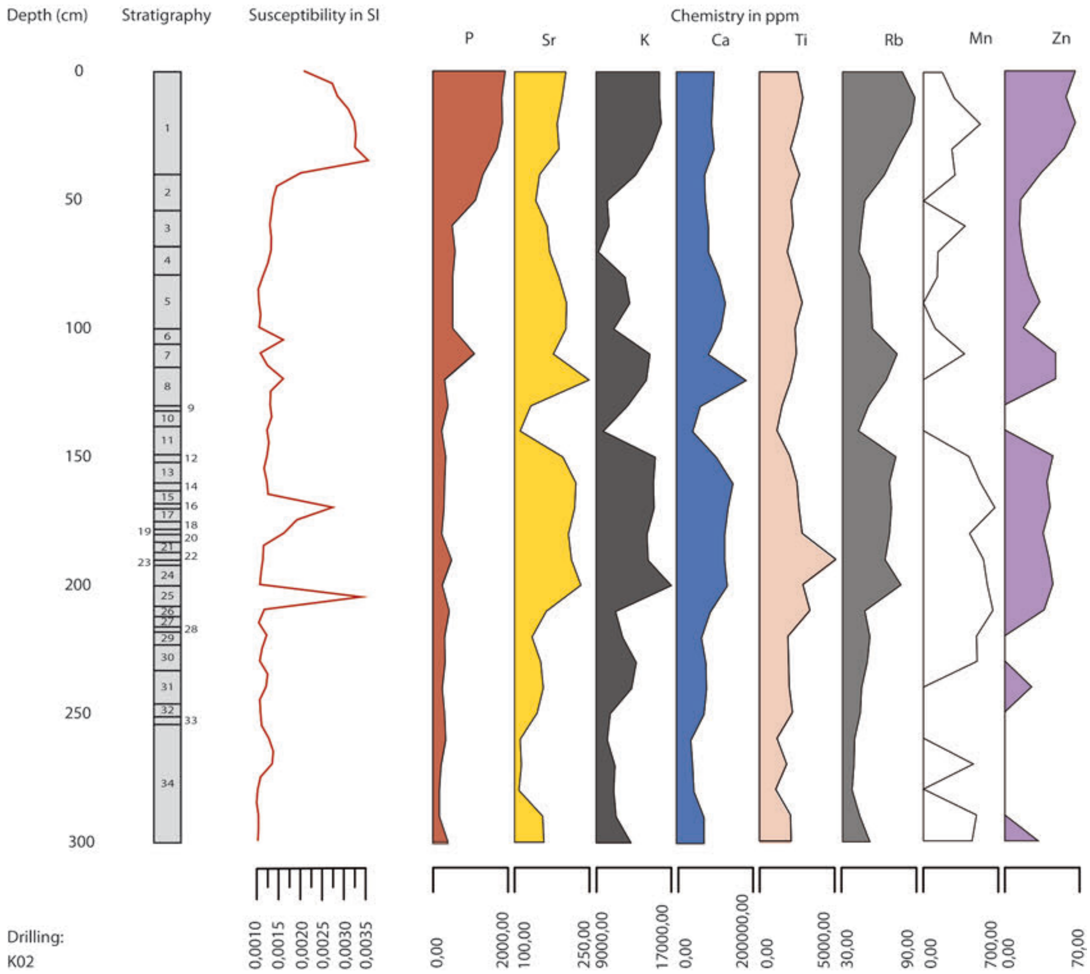

Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
1
2
3
4
5
6
7
Drilling:
G14
0,0001
0,0003
0,0005
0,0007
0,00
1500,00
150,00
350,00
15000,00
20000,00
90000,00
170000,00
1500,00
3000,00
60,00
110,00
300,00
700,00
50,00
100,00

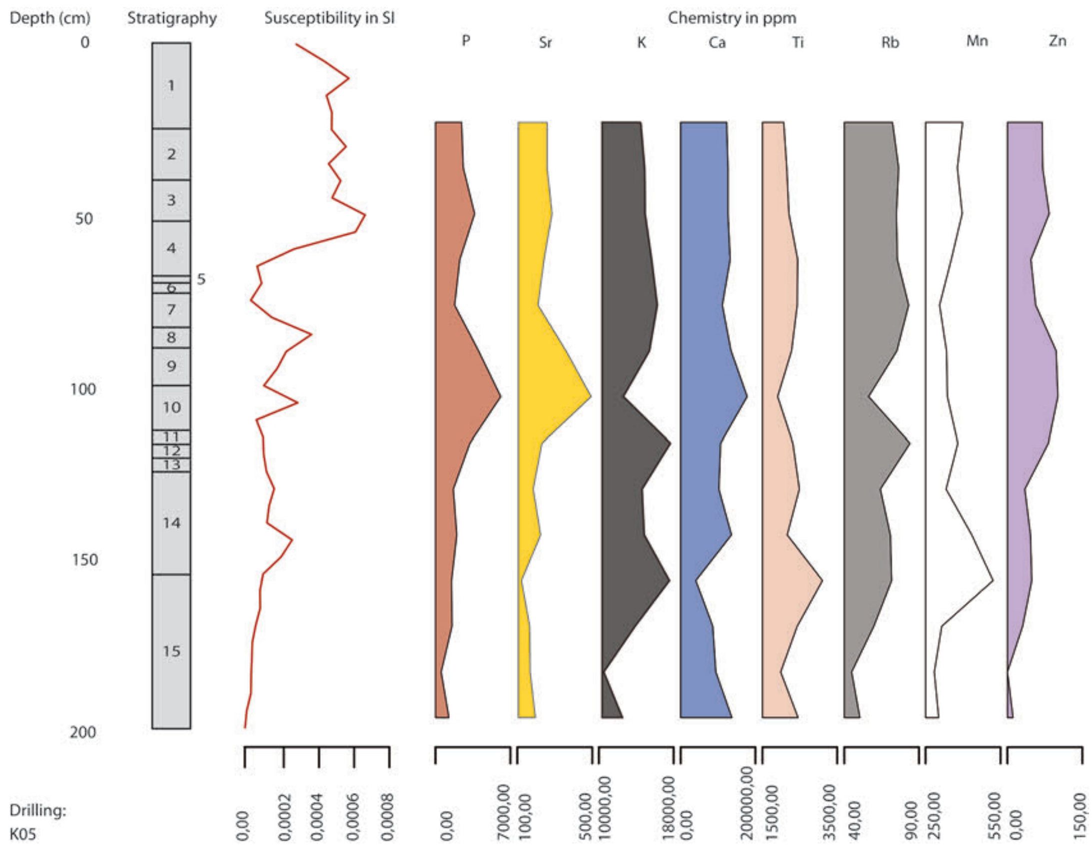

Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
1
2
3
4
5
6
7
8
Drilling:
G16
0,00
0,0002
0,0004
0,0006
0,00
2000,00
150,00
350,00
14000,00
21000,00
90000,00
180000,00
0,00
3000,00
50,00
110,00
300,00
800,00
30,00
100,00

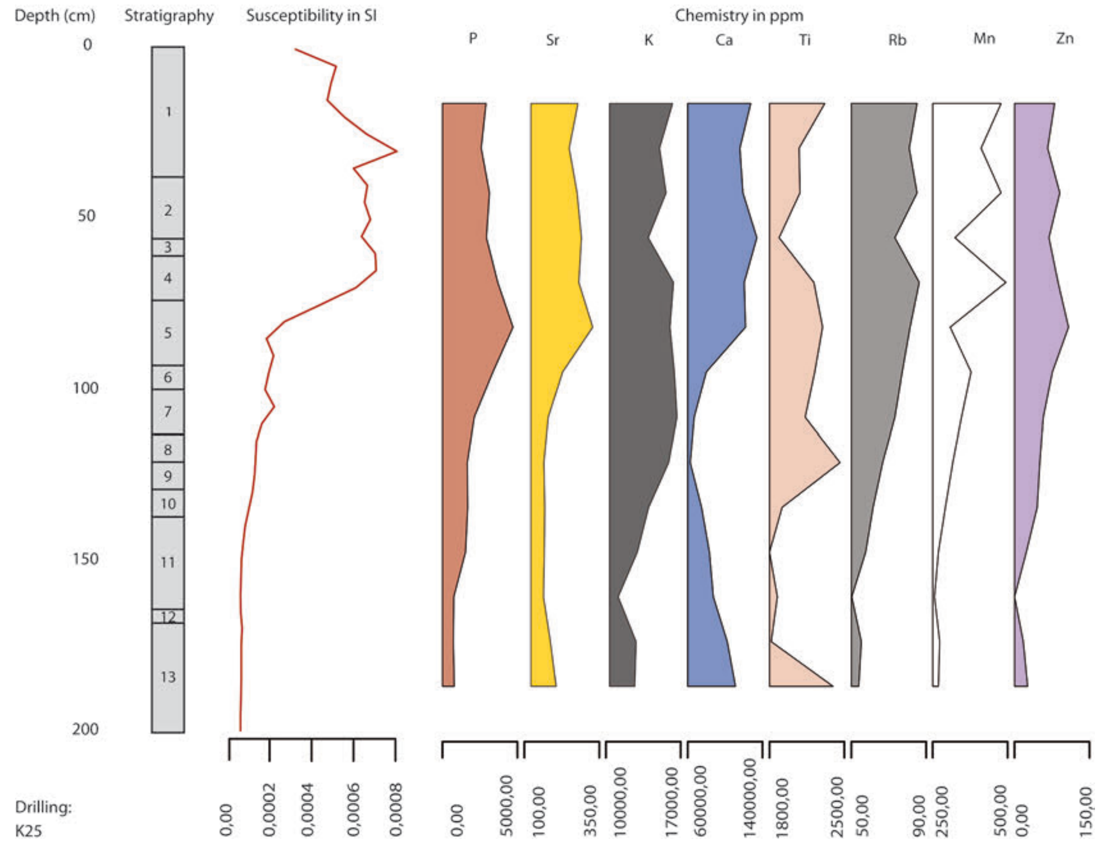


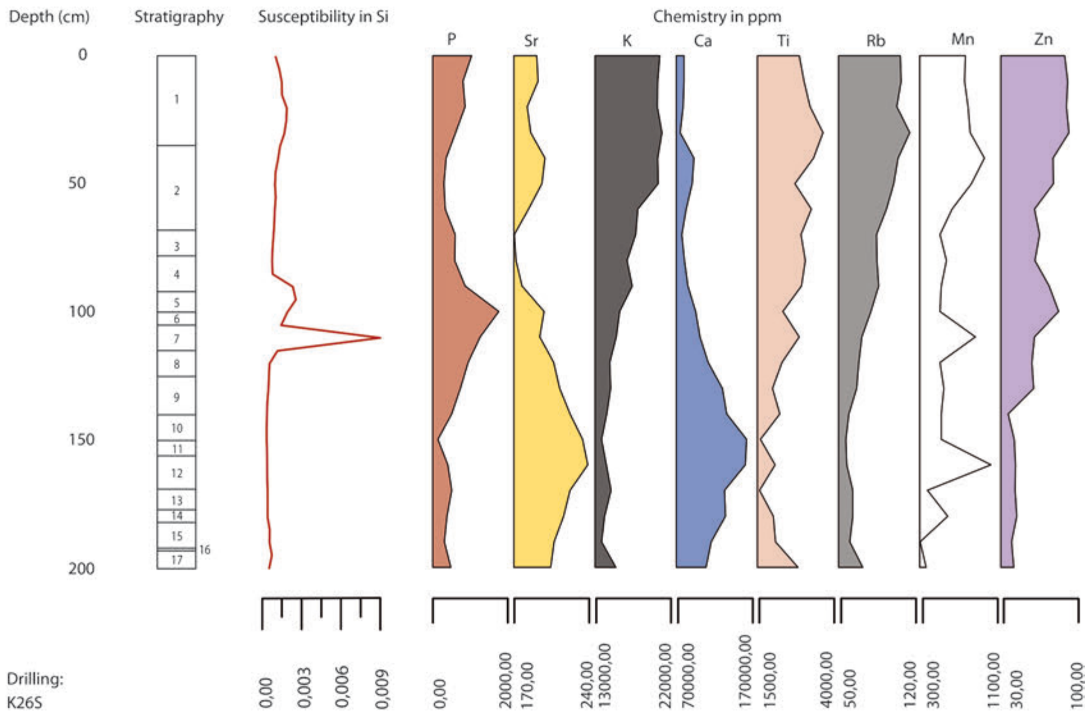
Appendix 2. Fajsz-Kovácshalom. Magnetic susceptibility and multi-element chemical analysis of Cores K02, K04, K05, K25, K26S, K37, K52, K57, K66.

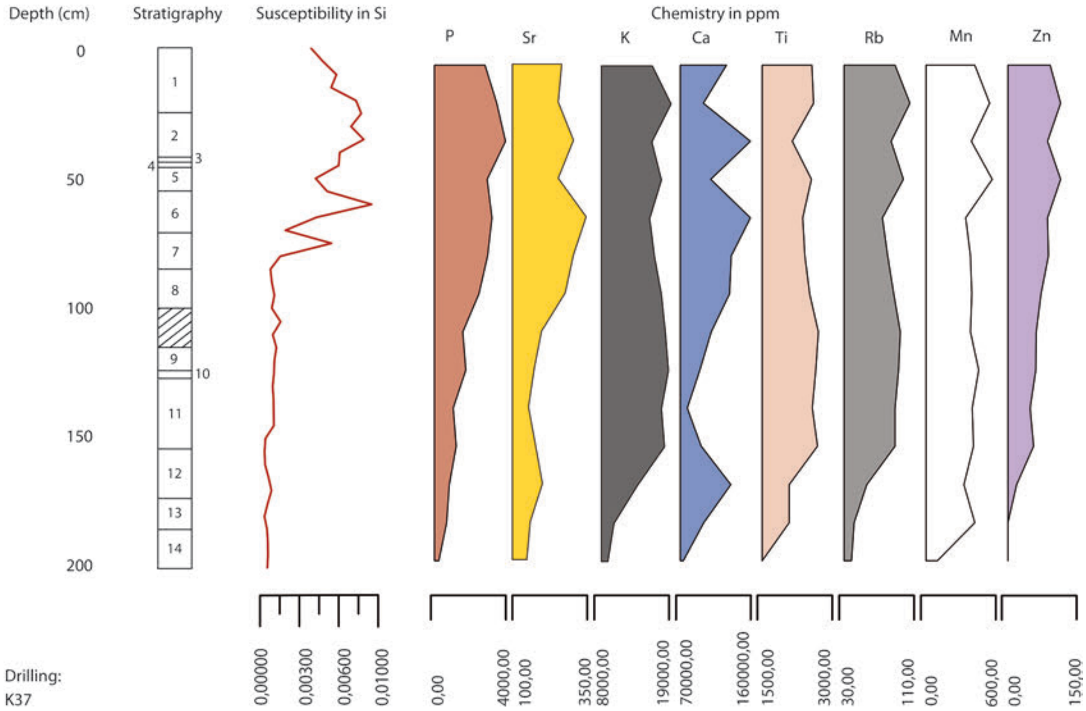


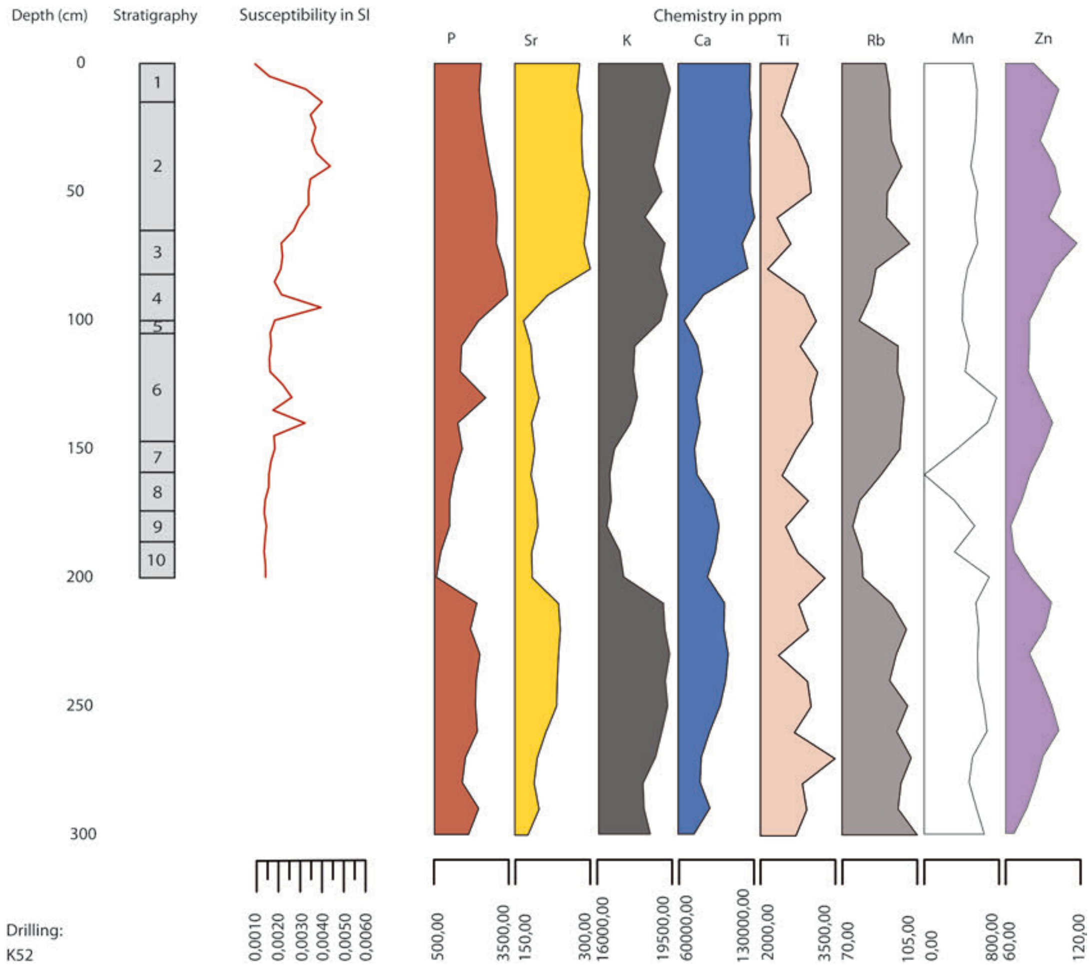

Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
250
300
Drilling:
K02
0,0010
0,0015
0,0020
0,0025
0,0030
0,0035
0,00
2000,00
100,00
250,00
9000,00
17000,00
0,00
200000,00
0,00
5000,00
30,00
90,00
0,00
700,00
0,00
70,00

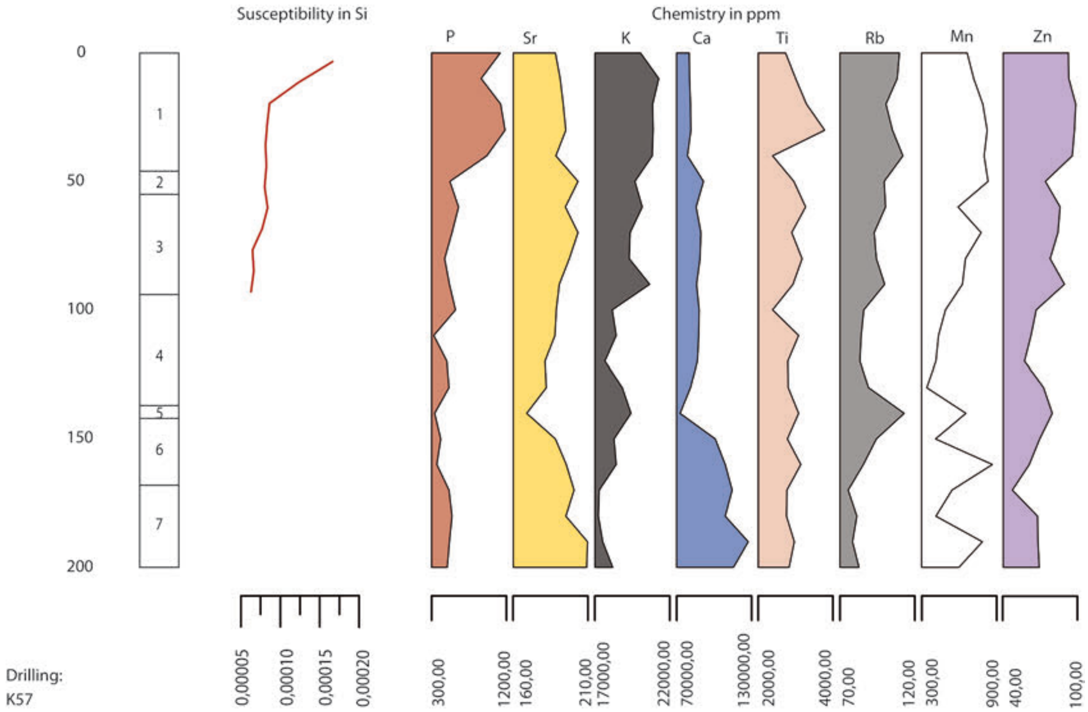

Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
Drilling:
K05
0,00
0,0002
0,0004
0,0006
0,0008
0,00
7000,00
100,00
500,00
10000,00
18000,00
0,00
200000,00
1500,00
3500,00
40,00
90,00
250,00
550,00
0,00
150,00

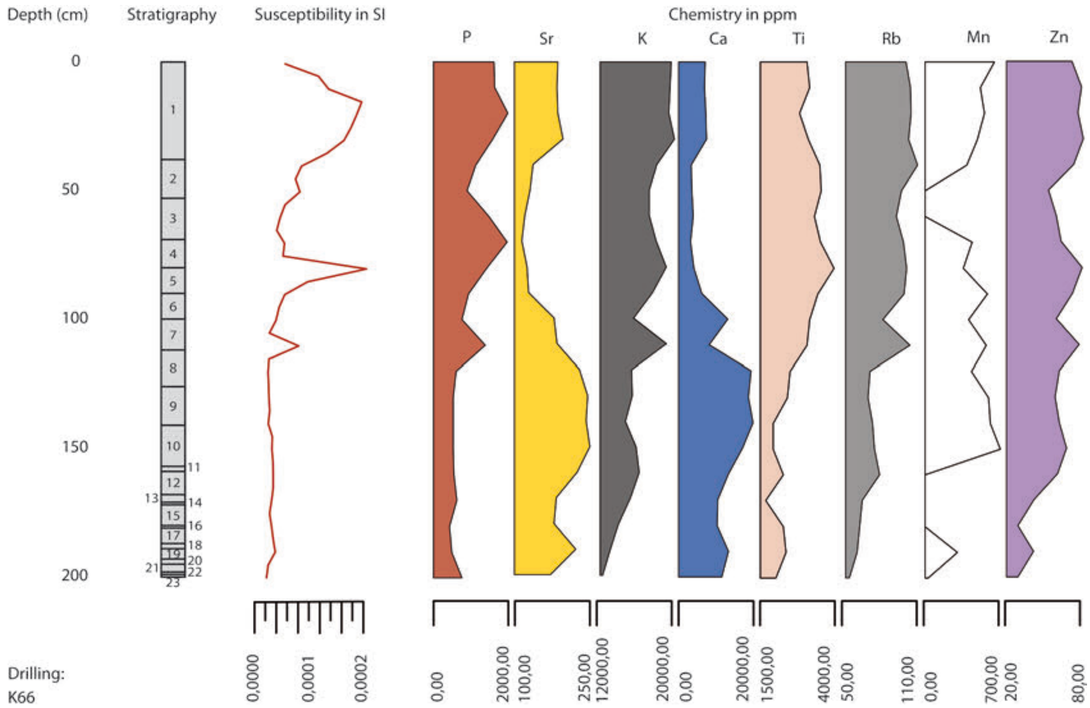

Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
Drilling:
K25
0,00
0,0002
0,0004
0,0006
0,0008
0,00
5000,00
100,00
350,00
10000,00
17000,00
60000,00
140000,00
1800,00
2500,00
50,00
90,00
250,00
500,00
0,00
150,00


Depth (cm)
Stratigraphy
Susceptibility in Si
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Drilling:
K26S
0,00
0,003
0,006
0,009
0,00
2000,00
170,00
240,00
13000,00
22000,00
70000,00
170000,00
1500,00
4000,00
50,00
120,00
300,00
1100,00
30,00
100,00


Depth (cm)
Stratigraphy
Susceptibility in Si
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Drilling:
K37
0,00000
0,00300
0,00600
0,01000
0,00
4000,00
100,00
350,00
8000,00
19000,00
70000,00
160000,00
1500,00
3000,00
30,00
110,00
0,00
600,00
0,00
150,00


Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8
9
10
Drilling:
K52
0,0010
0,0020
0,0030
0,0040
0,0050
0,0060
500,00
3500,00
150,00
300,00
16000,00
19500,00
60000,00
130000,00
2000,00
3500,00
70,00
105,00
0,00
800,00
60,00
120,00


Susceptibility in Si
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
Drilling:
K57


Depth (cm)
Stratigraphy
Susceptibility in SI
Chemistry in ppm
P
Sr
K
Ca
Ti
Rb
Mn
Zn
Drilling:
K66

Abstract: Windows onto the landscape: Prospections on the prehistoric sites at Alsónyék, Fajsz-Kovácshalom, Fajsz-Garadomb, and Tolna-Mözs in the Sárköz region

The investigated geographic area is a key region in the cultural exchange and communication network between the northern Balkans and Central Europe, occupying a position of special interest in Neolithic studies. The region known as the Sárköz, located along the Danube in southern Hungary, was the scene of major archaeological excavations in the past two decades, both on the eastern, Kalocsa side of the Danube (at Fajsz) and on the western side, in the Tolna Sárköz region. Here some of the authors partook in several excavations ahead of the planned motorway track. One of these was undertaken at the exceptionally large site of Alsónyék. The investigation of the Neolithic sites in the Sárköz region provided a good opportunity to invite the work team for non-invasive landscape surveys of the Römisch-Germanische Kommission (RGK) to the region in order to clarify the human impact on the unexcavated parts of the settlements. Since 2011, and especially after 2013, collaboration between the partners became closer and the intensive non-invasive survey work eventually became much more than just geomagnetic prospection. Topographic data were compared with borehole sampling and soil chemistry, while multi-element chemical analysis was supplemented with magnetic susceptibility measurements of the cores. Thus, a series of important new data can be compared and interpreted together with information based on the excavations. The present study offers an overview of the entire range of non-invasive research in the Sárköz region.

Zusammenfassung: Fenster in die Landschaft: Prospektionen auf den prähistorischen Fundplätzen Alsónyék, Fajsz-Kovácshalom, Fajsz-Garadomb und Tolna-Mözs in der Sárköz Region

Der untersuchte geographische Raum ist eine Schlüsselregion für den Kulturaustausch und die Kommunikationsnetzwerke im nördlichen Balkan und Mitteleuropa und erfährt eine besondere Aufmerksamkeit in der Erforschung des Neolithikums. Die als Sárköz bekannte Region, die an der Donau im südlichen Ungarn liegt, war in den vergangenen beiden Jahrzehnten Schauplatz wichtiger archäologischer Ausgrabungen, sowohl in der Kalocsa-Region auf der Ostseite der Donau (Fajsz) als auch auf der Westseite, in der Tolna Sárköz-Region. Hier nahmen einige der Autor*innen an mehreren Ausgrabungen im Vorfeld eines geplanten Autobahnbaus teil. Eine dieser Ausgrabungen fand auf dem ungewöhnlich großen Fundplatz von Alsónyék statt. Die Untersuchung neolithischer Fundplätze in der Sárköz-Region bot eine gute Gelegenheit zur Einladung des Teams für nicht-invasive Landschaftssurveys der Römisch-Germanischen Kommission (RGK), um den menschlichen Einfluss auf die nicht ausgegrabenen Bereiche der Siedlung zu klären. Seit 2011 und insbesondere nach 2013 wurde die Zusammenarbeit zwischen den Partnern enger und aus den nicht-invasiven Surveys wurde weit mehr als nur eine geomagnetische Prospektion. Es wurden topographische Daten mit Daten aus Bohrungen und Bodenchemie verglichen und chemische Multielementanalysen wurden um magnetische Suszeptibilitätsmessungen an den Bohrkernen ergänzt. So kann eine Reihe wichtiger neuer Daten miteinander verglichen und in der Zusammenschau mit den aus den Ausgrabungen gewonnenen Informationen interpretiert werden. Der vorliegende Beitrag bietet eine Übersicht über die gesamte Breite der nicht-invasiven Untersuchungen in der Sárköz-Region.

Absztrakt: Ablak a tájra: Alsónyék, Fajsz-Kovácshalom, Fajsz-Garadomb és Tolna-Mözs újkőkori lelőhelyek roncsolásmentes vizsgálata a Sárköz-vidéken

A Sárköz, amely az Észak-Balkán és Közép-Európa közötti kapcsolati háló fő ütőere volt, különös jelentőséget kapott az újkőkori régészeti kutatásban. A régió a Duna dél-magyarországi szakaszán a folyó mindkét partja mentén fontos régészeti feltárások színhelye volt az elmúlt két évtizedben. Ilyen a keleti, kalocsai oldalon fekvő Fajsz és a nyugati, Tolnai Sárköz területén fekvő lelőhelyek, közöttük a kivételes nagyságú alsónyéki intenzív telep és temető. A Sárközben folyó régészeti kutatások során kapcsolódott a munkába a frankfurti Römisch-Germanische Kommission (RGK) roncsolásmentes vizsgálatokra specializálódott csapata. 2011-től kezdve, de még intenzívebben 2013 óta, mióta személyes szakmai kötelék is egybefűzi a résztvevőket, a geomágneses prospekciót messze meghaladóan szélessé vált a vizsgálati módszerek skálája. A topográfiai adatok összevetve a fúrásokból nyert mintákkal, azok kémiai elemzésével ugyanúgy fontos elemei a vizsgálatnak, mint a minták szedimentológiai és mágneses szuszceptibilitás-mérése. Ez a számos új módszer az ásatásokból nyert adatokkal összevetve kiváló lehetőség az adatok összességének együttes kiértékelésére. A Sárközben végzett non-invazív régészeti kutatások összefoglalója a jelen tanulmány.

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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

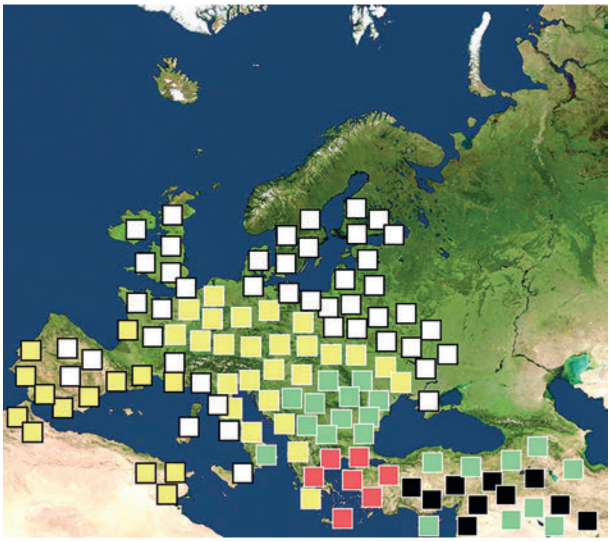

Fig. 1. The spread of the Neolithic transition obtained by interpolating the dates in uncalibrated years before present (uncal BP) of Neolithic sites (squares) in Europe and the Near East. Black squares: before 9000 uncal BP; red squares: 9000–8000 uncal BP; green squares: 8000–7000 uncal BP; yellow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

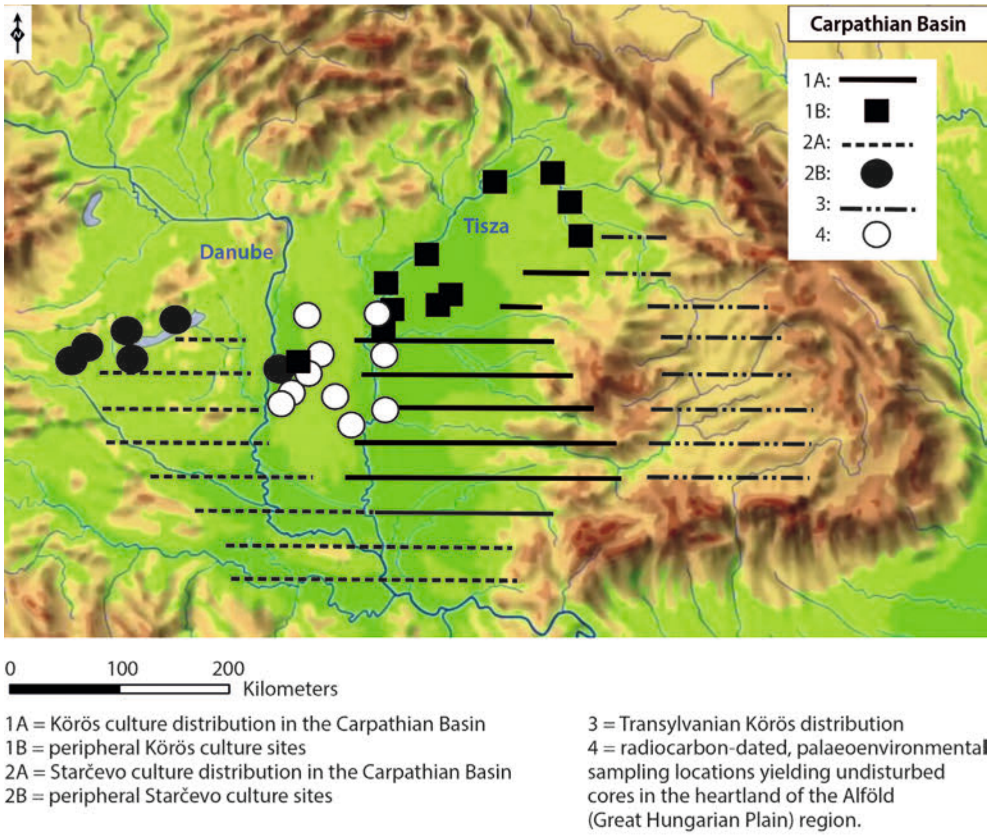

Fig. 2. Distribution of Early Neolithic cultures in the Carpathian Basin and of palaeoenvironmental sampling locations in the Danube-Tisza interfluve.

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 (Mihááltz 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

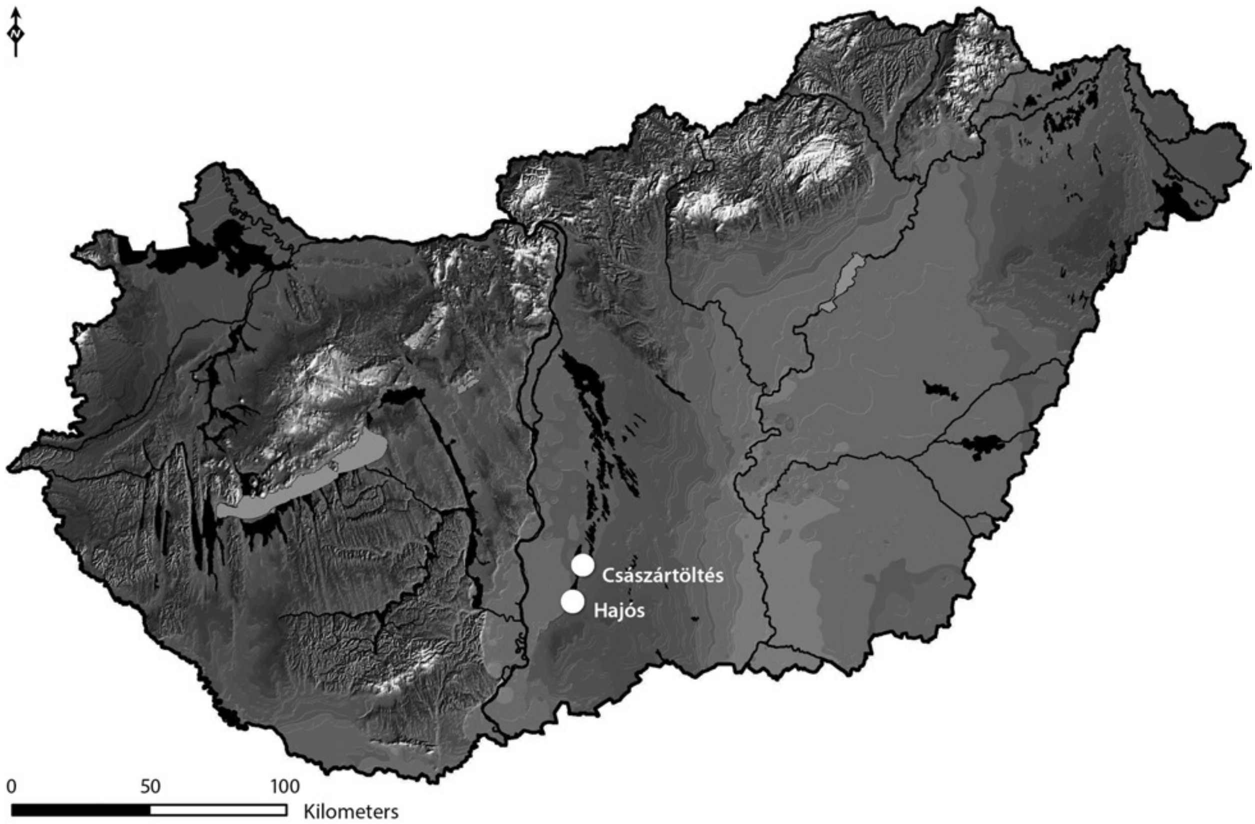

Fig. 3. The location of the Hajós and Császártöltés sites within sedge / reed peatlands (black colour) in the Carpathian Basin.

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

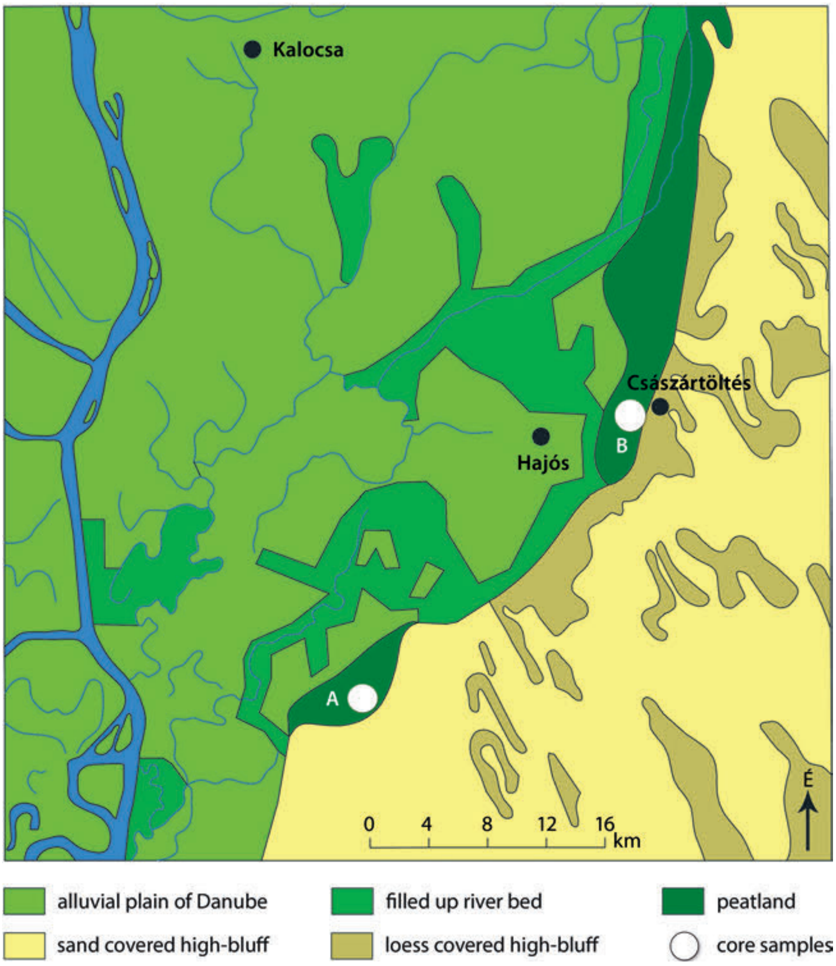

Fig. 4. The location of the peatland the sites at Hajós and Császártöltés in the Danube-Tisza interfluve (DTM). A: location of the analysed core samples from Kaszálók Mire at Hajós; B: location of the analysed core sample from Vörös marshland at Császártöltés; black circle modern town / village.

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

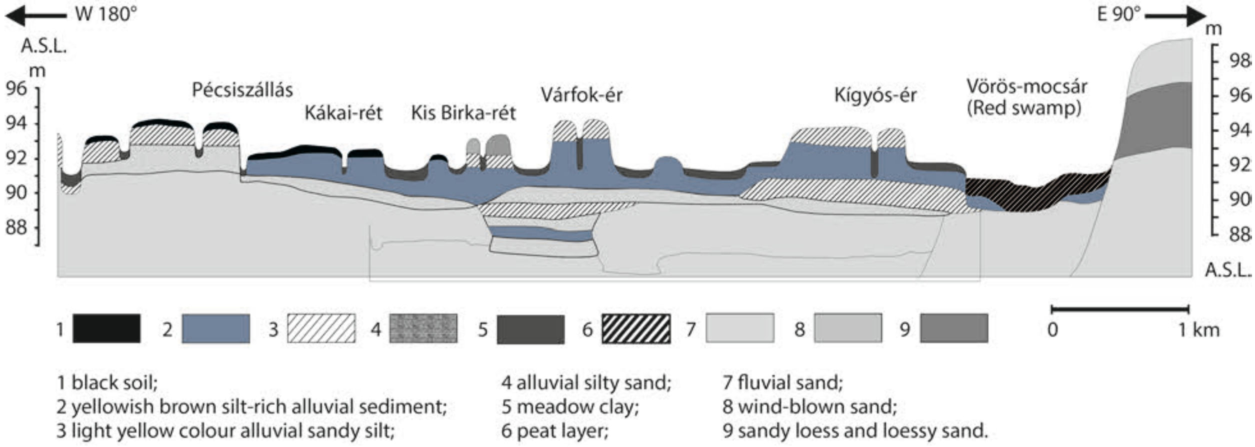

Fig. 5. East-West cross-section of the Danube alluvial plain between Vörös-mocsár (Red Marsh) and Transdanubia (Pécsiszállás village).

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 °C 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

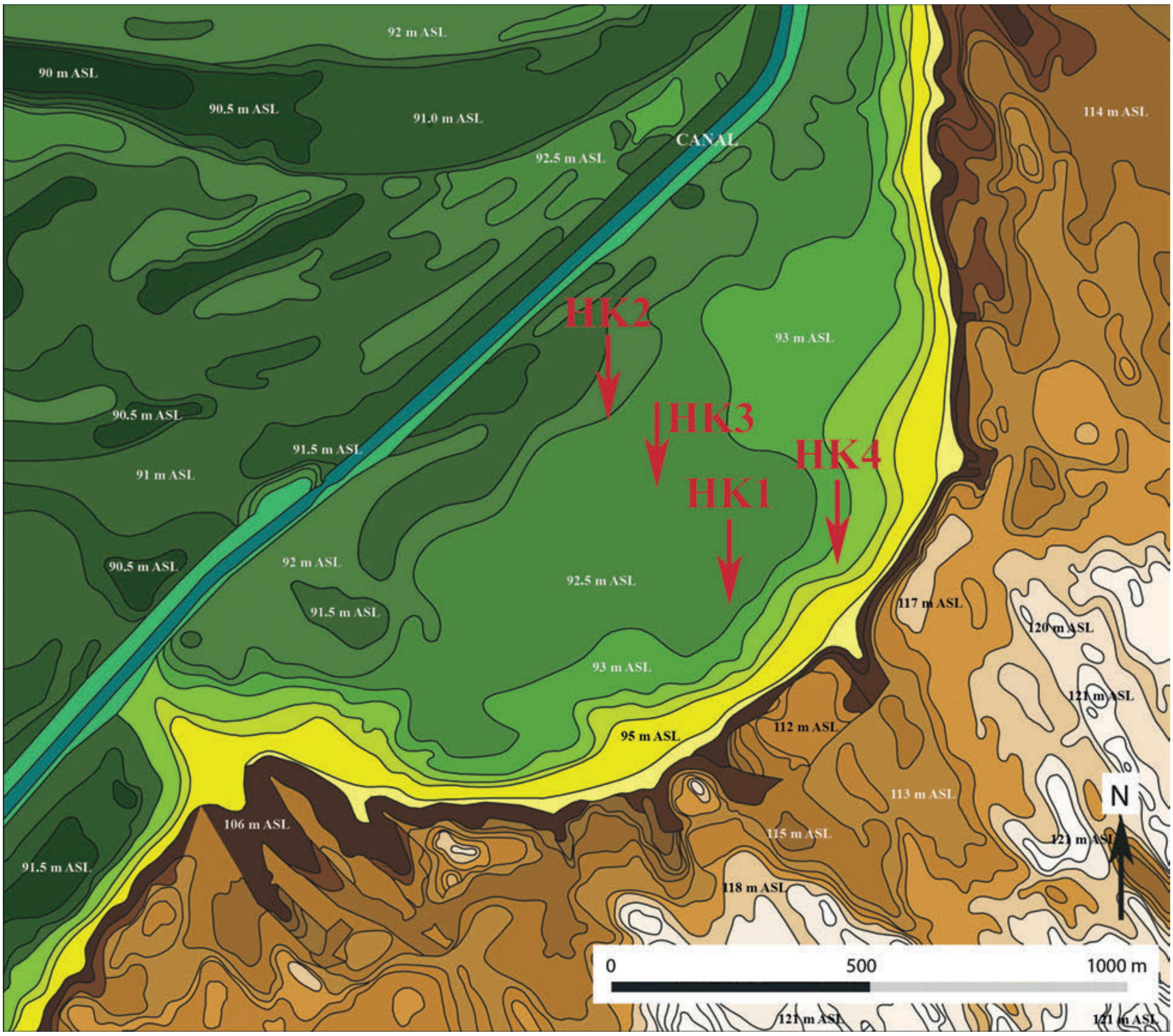

Fig. 6. Location of the undisturbed core points on the Kaszálók Mire at Hajós (DTM).

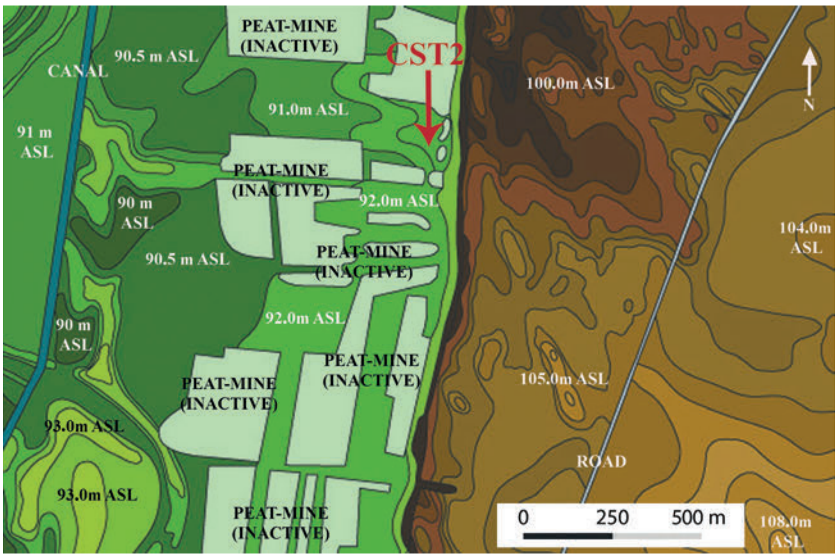

Fig. 7. Location of the undisturbed core point on the Vörös-mocsár (Red Marsh) at Császártöltés.

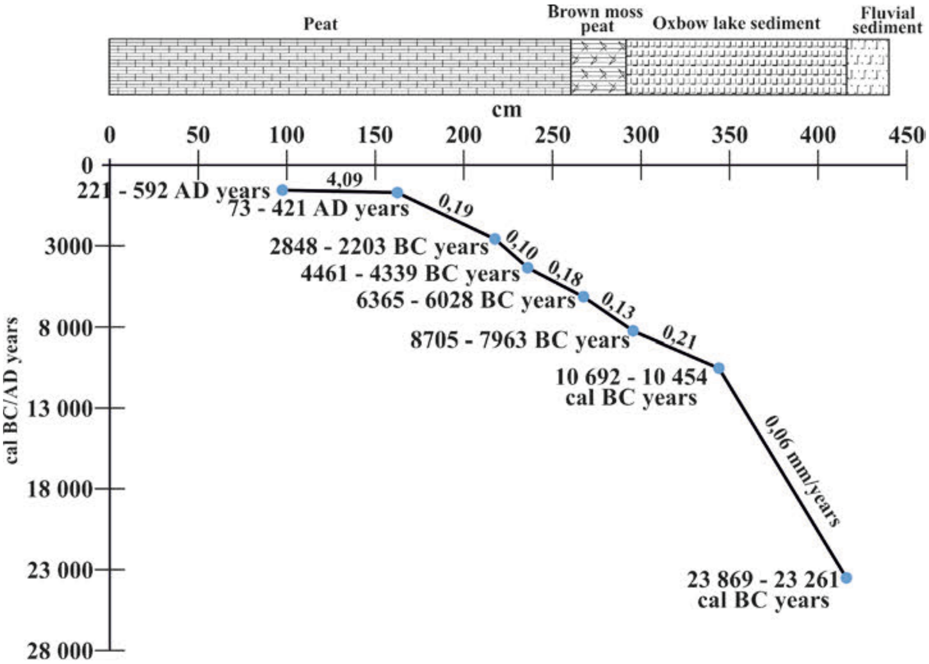

Fig. 8. The sedimentation rate changes based on calibrated radiocarbon ages from the undisturbed core sequence at Hajós *(Fig. 6)*.

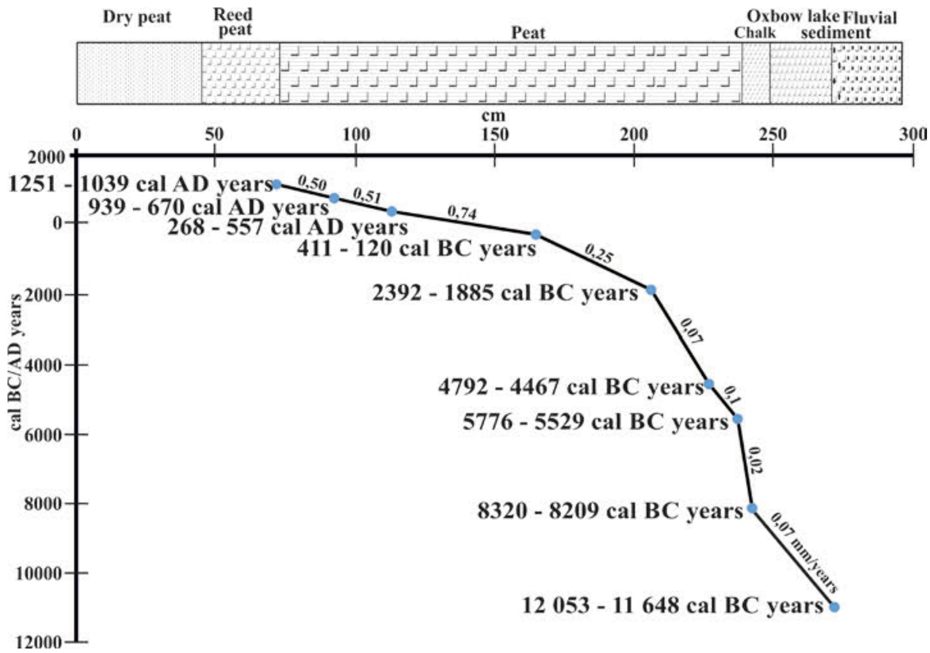

Fig. 9. The sedimentation rate changes based on calibrated radiocarbon ages from the undisturbed core sequence at Császártöltés *(Fig. 7)*.

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.

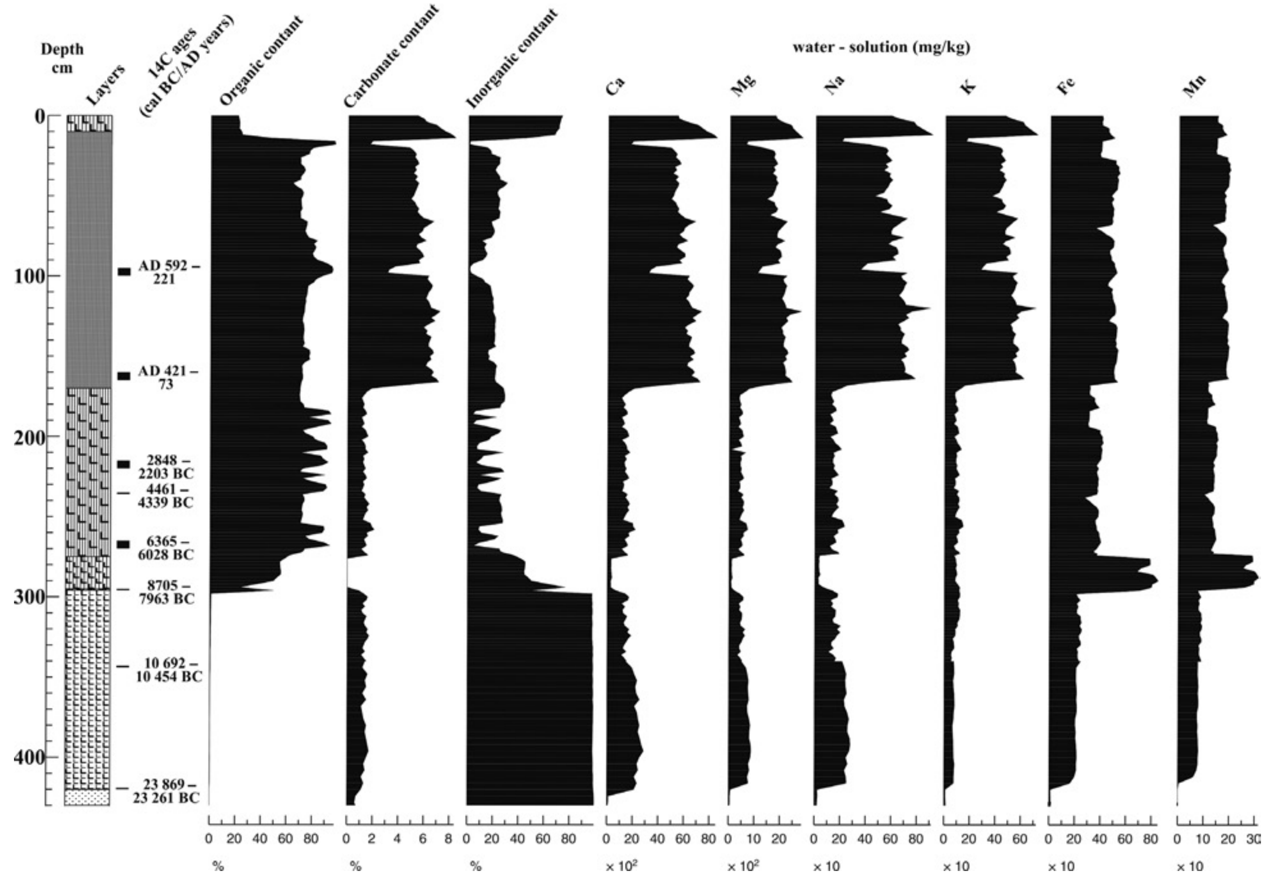

Fig. 10. Sediment and lithological changes in the undisturbed core sequence from Kaszálók Mire at Hajós.

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.

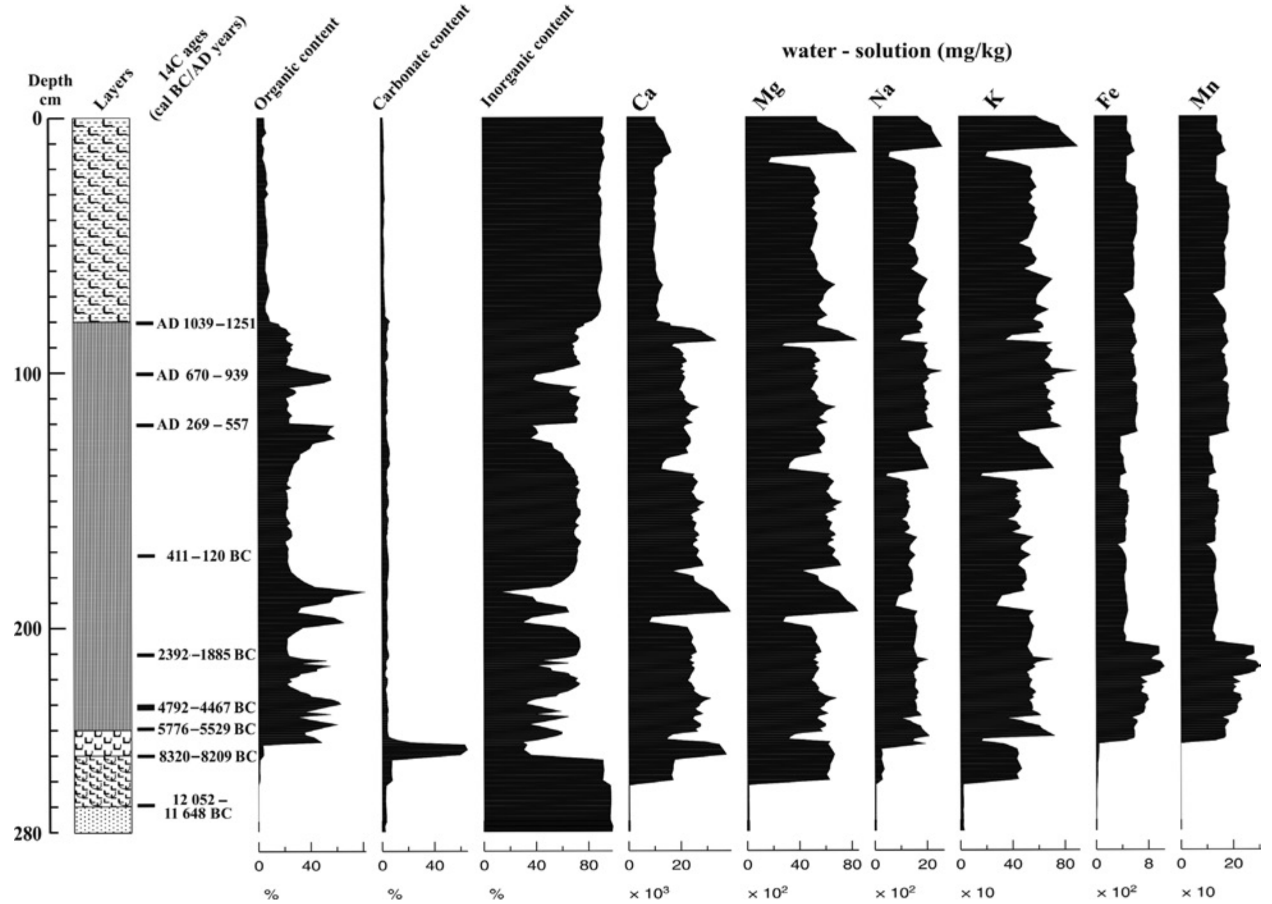

Fig. 11. Sediment and lithological changes in the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés.

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.

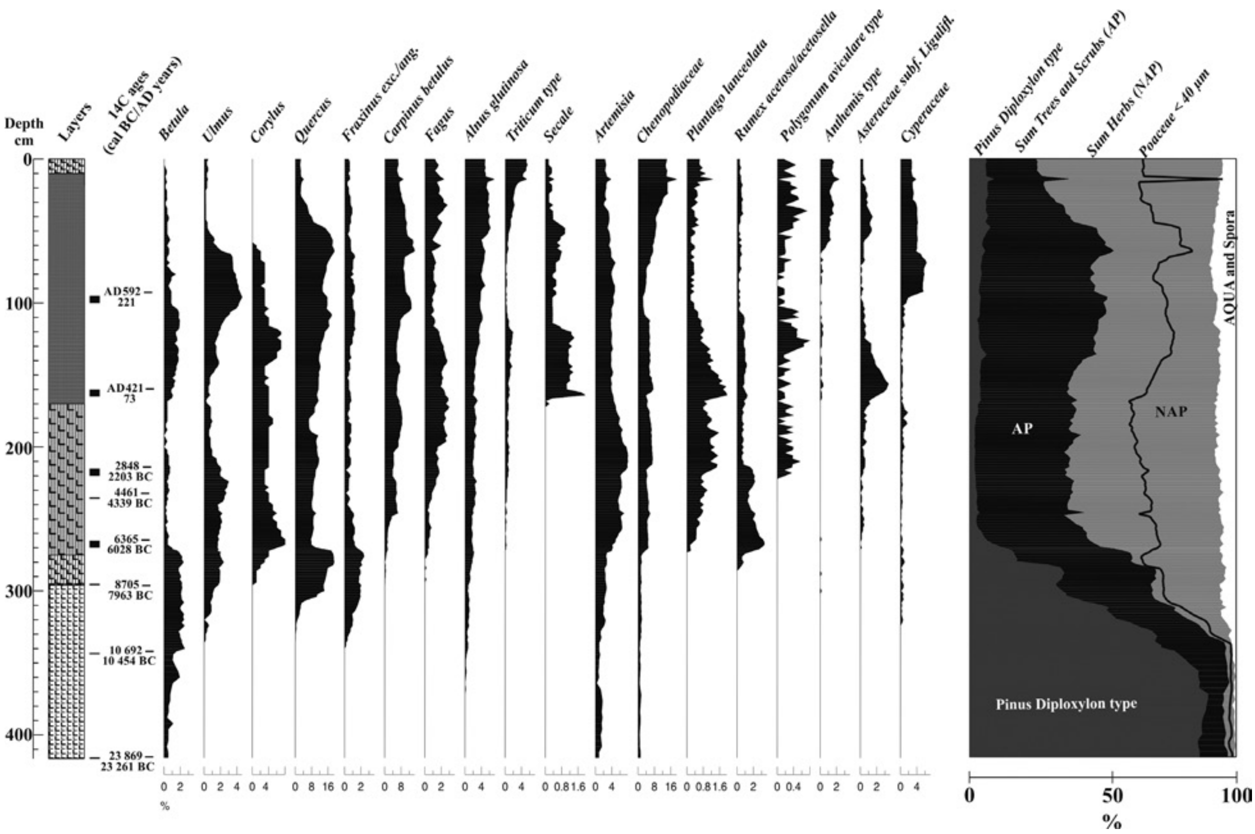

Fig. 12. Pollen (selective taxa) content changes in the undisturbed core sequence from Kaszálók Mire at Hajós.

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

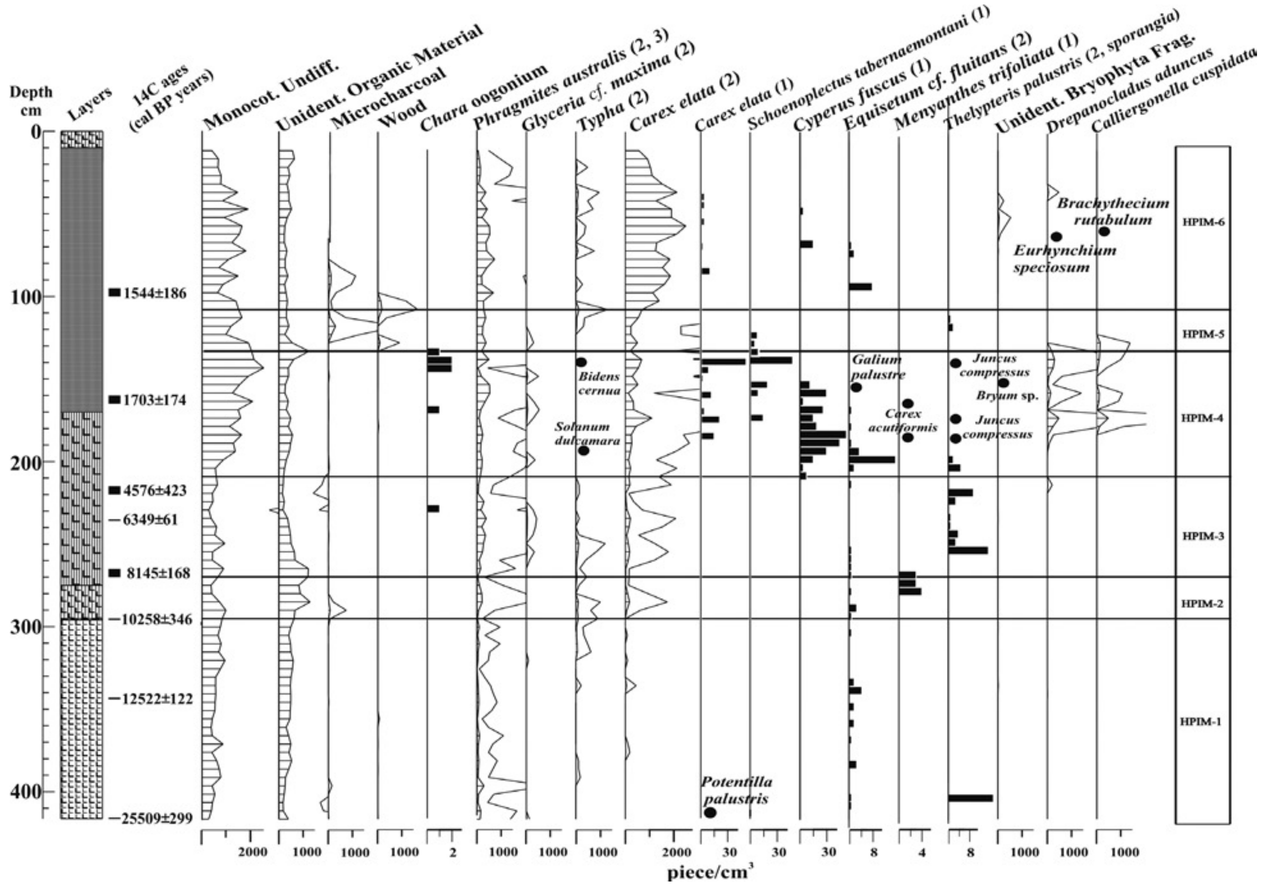

Fig. 14. Macrobotanical content changes in the undisturbed core sequence from Kaszálók Mire at Hajós (redrawn after Jakab / Sümegi 2011 within new radiocarbon data and J. Troels-Smith symbols).

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).

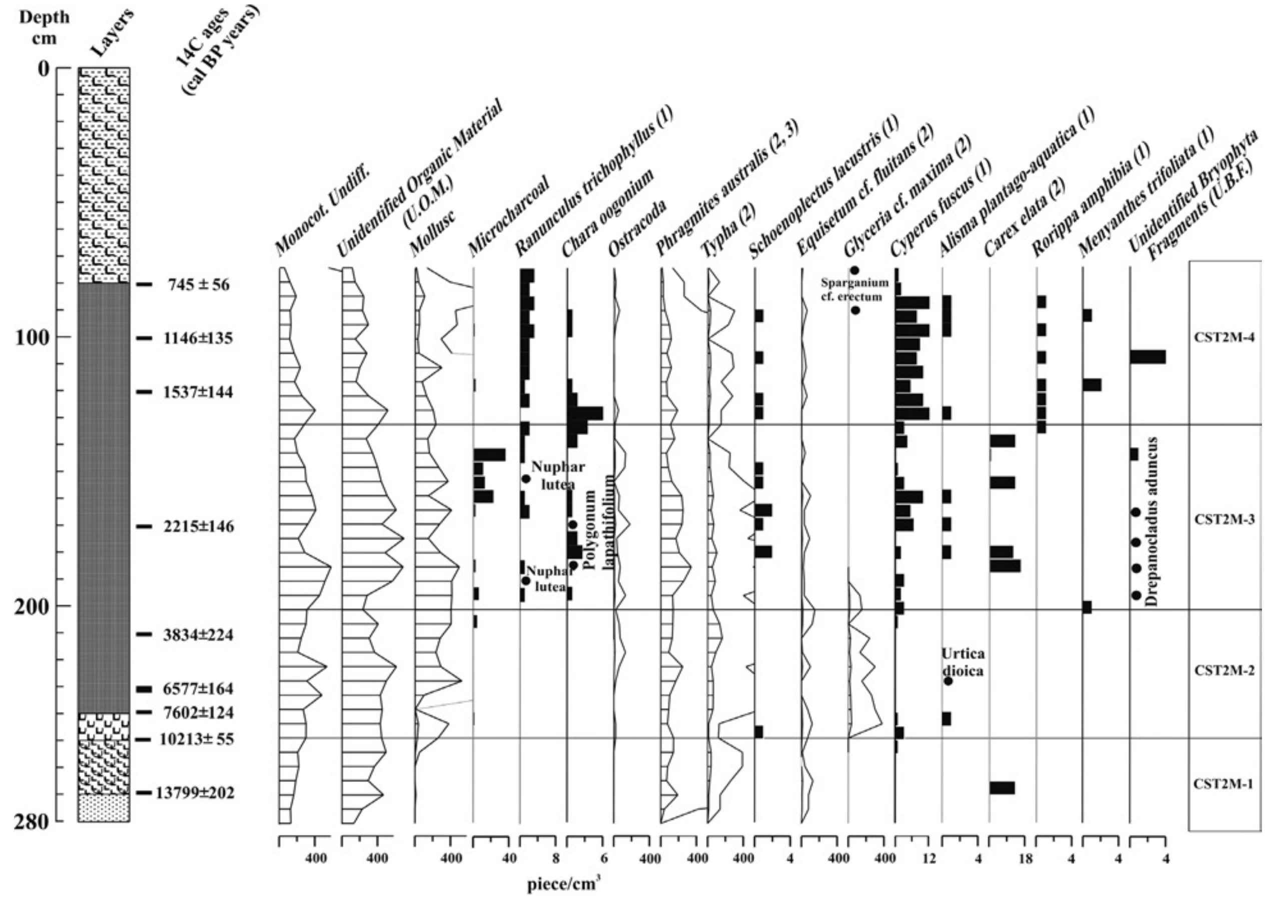

Fig. 15. Macrobotanical content changes in the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés (redrawn after Jakab / Sümegi 2011 within new radiocarbon data and J. Troels-Smith symbols).

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

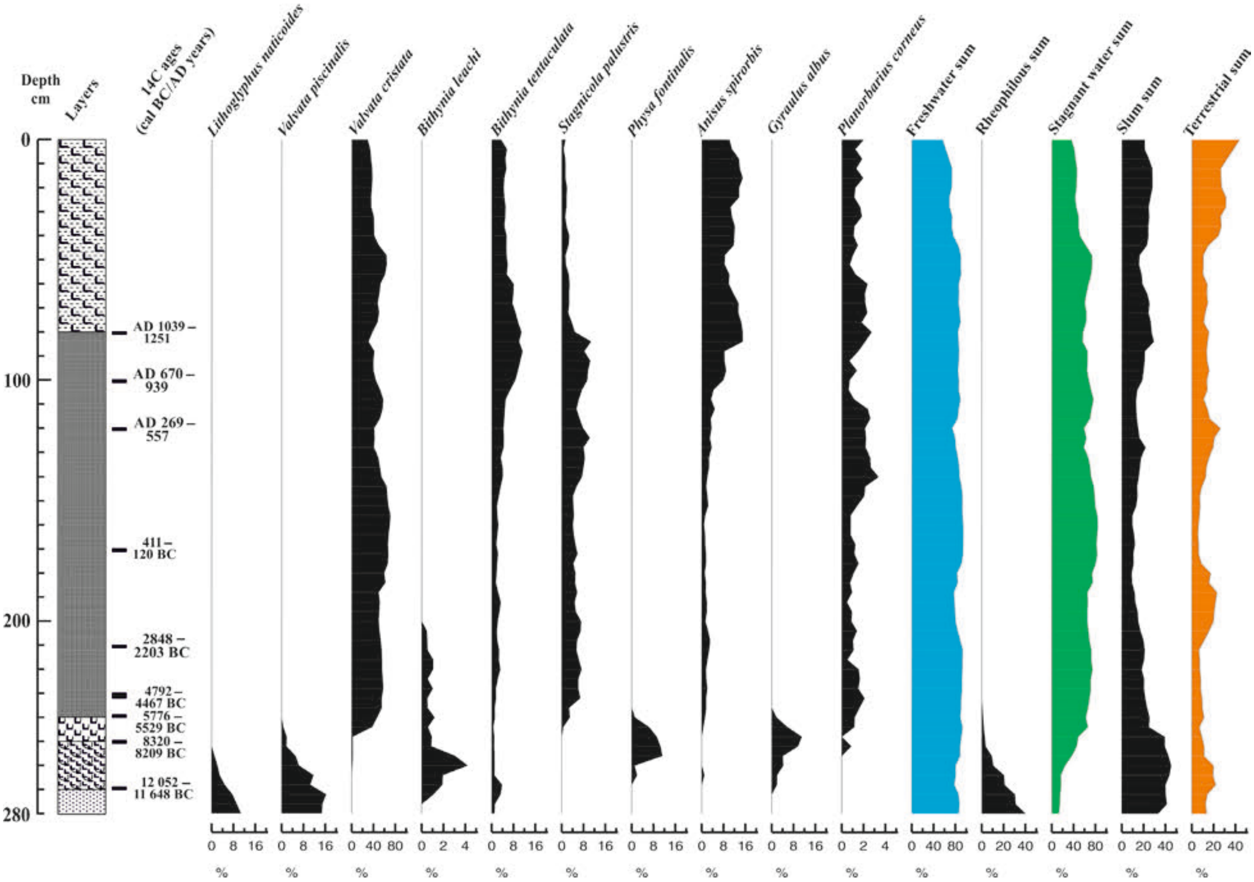

Fig. 16. Malacological changes in the undisturbed core sequence Császártöltés 1 from Vörös-mocsár (Red Marsh).

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

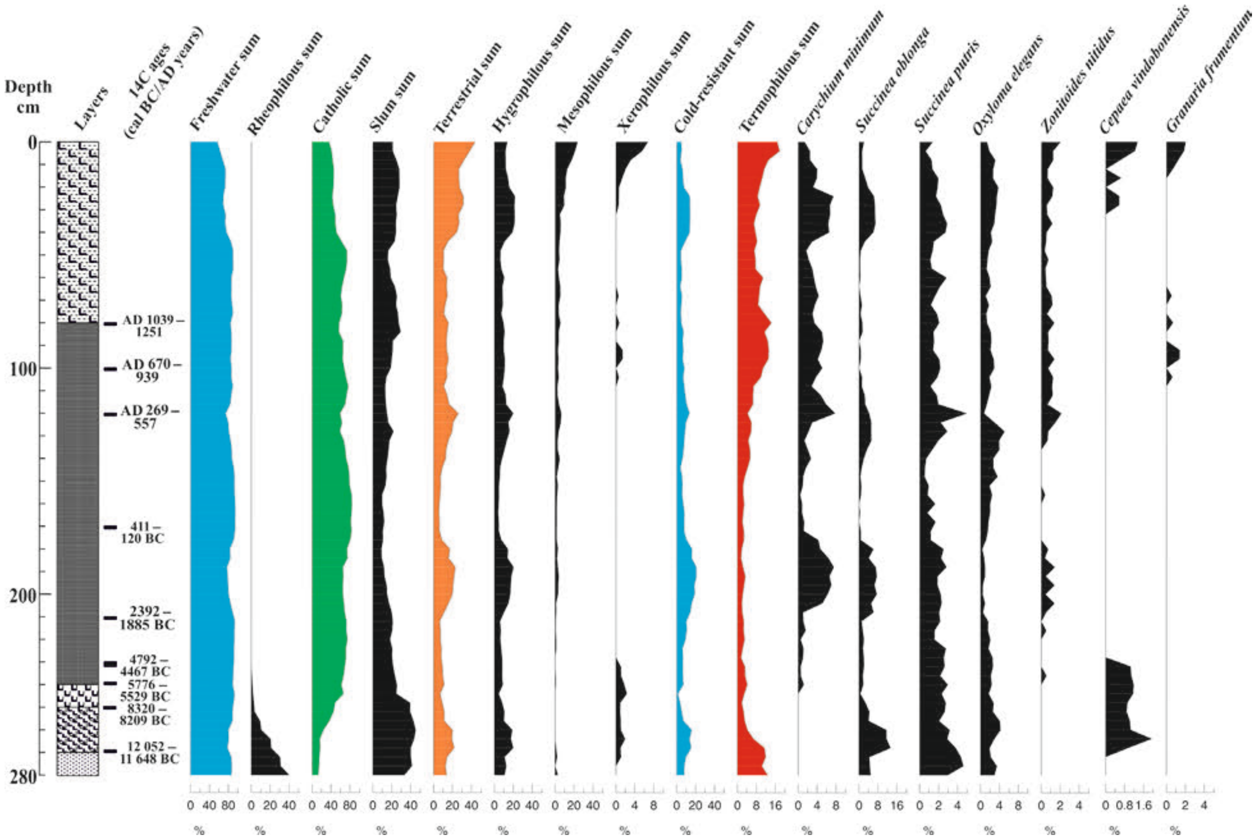

Fig. 17. Malacological changes in the undisturbed core sequence Császártöltés 2 from Vörös-mocsár (Red Marsh).

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

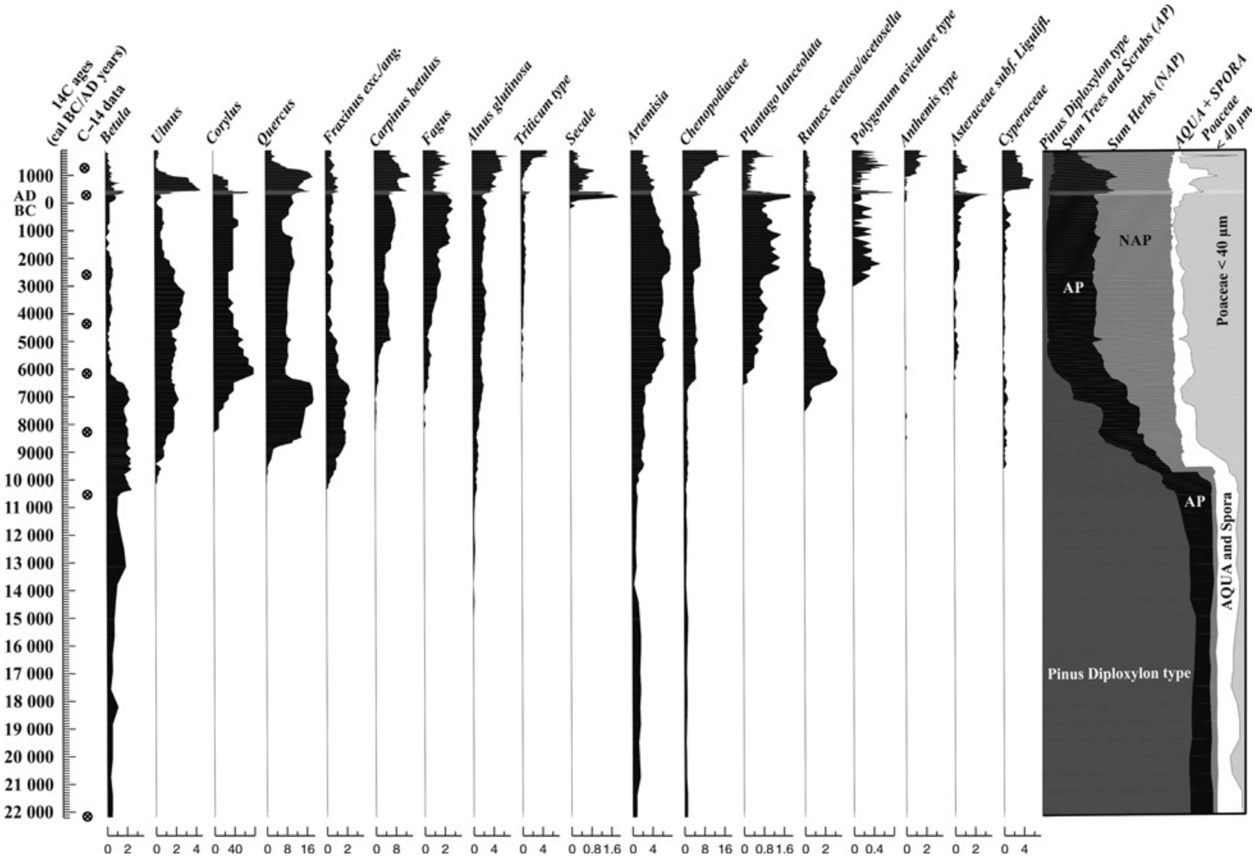

Fig. 18. Pollen percentage diagram for the undisturbed core sequence from Kaszálók Mire at Hajós. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

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).

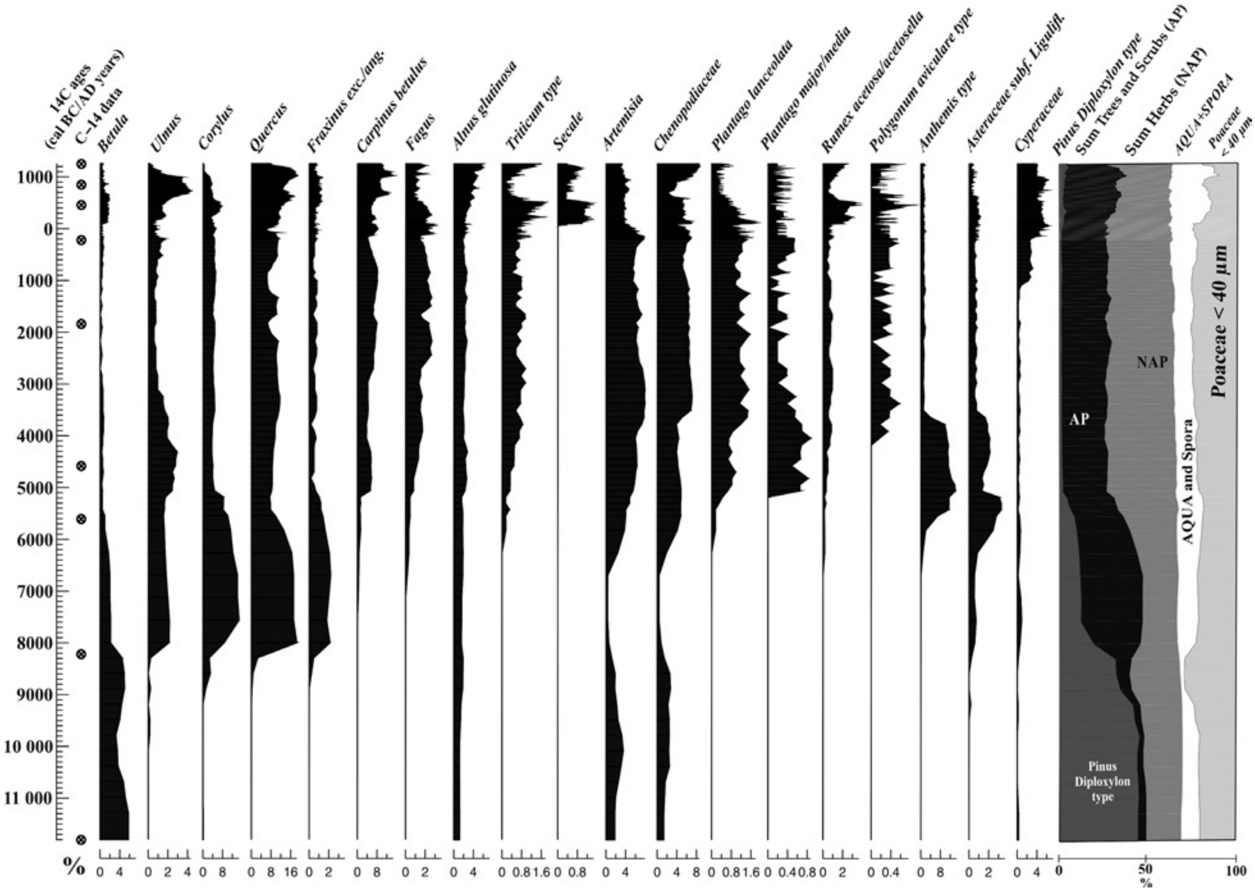

Fig. 19. Pollen percentage diagram for the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

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

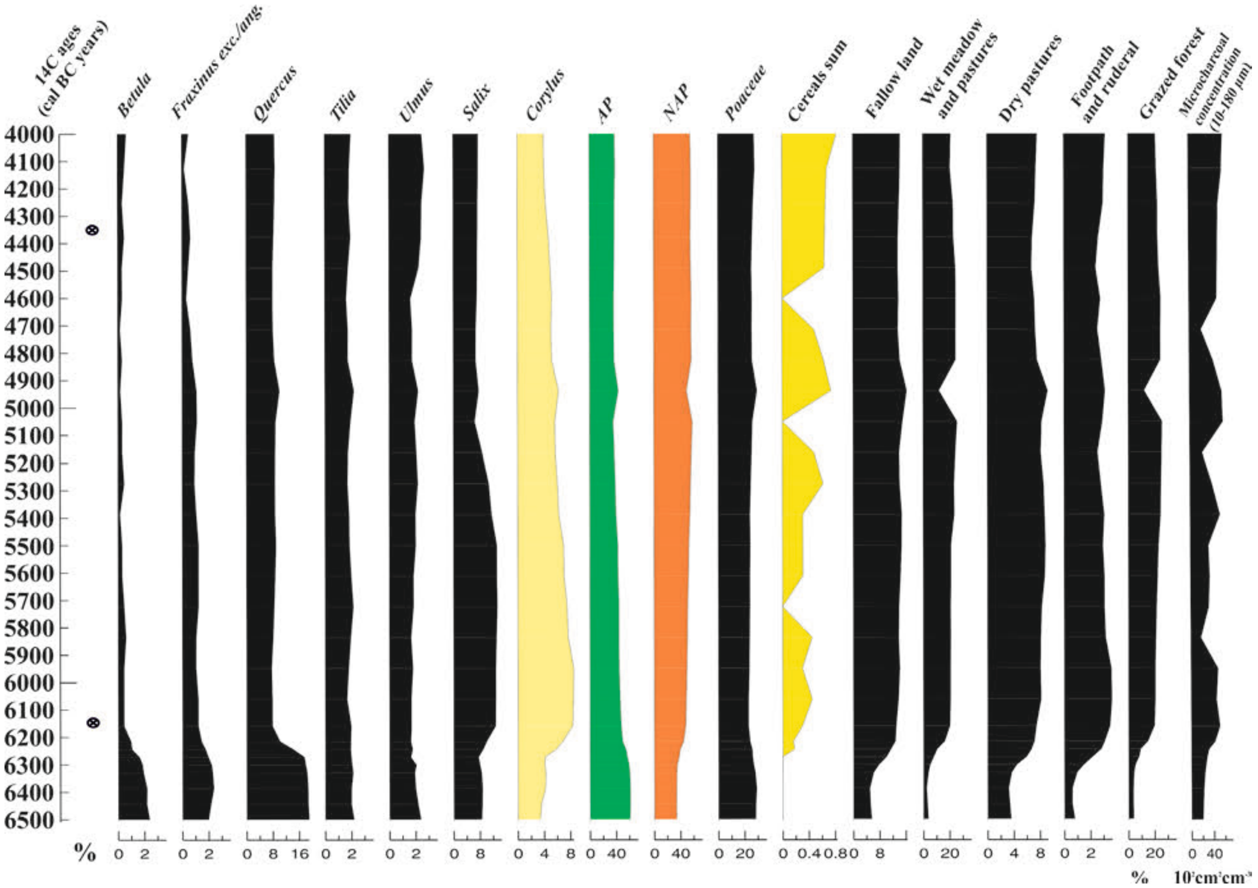

Fig. 20. Pollen percentage diagram and microcharcoal content change for undisturbed core sequence between Late Mesolithic and Middle Copper Ages from Kaszálók Mire at Hajós. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

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).

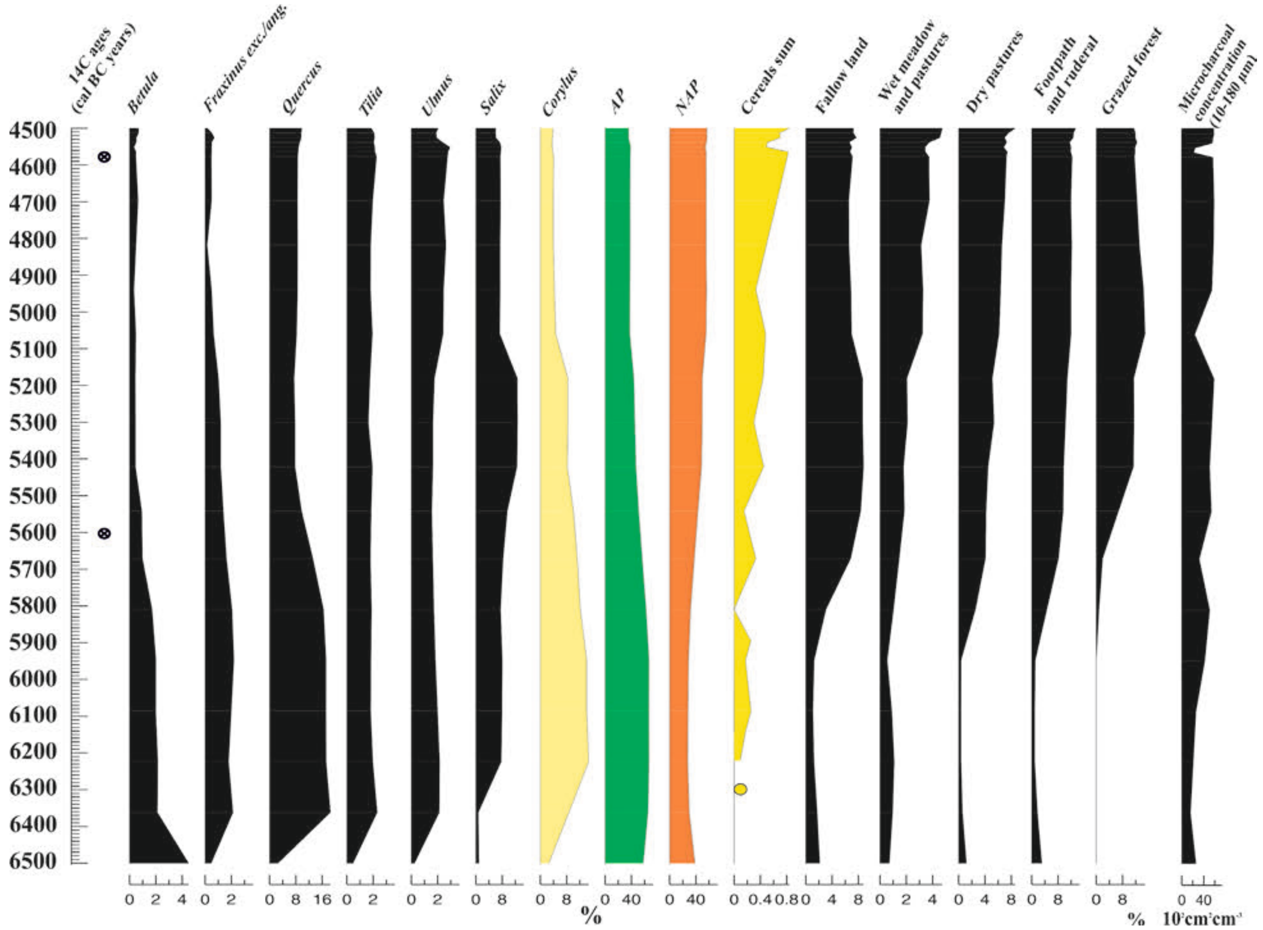

Fig. 21. Pollen percentage diagram and microcharcoal content change for undisturbed core sequence between Late Mesolithic and Middle Copper Ages from Vörös-mocsár (Red Marsh) at Császártöltés. Percentages of selected terrestrial pollen taxa are plotted against age (cal BP).

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

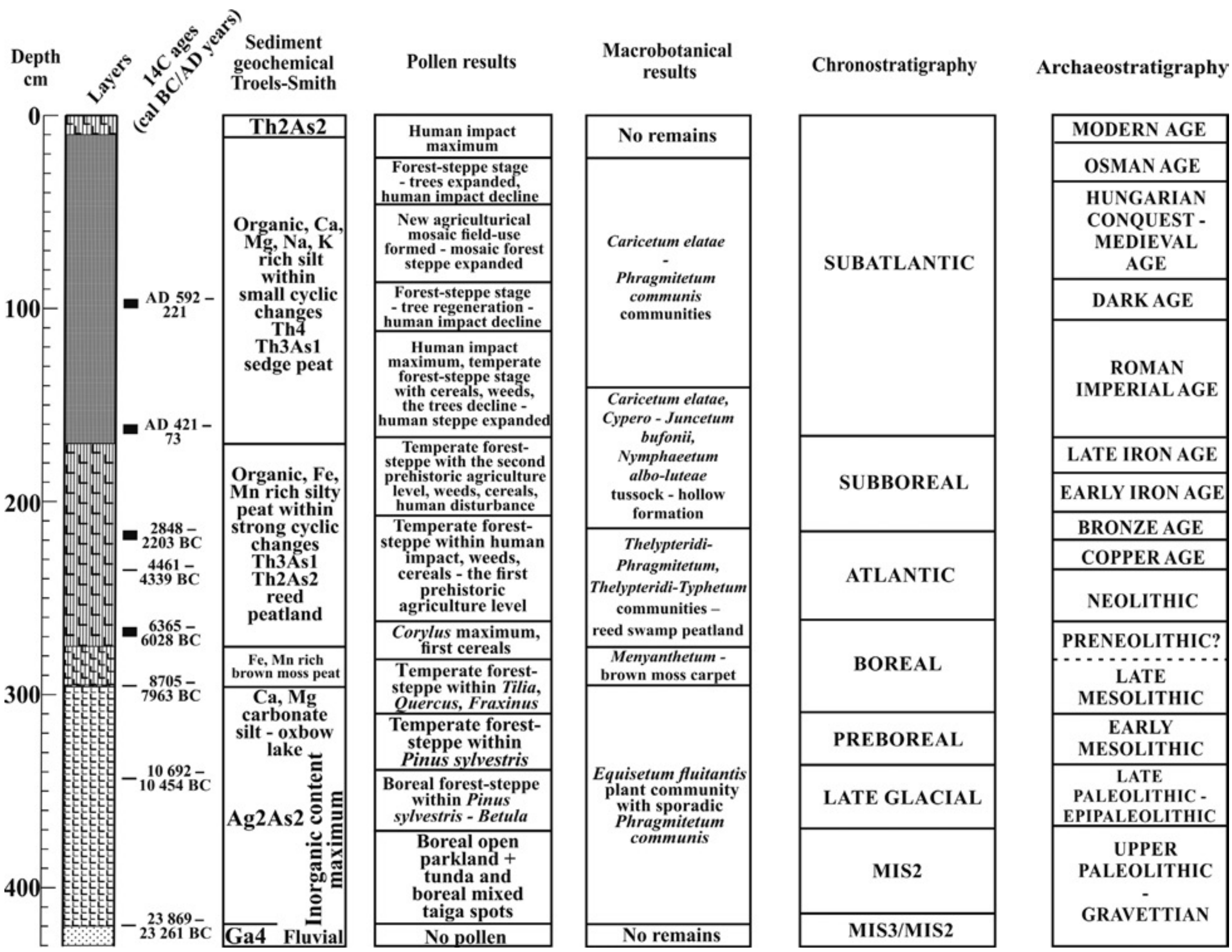

Fig. 22. Description of litostratigraphic, sedimentological, geochemical, pollenanalytical, macrobotanical, chronostratigraphic, and archaeostratigraphic zones for the undisturbed core sequence from Kaszálók Mire at Hajós.

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-

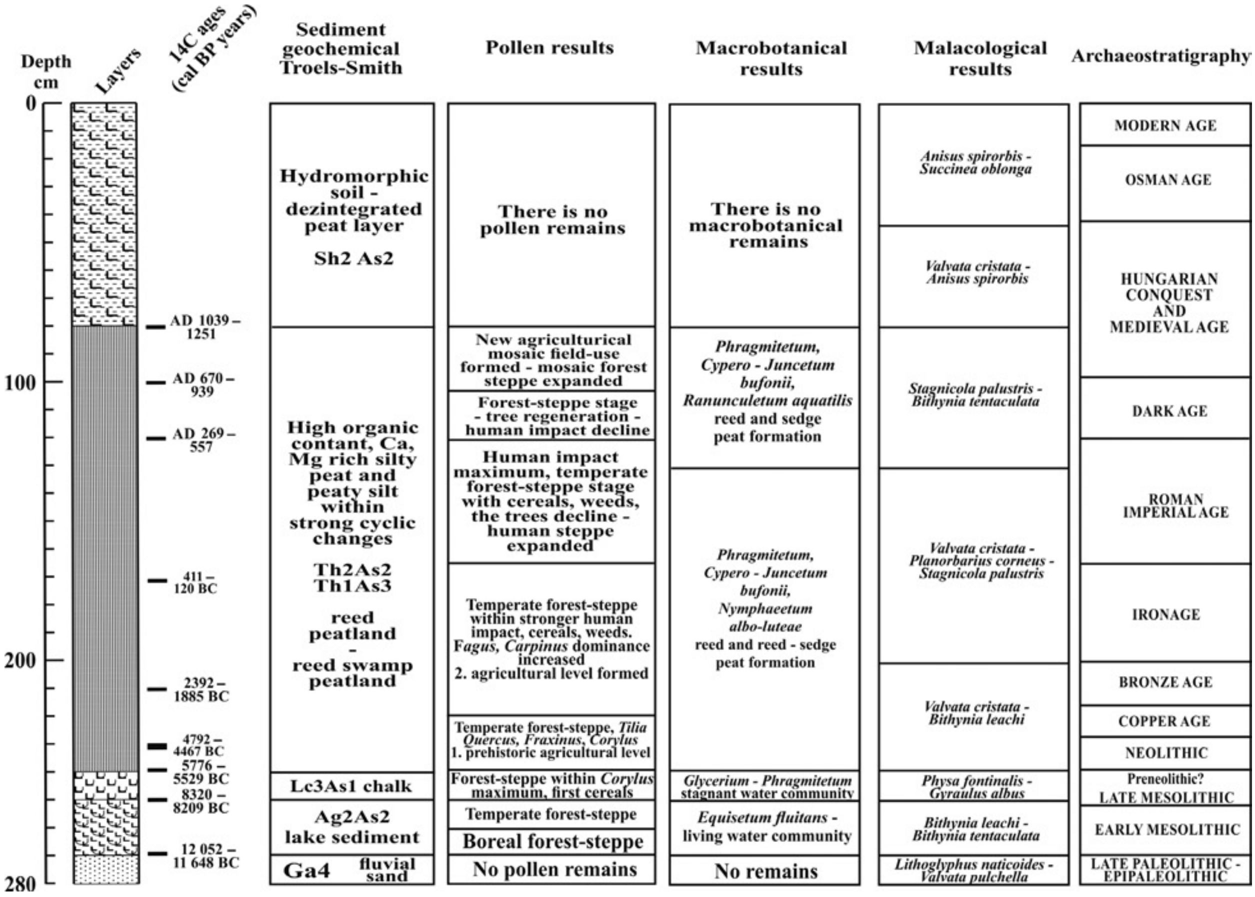

Fig. 23. Description of litostratigraphic, sedimentological, geochemical, pollenanalytical, macrobotanical, chronostratigraphic, and archaeostratigraphic zones for the undisturbed core sequence from Vörös-mocsár (Red Marsh) at Császártöltés.

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

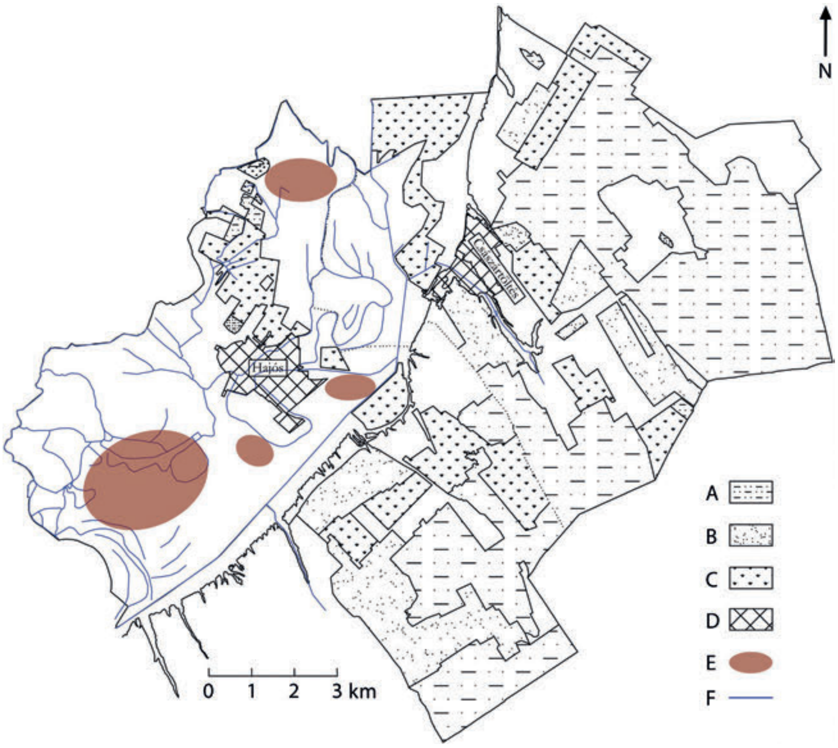

Fig. 24. Neolithic settlements of the Körös culture and Linienbandkeramik (LBK) in the analysed region (redraw after Knipl / Sümegi 2011). A = recent forest, B = recent fruit-growing / vineyard, C = recent pastureland, D = settlement inner area, E = Neolithic (Körös and Linienbandkeramik) settlement 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 6^{th}–5^{th} 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 19^{th}–20^{th} centuries. From the 18^{th} 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-18^{th} 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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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.

Gábor Serlegi

Groundwater under scrutiny: A hydrological aspect of human settlement strategy in the vicinity of the southern shoreline of Lake Balaton

Keywords: settlement, groundwater table fluctuations, optimal hydrological zone, static groundwater model, prehistoric periods, settlement zones

Schlagwörter: Besiedlung, Schwankungen im Grundwasserstand, optimale hydrologische Zone, statisches Grundwassermodell, prähistorische Zeitabschnitte, Siedlungszonen

Kulcsszavak: megtelepedési térfelszín, talajvíztükör-ingadozás, optimális hidrológiai zóna, statikus talajvízszint modell, régészeti korszakok, megtelepedési zónák

Introduction

The anthropogenic transformation of the physical and natural environment of the Carpathian Basin during the past two or two and a half centuries has profoundly changed natural conditions. In most cases, there is no direct relation between the geomorphologic conditions of a given archaeological site and the elements of the modern landscape. This phenomenon is particularly relevant for the formation of the hydrography of the Carpathian Basin. Following initial small-scale local water system transformations, the planned, sweeping river regulation measures launched in the late 18th century completely reshaped the hydrographic conditions of this geographic area. The extent of surface waters completely changed in the wake of the drainage of the periodically or permanently flooded areas, as well as due to meander cut-offs and the creation of new artificial channels connecting the closest sections of river bends. This drastic intervention in the regulation of the surface water system had also a significant impact on groundwater conditions.

A handful of earlier studies have dealt with the reconstruction of ancient conditions through the analysis of archaeological sites, archaeological phenomena, and river discharge, as well as the landscape forming potential of watercourses (Horváth 2004, 49–63; Székely et al. 2009, 71–93).

However, there exists a much broader range of scientific literature on the relationship between water level and the extent of water bodies, and the formation of archaeological sites. Among them, many research projects and studies covered Lake Balaton, alongside the identification of the lake's historic water level fluctuations. The results of the first phase of research with an archaeological perspective on the water level fluctuations of Lake Balaton and the past extent of the lake were published in the 1960s and 1970s by Károly Sági and László Bendefy. The relation between the depth of the archaeological features, the groundwater level, and the lake's water level was a regularly addressed issue in their publications. However, their primary goal was to estimate the past extreme water level conditions of the lake, while the associated climatic characteristics of the archaeological periods were based on the depth of the excavated archaeological features and the modern groundwater level conditions observed in them.

Due to the technological level of the geodetic measurements and the uncertainty of levelling at the time, these studies include a number of controversial issues. Research work was further complicated by the limited number of available data on this subject and the fact that these records were gained through the examination of individual archaeological sites located far from each other in different geomorphologic settings. Nevertheless, the most significant result of this early research was the growing awareness of the fact that both the surface water and groundwater conditions of the Lake Balaton area played a significant role in influencing the occupation strategies and spatial possibilities of past communities (Bendefy 1968, 257–263; 1970, 365–368; 1972, 335–358; Bendefy / Nagy 1969; Füzes / Horváth 1971, 491–497; Sági 1968a, 15–46; 1968b, 441–462; 1970, 200–207; 1971, 485–490; Sági / Füzes 1973, 247–260).

In the first decade of the 21st century, the large-scale excavations undertaken along the planned track of the M7 motorway catalysed research focusing on the relationship between the historical water level changes of Lake Balaton and the data from archaeological sites. The overwhelming majority of these studies, offering a complex assessment of possible correlations, is linked to the work of Pál Sümegi and his colleagues. As part of the interdisciplinary environmental historical and geoarchaeological analyses, the data provided by satellite imagery, aerial photographs, historic maps, and topographic surveys, as well as the evaluation of sediment samples obtained from the cores of the sedimentary basins were used to reconstruct ancient environmental conditions. The significance of these complex studies is that the reconstruction of the palaeovegetation of a particular environment was based on palynological, macrofossil, and malacological analyses. Moreover, the results gained through the corings and the observations of the groundwater fluctuations in numerous archaeological features were also considered when reconstructing the water level of Lake Balaton during different archaeological periods (Sümegi et al. 2004, 399–420; 2007, 241–253).

It is clearly visible even from this brief review of previous research that researchers were aware of the relationship between the depth of the archaeological features and that of the groundwater level already at an early stage. However, the isolated point-wise data did not allow the detailed examination of the characteristics of groundwater movements at previously excavated archaeological sites. Due to the extensive excavation work ahead of the motorway construction, the data of thousands of archaeological features across many hectares of contiguous area, the spatial data provided by modern geodetic instruments, as well as the GIS analysis of the excavations offered the possibility of analysing the changing strategies of environmental utilisation and landscape occupation during different archaeological periods around Lake Balaton. The spatial distribution of the archaeological features of a given period determines the nature of how space was used on the former settlement, which can be used to identify the occupation strategies of ancient communities. Based on my research, I have come to the conclusion that the depth and the fluctuation of the groundwater level of the occupation area are among the most decisive environmental factors in this regard. This study focuses on the detailed examination of this issue. It is based on the comparison of the spatial analysis of the archaeological features of a multi-period archaeological site located along the M7 motorway with the static groundwater model generated for the area of the site.

The broader environment

In order to understand the details of the environmental model to be described at greater length below and its results, a brief introduction to the broader geographic and geomorphologic environment of the archaeological site as well as the determining landscape elements seems in order *(Fig. 1)*.

Marcali Ridge

This ridge area divides the Inner Somogy alluvial cone. Its northern territory borders on the shoreline of Lake Balaton, whilst its southern territory flattens towards the alluvial fan. The geomorphology of this micro-region is characterised by smaller alluvial fans that developed along fault lines and by the ridges formed in-between incised valleys running from Lake Balaton toward the Inner Somogy area. The slopes of the micro-region are moderately steep; only the northern territories have steeper inclinations (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475). The geology of the Marcali Ridge is characterised by Pannonian sand, clay, and Pliocene cross-bedded sand. These sediments are covered by fluvial gravel and thick loess sediments (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475).

The area has a significant water surplus: the watercourses only seldom dry up, and a larger water discharge only occurs in spring or early summer. The groundwater level can be found within a 4 to 6 m relative depth, whilst in the deeper valleys, it occurs within 2 m. In contrast, the depth of the groundwater table can reach 10 m on higher reliefs (Marosi / Somogyi 1990, 528–536; Dövényi 2010, 471–475).

Nagyberek

The northern section of the eastern slope of the Marcali Ridge extends to the Nagyberek, once the biggest embayment of the Balaton Basin. The former embayment extends south into the Inner Somogy alluvial cone, lying at a distance of approximately 30 km from the present

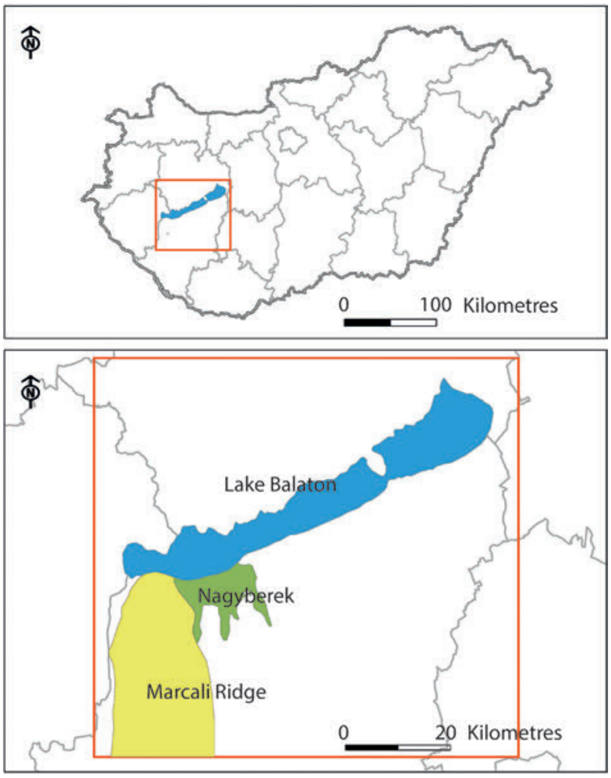

Fig. 1. The broader environment of the investigated area with the landscape zones Marcali Ridge and Nagyberek in present-day Hungary.

shoreline. The territory of the embayment is flat, with higher ridges only appearing at its margins. Its surface is plain, only lower bay barrier bars vary together with oval marshland basins (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439). Its area was once filled with the water of Lake Balaton and, as a result, not only the gritty, sandy alluvial cone material of the "pre-Balaton phase" occurs here, but younger silty, clayey, and sandy lacustrine sediments were also deposited throughout the Holocene. The bay barrier bars were formed from these latter sediment types. They slowly isolated the embayment from the lake body, resulting in the appearance of dead water. Under these conditions, significant amounts of peat, lime mud, as well as meadow and peat soils developed (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439). In fact, the entire area can be considered as a flood basin, which is underlined by the fact that at present only an extended irrigation channel system can regulate the territory's water balance. The discharge of the incoming watercourses is low, and a significant increase can only be experienced in spring or early summer. This area also acts as a buffer zone. The groundwater level is within a 2 m relative depth (Somogyi / Marosi 1990, 487–491; Dövényi 2010, 436–439).

Lake Balaton

At present, Lake Balaton is a south-west to north-east oriented, 77 km long elongated lake. Its shape and shoreline were formed in the wake of the afore-mentioned drastic anthropogenic effects. From the later 18th century onward, the demand for additional agricultural land in the Transdanubia region increased significantly. Permanent forest clearings resulted in significant soil erosion, which accelerated the eutrophication of the bays of Lake Balaton. In order to gain more arable land in the proximity of Lake Balaton, the hydrological interventions were intended to reduce the lake's water level. From the early 1820s, the water level was reduced in successive phases. In the wake of these interventions, the construction of the Budapest–Zagreb–Fiume railway began in 1858 on the bay barrier bars along the new shoreline. Due to the more humid and cooler years after the railway construction, the lake's water level began to rise. The storms of the drifting ice during the winter of 1860/61 caused serious damage to the railway track under construction. Therefore, following the effective intervention of the South Railway Company, a detailed regulation plan for Lake Balaton was adopted in the summer of 1862. The floodgate on the Sió Channel was built according to this regulation plan in 1863. The current state of Lake Balaton, its present extent, and its shoreline, which hardly resembles the one-time natural conditions, developed according to those measures, which were principally driven by modern economic interests.

Geology of Lake Balaton

Several studies have covered the geological evolution of the lake. Already at the turn of the 19th and 20th centuries, scholars like Lajos Lóczy (Lóczy 1913, 617), Gábor László (László 1913, 567), and Jenő Cholnoky (Cholnoky 1918, 11–22) noted that the water level and the water extent of Lake Balaton periodically exceeded its modern conditions. Their assertions were supported by the examination of the shoreline bay barrier bars, the emerged shoreline platforms, and the thickness of the peat sediment layers. One of the key findings of these geological surveys is that even a slight rise in the water level results in the flooding of the meridional valleys located south of the lake, similarly to the territory of the Nagyberek. In their publications they emphasised that in case of a water level increase, these areas become the natural embayments of the lake *(Fig. 2)*.

Later geological research noted that Lake Balaton lies on the boundary of two neo-tectonically active geological units. These active geological areas imply the gradually uplifting Transdanubian Mountains to the north and

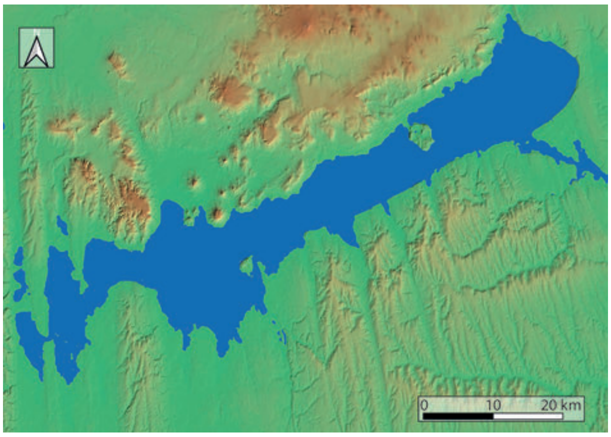

Fig. 2. The reconstructed natural watercover of the lake basin at 105 m a.B.s.l. (cf. Timár et al. 2006).

the gradually subsiding Pannonian Basin to the south. Geological surveys conducted for clarifying the geological evolution of the lake found that the Pannonian Sea was present in this area well before the formation of the lake basin. The geological cores penetrated Upper Pannonian sediment layers within the relative depth of 8 to 10 m. However, this water body cannot be identified as the progenitor of Lake Balaton (Nagy-Bodor / Cserny 1998, 360).

Lake Balaton can be divided into four distinct sub-basins: the Keszthely Basin, the Szigliget Basin, the Szemes Basin, and the Siófok Basin, and as an additional geomorphologic depression, the Little Balaton is attached to the lake. Although the Little Balaton seems to be genetically part of the lake, it differs from the other four sub-basins of Lake Balaton in terms of its geological evolution and formation time (Lóczy 1913; Tullner / Cserny 2003, 216).

Silurian, Permian, Triassic, Miocene, Pliocene, and Quaternary geological formations can be found north of Lake Balaton, whilst Pliocene and Quaternary sediments dominate on the southern shore. The most extensive geological formations are the Upper Pannonian sediments (limestone, sand, clay) together with Quaternary sediments such as Pleistocene loess, diluvial, alluvial, and fluvial sediments. The formation process of the lake basin was determined by the interaction of several environmental factors and began around the end of the Würm glaciation period, around 15 000–16 000 cal BC (Sümegi et al. 2007, 242). Current research has shown that the basin of Lake Balaton was formed on the boundary of the afore-mentioned neo-tectonic fault during the Upper Pleistocene and was further deepened by subsequent deflation and erosion effects (Nagy-Bodor / Cserny 1998, 360; Tullner / Cserny 2003, 219). The inundation of the sub-basins did not occur simultaneously, but gradually, starting in the west and progressing towards the east due to the increased precipitation and surface water drainage. The Siófok Basin was only filled up with water at the end of the Pleistocene. The gradual process can most probably be ascribed to the fact that the larger part of the water catchment area is linked to the lake's western sub-basins. With time, and in the wake of lacustrine abrasion, the ridges that separated the sub-basin were gradually eroded. This process formed the seemingly uniform basin of Lake Balaton. Early research assumed that the merging of the sub-basins occurred already during the Pleistocene (Lóczy 1913; Marosi / Szilárd 1981, 22–27). In contrast, current palaeolimnological research contends that the process of sub-basin union occurred continuously during the Holocene (Nagy-Bodor / Cserny 1998, 361; Tullner / Cserny 2003, 219; Jakab et al. 2005, 407). The most recent complex surveys have proven that this occurred at the very beginning of the Holocene (Sümegi et al. 2014, 76).

Hydrography and sedimentology of Lake Balaton

Currently, the lake's water surface has an extent of 600 km^2 and a volume of 2 km^3 of water. The average depth of the lake is 3.35 m. The water catchment area of the lake, together with the river Zala, is approximately 5200 km^2 (Tullner / Cserny 2003, 216–218). In addition to the rainfall that falls on the surface of the lake, it is fed by 30 permanent and 20 periodic watercourses, the largest of which is the river Zala. Due to the lake's shallow water level, the wind has a significant effect on the movement of the water in the basin. The height of the waves can reach 1 m, while their length varies between 7 to 10 m. As a result of the dominant north-westerly wind, a so-called standing wave effect may occur, in which case the water level in the Siófok Basin can be 1 m higher than in the Keszthely Basin (Tullner / Cserny 2003, 218; Dövényi 2010, 445).

As a result of various factors such as the erosion of the shoreline areas and the eutrophication of the water, the sedimentation process in the lake basin is quite significant. The mean value of the lake's sedimentation rate, calculated from a 300 years long period, is 0.6–0.8 mm / a[1]. This rate can reach up to 1.5–1.7 mm / a in the western areas, especially in the Keszthely Basin, due to the alluvial effect of the river Zala. Owing to the regular wind, the redeposition of the silty sediments is also a usual process in the lake (Tullner / Cserny 2003, 216 f.). The thickness of the lacustrine sediment is the greatest along the northern shoreline. Due to the current

1 Millimetres annually.

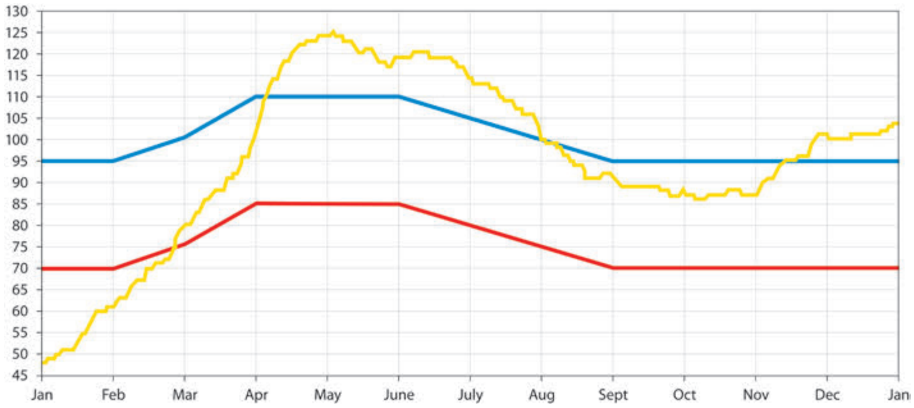

Fig. 3. Annual fluctuation of the waterlevel of Lake Balaton in 2013. Blue: maximum regulation level; red: minimum regulation level; yellow: real waterlevel.

conditions in the lake, the northern shoreline is made up of silty, whilst the southern of sandy textured sediment types. The mean sediment thickness of the lake is 5 m, but due to the extremely varied basin surface underneath the loose sediment, the actual thickness can vary between 1.5 and 8.0 m (Jakab et al. 2005, 408).

The water balance of Lake Balaton

The current water balance of Lake Balaton is essentially determined by four factors: the quantity of precipitation, evaporation, and the quantity of external water input through surface runoff and drainage (Dövényi 2010, 445). Since the rate of the water input and evaporation primarily depends on climatic conditions, the anthropogenic control over the lake's water level can only be exercised at the drainage. For this reason, a floodgate was built on the Sió Channel at Siófok, which was later rebuilt and its capacity was increased. The maintenance of the lake's water level between the required values is a significant economic, touristic, and shore protection issue, in addition to being a complex and sensitive type of hydrological intervention as well. According to the current regulation measures, the water level is determined according to the zero point of the Siófok water depth gauge (103.41 m a.B.s.l.[2]). The water level of Lake Balaton is supposed to vary between a 0.70 to 0.85 m (104.16–104.31 m a.B.s.l.) minimum and a 0.95 to 1.10 m (104.36–104.51 m a.B.s.l.) maximum value range *(Fig. 3)*.

In its natural condition, the lake's water level was determined solely by climatic factors, and we may reckon with a more significant water level fluctuation before the 19th century regulations (Jakab et al. 2005, 407).

In addition to the significant fluctuations of the water level, it is also important to note that the shape and shoreline of the lake also change due to the flooding of the southern meridional valleys and of the Nagyberek area. Thus, these areas become shallow and open embayments of the lake. These conditions change the lake's surface extent, which has an impact on evaporation too (Szesztay 1959, 193). In the lack of modern water regulation measures, this condition can occur already at a water level that is only 0.5 m higher than the maximum of the lake's currently maintained low level (104.5 m a.B.s.l.). The extent of the lake can increase to 900 km^2, which is one and a half times larger than its current surface. To increase the lake's extent by 300 km^2, to its doubled size of 1200 km^2, a water level increase of 5 m would be necessary. However, the 110 m a.B.s.l. water level would result in an extremely huge lake volume, together with an increased water amount, which can only be imagined during a long and extremely cool and moist climatic period. Based on published hydrological values (Szesztay 1959, 191–199), this 5 m interval between 105 and 110 m a.B.s.l. is the value range in which the natural water level of the lake varied during the Holocene. Its permanent water level was probably between 106 to 107 m a.B.s.l. (Sümegi et al. 2007, 251).

The lake's water level and the extent have always played a significant role in the groundwater conditions of the ridges of the shoreline areas, and therefore the water level fluctuations indirectly influenced the options of human occupation in the lake's immediate proximity. The experiences of the last decade indicate that due to the weather conditions it is a difficult task to keep the lake's artificially low water level within the previously set limits *(Fig. 3)*. Considering the values that influence the lake's water balance (e.g. precipitation: 650 mm / a; evaporation: 870 mm / a; surface water in-put: 880 mm / a; drainage: 640 mm / a), it can be assumed that even in

2 Metres above Baltic sea level.

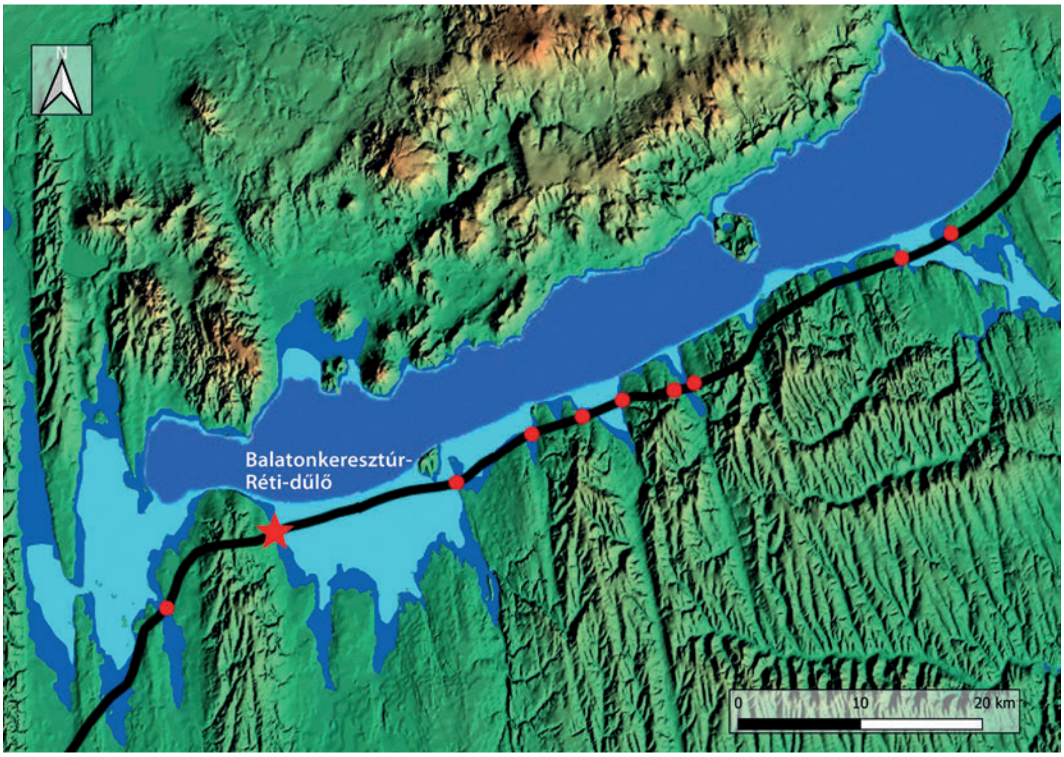

Fig. 4. Archaeological sites on the track of the highway along the southern shoreline of the former natural embayments and location of the site at Balatonkeresztúr-Réti-dűlő. Dark blue: modern shoreline of the Lake Balaton.

its natural state, the lake most likely reacted sensitively to the changing rates of these external factors. The depth of the groundwater, which was always dependent on the periodical or even seasonally raised water level and the changes in the lake's surface extent, undoubtedly influenced the conditions of human occupation. Consequently, we may posit that human communities favoured areas where environmental stability could be observed, longer or shorter changes in the previously mentioned environmental conditions notwithstanding.

Archaeological sites along the shore of Lake Balaton

At the beginning of the 21st century, numerous archaeological sites were identified and investigated during the excavations ahead of the construction of the M7 motorway running for roughly 80 km along the southern shoreline of Lake Balaton and at the eastern edge of the Little Balaton. Given the lake's recent, artificial extent and shoreline, it is difficult to assess the relation between the location of a number of archaeological sites and the lake itself as a landscape element. This can be explained by the lake's significantly different shape and extent in its natural, non-regulated condition, and its effect on the surrounding landscape. As mentioned in the above, the first geological surveys (Lóczy 1913; László 1913; Cholnoky 1918) targeting the lake's geology proved that the extent of the water surface before the regulation measures was well above the present conditions and that the shoreline along the southern shore had several smaller and larger embayments (cf. *Fig. 2*). The main reason for the discovery of numerous archaeological sites along the track of the motorway (Bondár et al. 2000, 91–114; Honti et al. 2002, 3–36; 2004, 3–70; 2007, 7–70) was that the track was designed to run parallel to the lake's current, north-east to south-west shoreline, almost perpendicular to the north to south oriented shoreline of the former natural embayments, which thus affected the area of the one-time lakeside settlements *(Fig. 4)*. These archaeological sites are located on the higher loessy slopes that lie between the former embayments. As mentioned above, the lake's water level and its extent significantly determine the groundwater level of the higher loess ridges, which outlines the extent of the areas that are suitable for human occupation and also defines their economic usefulness. Traces of human occupation from the Neolithic to the late Middle Ages were identified among the archaeological sites of the Lake Balaton area. Although they appeared in different proportions, the vast majority of the sites featured settlement sections of successive archaeological periods. The fact that the settlements were periodically concentrated in the same locations through several archaeological periods suggests that places suitable for human occupation, as well as their economic potential were very limited in the surroundings of Lake Balaton during its non-regulated, natural condition.

The hydrological conditions of human occupation

With regard to the location of the settlements of the different archaeological periods, one of the most important hydrological factors is the groundwater level of the hillsides. The groundwater depth is in close relation to the lake's water level. The extent of the water surface results in an increased groundwater level of the hillside areas around the lake. Waterfront settlements did not exist along the southern shoreline of Lake Balaton because the lake's shoreline zone graded into marshy wetlands due to the geomorphologic properties and the relatively shallow water depth.

Settlements located close to the water can only be assumed. The currently known settlements were located on the loess ridges that run in-between the embayments, meaning that hillside settlements were always located in a zone that was influenced neither by seasonal, nor by any short-term changes in the lake's water level. The communities settling in this geographic area always occupied places where the groundwater level fluctuations associated with the water level changes would not endanger their storage pits, sunken-floored houses, graves, and burials. At the same time, one important consideration in the occupation zone was that water supply features such as wells should not have to be dug too deep to fulfil their function, namely to securely and permanently reach the groundwater table. In other words, the settlements were established at an altitude where the dynamics of the groundwater level in terms of its depth and availability ensured the stable water supply of the settlements. Another important factor was a location close enough to the open water surface, since it was an important transportation route in addition to playing a significant role in subsistence strategies.

Based on the above and from a hydrological perspective, it can be surmised that the areas suitable for human occupation in any archaeological period were those locations, in a presumably narrow geographic zone, which met the criteria of the so-called hydrological optimum. The latter implies the optimal characteristics of the groundwater fluctuations and the optimal distance of the settlement from the open water surface. In addition, several other factors (e. g. geomorphology, soil type, and cultural aspects) also played a role in the selection of the settlement area, which further narrowed the extent of the places suitable for human occupation. During a longer period of drought in the settlement's lifetime, wells could dry up due to the sinking of the groundwater table and the settlement's growing distance from the open water surface. On the other hand, during a longer humid period, a rising groundwater level could reach the storage pits, while the arable lands and pastures around the settlement could become waterlogged, and therefore unsuitable for farming. In both cases, the communities most likely reacted in one way or another, which probably differed according to the robustness of these changes in their environment. This could have taken the form of the shift of the central settlement part or, as an ultimate scenario, the total abandonment of the settlement. In this sense, the analysis of the occupation patterns of the archaeological cultures of different periods within the same geomorphologic setting can reveal the level and dynamics of the groundwater table, and shed light on the hydrological regularities, which, together with other factors, determine the potential locations of human occupation in the landscape.

In order to test the above theory and to assess the impact of the depth and fluctuation of the groundwater level on the location of human occupation sites, a static groundwater model was created. This model is based on the soil mechanics survey conducted within the area of Balatonkeresztúr–Réti-dűlő. The outcome of the model was compared to the spatial distribution of the features of the site's numerous archaeological periods.

Balatonkeresztúr-Réti-dűlő

The archaeological site is located in the south-western part of Lake Balaton, relatively close to the current shoreline, 2 km south of the settlement of Balatonkeresztúr, but still in the transitional zone of the Marcali Ridge and Nagyberek micro-regions *(Figs 4–5)*. The excavation of the site was undertaken between 2003 and 2005 during the preventive and rescue excavations along the track and during the construction of the M7 motorway in county Somogy (Fábián 2004a; 2004b; 2005; 2007; Fábián et al. 2007)[3].

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3 On the request of the Somogy County Museums Directorate (currently called Rippl Rónai Museum, county museum, Kaposvár), the Institute of Archaeology of the Hungarian Academy of Sciences (currently called the Institute of Archaeology, Research Centre for the Humanities, Eötvös Loránd Research Network [ELKH]) was also involved in the excavation work preceding the major motorway construction project. The excavation of the site, which is discussed in this present case study, was directed by Szilvia Fábián between 2003 and 2004. During the 2004 and 2005 seasons, the territory of the complex service area was excavated, too. I would like to thank Szilvia Fábián for kindly providing access to the archaeological data used in this case study.

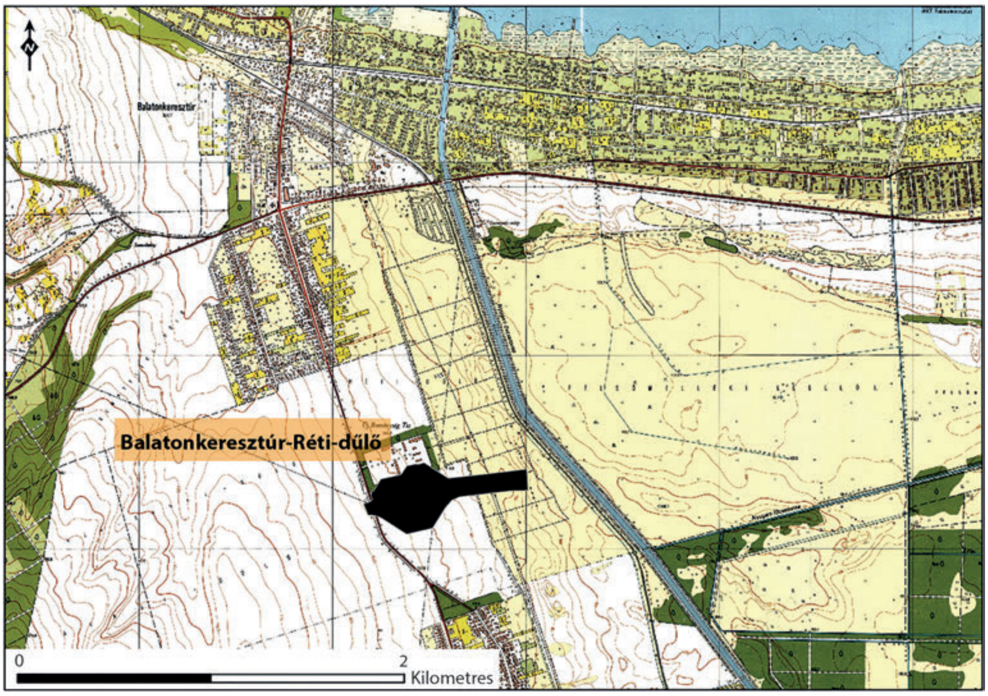

Fig. 5. Balatonkeresztúr-Réti-dűlő. Location of the excavated area on the southern bank of Lake Balaton.

The planned motorway track runs parallel to the shoreline of Lake Balaton on the eastern slopes of the Marcali Ridge, and runs across the archaeological site with a width of 100 m and a length of 900 m. The only exception is the territory of the complex service area, where it broadens to 350 m. Except for a few shorter periods in history, the excavated hillside was occupied from the onset of the Middle Copper Age until the Middle Ages (Fábián 2004a; 2004b; 2005; 2007; Fábián et al. 2007; Fábián / Serlegi 2007; 2009). The western part of the excavated area was utilised as arable land, while its eastern part, which is connected to the marshland of the Nagyberek with a steep slope, was used as a grazing land before the excavation. Between 2003 and 2005, over 3000 archaeological features were excavated in an approximately 60 000 m^2 large area *(Fig. 6)*. The remains and heritage of several communities from at least seven archaeological periods were brought to light.

Archaeological periods

The population of the Middle Copper Age Balaton-Lasinja culture was the first to occupy the area. Their settlement, characterised by densely spaced pits, pit complexes, and a house with a foundation trench, was located in the western part of the investigated area, although a few sporadic features were also found on the steeper slope section (Fábián 2004a, 10; 2007, 28; Fábián et al. 2007, 42–44).

The population of the Late Copper Age Baden culture complex settled east of the Middle Copper Age settlement zone. During this period, the settlement features of both the Boleráz group and of the classical and late Baden phases lay closer to the edge of the Nagyberek. The centre of the Baden settlement was located in a level plateau-like area, while the remains of the Boleráz settlement were also found on the slope running east, towards the margin of the Nagyberek. Archaeological features on the plateau were made up of extensive pit complexes, middens and storage pits, hearths, and an oven with a foundation of pottery sherds of the Baden culture. In addition to these settlement features, several "sacrificial" pits containing entire animal skeletons and a few Baden graves were also excavated. A few graves with crouched burials located in close proximity to the marshy Nagyberek were associated with the Late Copper Age based on their grave goods (Fábián 2004a, 10; 2007, 27–28, Pl. VIII.1; Fábián / Serlegi 2007, 273–275; 2009, 203–205).

The settlement remains and graves of the Somogyvár-Vinkovci and Kisapostag cultures were concentrated in the western part of the excavated area. Features of these two cultures appeared but sporadically in the eastern part of the site. It seems likely that the eleven graves in which the dead were deposited in a slightly crouched position on their side with their hands drawn up in front of their faces uncovered in the central part of the site can be assigned to the second half of the Early Bronze Age. A few bronze jewellery items were recovered from

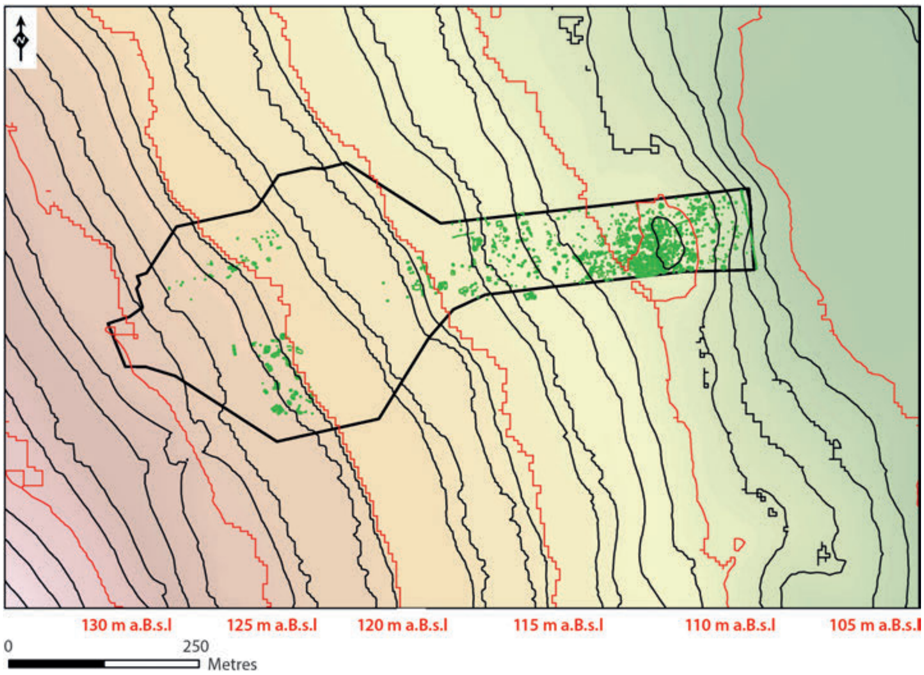

Fig. 6. Balatonkeresztúr-Réti-dűlő. Location of archaeological features within the excavated area.

these graves. The sporadic settlement traces that can most probably be associated with the Encrusted Pottery culture were also observed in this area (Fábián 2004a, 13 f.).

The Celtic population of the Late Iron Age occupied the eastern loess slope of the Marcali Ridge. Traces of intense occupation could be noted across most of the excavated area, extending to the edge of the Nagyberek. The heritage of this archaeological period on the lower part of the sloping area included eleven sunken-floored buildings, five ovens, numerous pits, and post-holes (Fábián 2004a, 13; 2007, 28).

The remains of three slightly sunken-floored buildings with a characteristic structure of six posts were excavated very close to each other within a small area, also in the eastern part of the site, close to the marshland. Based on these typical traits and on a few pits and storage facilities in their surroundings, as well as on a well lined with Roman *tegulae*, it seems likely that it was a Langobard settlement of the 6th century AD (Skriba 2006, 55–93; von Freeden / Vida 2007, 378–383). Vessel fragments with typical stamped ornamentation, iron tools, and *tegulae* were brought to light from the floor of the houses, from the post-holes, and from the fill of a few pits (Fábián 2007, 29).

Although traces of the Árpádian Age occupation could be noted across the entire archaeological site, these appeared to be quite sporadic. Most of the settlement features, among them a sunken-floored building, pits, and the remains of three ovens, were concentrated in the plateau area of the site. A little farther to the west from the house, five graves with extended burials were discovered. The skeletal remains of two adults and three children were recovered from these 10th to 11th century graves. An unusual grave, which contained an extended burial lying on its side, lacking any grave goods, can also be associated with the medieval occupation at this site. This grave was excavated on the northern periphery of the site (Fábián 2004a, 14; 2007, 29).

A more significant concentration of features from the later periods of the Middle Ages was uncovered on the east to west running loess plateau and on the upper section of the hillside, while no traces of occupation were detected on the lower section of the slope bordering the Nagyberek area. This 13th to 15th century settlement can perhaps be identified with the medieval village of *Cholta* located south-west of present-day Balatonkeresztúr (Kiss 2006, 7–11). On the western side of the horizontal plateau, very intensive settlement features lying directly underneath the modern surface were documented. The foundations of a multi-roomed dwelling house were preserved in a good state, enabling the reconstruction of the details of its structure. An oven with a foundation of pottery sherds that was repeatedly renewed was uncovered inside the house, alongside significant amounts of archaeological finds. In addition to this house, numerous post-framed, sunken-floored workshops, pits, hearths, a few wood-lined wells, and an east-west oriented narrow ditch section reflects the site's late medieval occupation (Fábián 2004a, 14–15; 2007, 29).

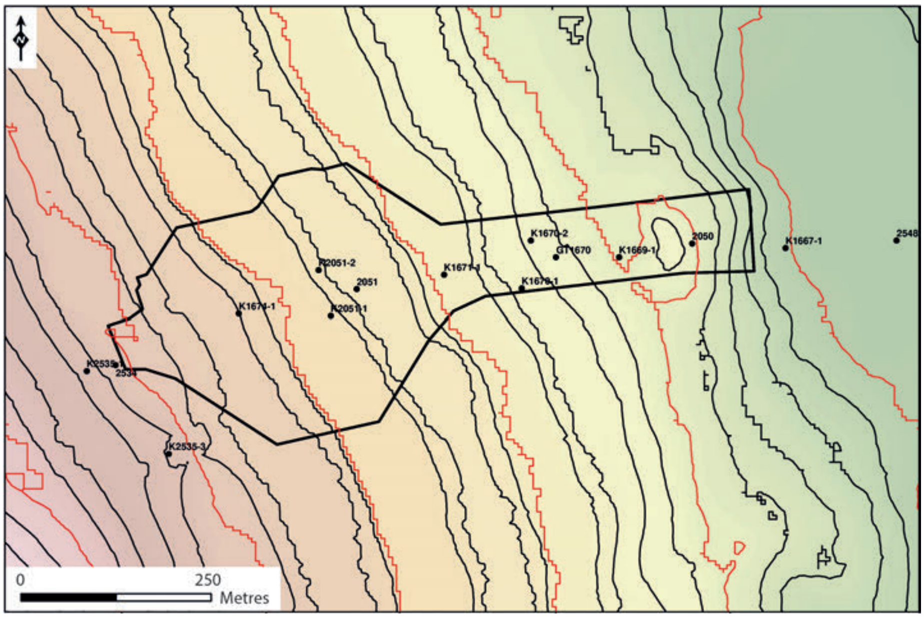

Fig. 7. Balatonkeresztúr-Réti-dűlő. Coring points within the excavated site and in its vicinity.

Due to the extensive excavated areas, the impact of the geomorphologic conditions on human occupation could be clearly observed. The plateau in the lower third of the loess ridge was a popular location for settlement in all archaeological periods. This is underlined by the densely intersecting features. The density of the archaeological features decreases both east and west of this area and a clear change in the utilisation of the various parts can be seen during the different periods (Fábián / Serlegi 2007, 275 f.).

The static groundwater model

The stratigraphy of the archaeological site

The intensity and the tendencies observed in the utilisation of the occupation areas during successive archaeological periods at the Balatonkeresztúr site provided an excellent opportunity for examining the earlier outlined theory of the optimal hydrological zone. This called for the reconstruction of the site's geological stratigraphy and groundwater conditions. Since a targeted geological survey with this particular purpose had not been conducted at the site, the only information available on the area's geology was the documentation of the soil mechanics survey carried out prior to the construction of the motorway[4].

The stratigraphy and groundwater level conditions of the archaeological site were compiled based on the description and evaluation sheets of the corings. The original purpose of the corings was to provide soil mechanics data for the construction of the motorway, and thus the available data did not contain an exact stratigraphic description of the cores. For this reason, it was not possible to evaluate the geological evolution of the site in detail, or to determine the geological age of the identified layers. Besides the depth data of the different layers described on the basis of the soil mechanics survey, the gravel, sand, silt, and clay fraction of the layers, as well as their density and compaction ratios were recorded. In addition, the groundwater level was also documented. Due to the depth data of the layer boundaries and that of the groundwater levels, the documentation was suitable for the reconstruction of the site's subterranean geomorphologic conditions, as well as for the compilation of the groundwater levels of two different time periods.

A total of 17 cores were extracted in the territory and in the close vicinity of the so-called complex service area *(Fig. 7)*. Ten coring profiles could be used for compiling a shallow geological cross-section along an approximately north-east to south-west axis across the site *(Fig. 8)*. Eight of the ten corings used for this purpose were extracted on the eastern slope of the Marcali Ridge (K2532-1, 2534, K1674-1, 2051, K1671-1, GT1670, K1669-1, 2050), whilst two from the Nagyberek area (K1667-1, 2548). The depth of the corings varied, the deepest reached 18 m of relative depth (K2535-1), whilst the shallowest ones were 5 m in depth (2050, 2051).

4 The survey was carried out by the Soil Mechanics Bureau of the Fővárosi Mérnöki Tervező P.L.C. (FŐMTERV), commissioned by the former Nemzeti Autópálya (National Highway) P.L.C. The data used in this paper was provided by FŐMTERV with the permission of the Nemzeti Autópálya (National Highway) P.L.C. for scientific purposes.

Most of the corings were performed in February 1992 (4 pieces) and during the summer of 2003 (5 pieces), and an additional one in November 2001.

If we compare the water level values of the lake with the relation between the extent and level of the surface waters and the hydrological conditions of the groundwater, we can determine whether the groundwater levels recorded during the soil mechanics coring represent low, moderate, or high groundwater level tendencies.

Based on the data of the Central Hydrological Inventory of the VITUKI[5], the water level of Lake Balaton in February 1992, at the end of winter, can be considered as average. The water level was measured to be 1.02 m higher (104.43 m a.B.s.l.[6]) than the zero point (103.41 m a.B.s.l.) of the Siófok water depth gauge. This value is still within the current regulatory maximum.

During the driest summer of the past two decades, in August 2003, the water level stood 0.35 m above the zero point of the Siófok water depth gauge. This value was 103.67 m a.B.s.l., which is 0.35 m below the current regulatory minimum[7]. It indicates an extremely low water level under natural conditions as well. Based on these data, we may conclude that the 1992 winter groundwater level can be identified as a moderate one, whilst the 2003 summer level as an extremely low one.

Methodology of the construction of the static groundwater model

When constructing the geological stratigraphy of the area, the starting points were the description and evaluation sheets of the soil mechanics corings. Since the corings of 2003 were carried out after the beginning of the excavation, the drilling began on a lower surface because the uppermost humus layer of the soil had already been removed by that time. In these areas, no humus layer thickness values were available, but according to other coring data, an average of 0.6 m can be used for the calculations. The deeper layers of the core profiles were distinguished based upon their particle size distribution, such as sandy, silty, or clayey. The same layers could be matched between the different core profiles. By knowing the coordinates of the boreholes and the altitude values of their bases, the relative height of the layers, described on the evaluation sheets, could easily be converted to an absolute altitude value. Based on this information, the three-dimensional spatial position of the layer boundaries could be generated. Subsequently, the raster files of the layer boundaries could be produced with interpolation, on which the continuous boundaries of the related layers between the neighbouring cores could be drafted. As a result of this method, only the theoretical boundary of the layers could be defined by the interpolation between the ten core profiles. These cover an almost 1 km long cross-section. A similar interpolation method was used for constructing the area's groundwater table.

Results of the static groundwater model

Based on the compiled cross-section, it can be observed that the stratigraphy of the deeper parts of the hillside is similar to the modern surface *(Fig. 8)*. Underlying the 0.6 m thick humus layer is a sandy-silty sediment of varying thickness, reaching as much as 10 m at some points. This layer is followed in depth by a shallower clayey sediment reaching a thickness of 3 to 6 m. The next layer is another, but thinner sandy-silty layer, which is again followed by a clayey one. No information is available on the thickness of the lowermost clayey layer and even the deepest cores did not fully penetrate this sediment unit.

We may in general assert that the layers of the subterranean geomorphology are similar to the current surface conditions, the only exception being the boundary zone between the Marcali Ridge and the Nagyberek, where clayey layers and the deeper-lying sandy-silty sediments have a steeper inclination before reaching a flat section. At this point, the gap between the relief of the modern surface's humus horizon and of the geological older surface is filled by the thickening of the uppermost sandy-silty sediment material. The two cores of the Nagyberek area (K1667-1, 2548) indicate that silty and clayey, grey-coloured lacustrine sediments were deposited during the Holocene over the deep-lying sandy and clayey layers. The appearance of these lacustrine layers on the geomorphologic boundary between the hillside and the marshy area conforms to the geological evolution of Lake Balaton described in the above.

Based on the groundwater level data recorded on the description and evaluation sheets of the shallow geological cores, the groundwater table of two, climatically different periods could be modelled. By considering the relation between the dynamics of the surface water system and the groundwater movements of the area, as well as the measured values of the groundwater depth, a moderate and an extremely low groundwater level could be reconstructed *(Fig. 8)*.

In both hydrological cases, the depth of the groundwater level is the deepest on those surfaces of the studied hillside, which lie between 126 and 127 m a.B.s.l. Based on the coring data, the depth of the groundwater level

5 Research Institute of Environmental Protection and Hydrology Non-Profit Ltd.

6 Http://www.hydroinfo.hu/vituki/archivum/ba.htm.

7 Http://www.kvvm.hu/balaton/lang_hu/vizszintb.htm.

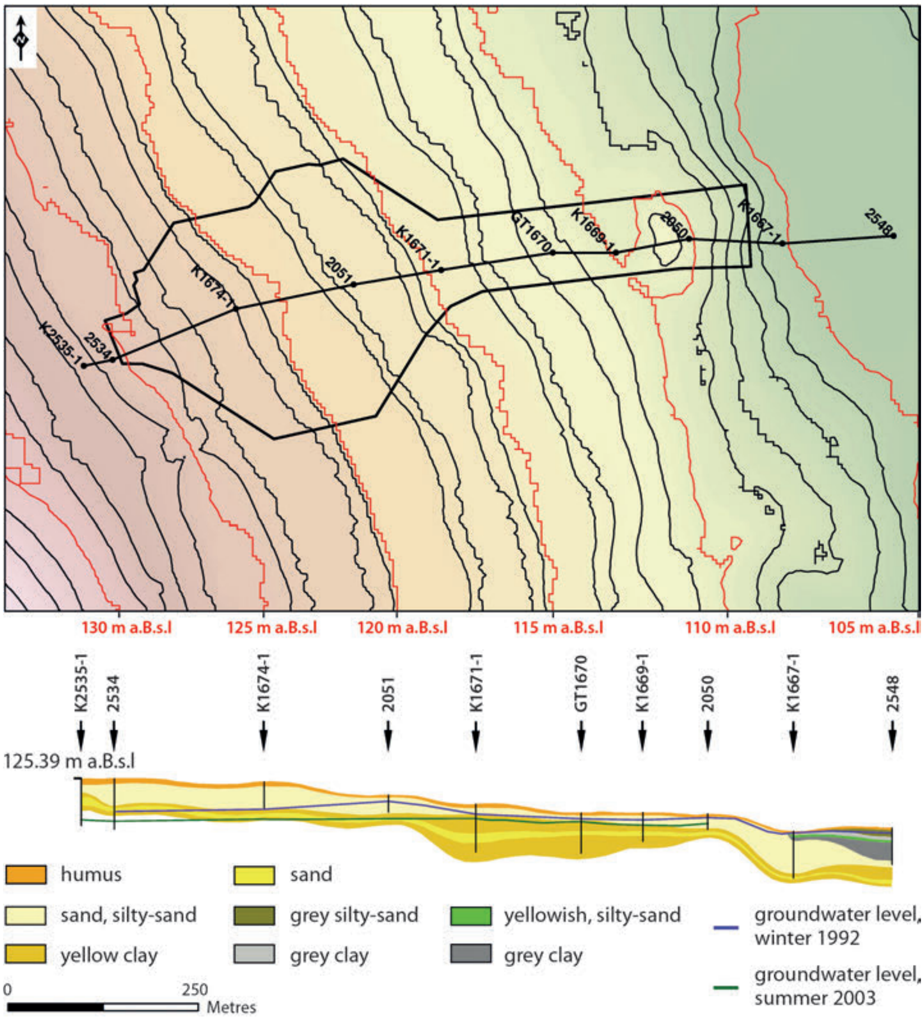

Fig. 8. Balatonkeresztúr-Réti-dűlő. Coring points used for modeling and compiled soil mechanics cross-section of the investigated area.

may even be set at 8 to 10 m in relative depth, and the groundwater level difference between the two hydrological situations can add up to almost 1.5 m (8.5 m at moderate water level and 9.8 m at extremely low water level). Based on the outcome of the model, both groundwater tables have a parallel position along the entire length of the slope under any of the reconstructed hydrological conditions. The only exception can be seen in the middle section of the slope, around 116 to 117 m a.B.s.l., where the groundwater level is relatively close, not even within a 2 m relative depth of the surface when the lake's water level is high. At low water level, the groundwater table is located much deeper. It must be added, though, that in 2003, the groundwater table was not reached within a 6 m relative depth at coring point K1674-1. This would suggest a deep-lying groundwater table; however, only the interpolated data are available on the depth of the groundwater in 2003 on the long cross-section part between cores K2535-1 and K1671-1. The results of the interpolation are supported by the groundwater data of two other cores (K2051-1, K2051-2). These cores were also extracted in summer 2003, presumably for control purposes. Although they do not fall in the line of the analysed cross-section, they are positioned perpendicular to core 2051 from 1992 (cf. *Fig. 7*). The groundwater level in core 2051 was measured to be at 116.3 m a.B.s.l. in winter 1992. Both in core K2051-1 and core K2051-2, the groundwater level was found to be 3.5 m deeper at 112.9 m a.B.s.l. than in core 2051. This observation underlines the accuracy of the interpolated data.

Starting from the middle section of the slope, until the plateau-like horizontal area, which lies at 110 to 111 m a.B.s.l., the two groundwater tables run approximately parallel to each other at a relatively low depth below the surface. At the horizontal part of the plateau, the groundwater table lies at a moderate depth. At 110 m a.B.s.l. on the steeper slope section running to the edge of the Nagyberek, the groundwater table is approximately parallel with the inclination of the surface and lies at a moderate depth. In this steeper part, the difference between the depth of the groundwater level between the two previously described hydrological conditions is greater than on the plateau. At the boundary between the Marcali Ridge and the Nagyberek area, the groundwater was located relatively close to the surface (it was observed at 1.1 m relative depth in core K1667-1 in summer 2003). Moreover, the interpolation results of the 1992 data also give a fairly high groundwater level for this area.

In sum, it can be said that the deep-lying older geological layers of the eastern slope of the Marcali Ridge are composed of a variety of clayey and sandy-silty sediments. The subterranean geomorphology and inclination conditions of these layers are more-or-less similar to that of the surface conditions. The older geological layers can also be found under the area of the Nagyberek. At the lowest end of the slope, within the area of the marshland, lacustrine sediments were deposited on the older geological sediments. Based on the description of the geological evolution of Lake Balaton, these clayey and silty sediments could have already been deposited in the Holocene when periodical flooding affected the embayments of the lakeshore. The modelled depth of the groundwater was based on the data gained from the soil mechanics survey. The groundwater level in the upper sections of the hillside is located deep, irrespective of the lake's water regime, but by moving in an eastern direction on the slope, it rises closer and closer to the surface.

On the horizontal plateau, no significant differences can be reconstructed at around 110 to 111 m a.B.s.l. for the groundwater levels of the two different water regime options. In the steeper section running towards the Nagyberek area, the two reconstructed groundwater table positions show a more significant depth difference. However, at the boundary between the Nagyberek marshland and the foot of the hillside (Marcali Ridge), both are situated low. In order to correctly interpret the outputs of the model, it must be added that the groundwater data is divided between the 10 coring points, which were used for constructing the approximately 1 km long cross-section. As a result of this, the length of the interpolated sections between the two points increases. It can be said that the two modelled groundwater tables run parallel, which enhances the usefulness of the model, but it must be emphasised that the model is not suitable for determining the absolute altitude values of the groundwater level between the two known points (cores). Obviously, this is also valid for the absolute altitude values of the stratigraphic boundaries of the geological layers. In this latter case, the resolution of the model is somewhat higher, due to the higher number of available data points.

The characteristics of the groundwater table, which was reconstructed based on the data of the corings, show the best correlation with the characteristics of the hypothesised optimal hydrological zone of the horizontal plateau at 110 to 111 m a.B.s.l. Namely, it is not situated too deep and shows great stability. This area is only 100 m away from the edge of the Nagyberek, which was part of the lake's basin and of the surface water system in the lake's natural condition. Consequently, we can conclude that the hypothesised optimal hydrological zone in this area was located on the horizontal plateau.

Occupation zones of the archaeological periods within the site

It was necessary to test and verify the functionality of the static groundwater model, which was based on the recent groundwater data of the Balatonkeresztúr site. In addition, it was also important to verify the correctness of the conclusions regarding the optimal hydrological zone theory. One obvious question is to what extent these observations and assertions can be used for the examination of archaeological periods. It was therefore necessary to compare the conclusions drawn from the recent data with the data gained through the excavation of human settlements. For this reason, the extent and position of the occupation zones, the centre of the settlements of the various archaeological periods were compared to the outcome of the model. The aim was to see whether or not the archaeological data support the model-based localisation of the optimal hydrological zone.

Middle Copper Age: Balaton-Lasinja culture (4300–4000 BC)

The occupation zone of the Middle Copper Age is located on the higher altitude surfaces, approximately at 120 m a.B.s.l., on the eastern slope of the Marcali Ridge *(Fig. 9)*. In both hydrological cases, i. e. at low and high water level conditions, the groundwater in this section of the examined area is located at a great depth, regardless of the lake's water level. Given the determinative role of the groundwater conditions mentioned above, extremely high groundwater levels could be reconstructed for this period on the slope. Beyond the central part of the Middle Copper Age occupation zone at 120 m a.B.s.l., features with typical finds of this period were found sporadically across the excavation area. Among others, a well-like feature was also uncovered[8]. The well was located approximately 10 m lower than the settlement centre, roughly on the lower boundary of the modelled optimal hydrological zone at 109.5 m a.B.s.l.

8 Szilvia Fábián's kind pers. comm.

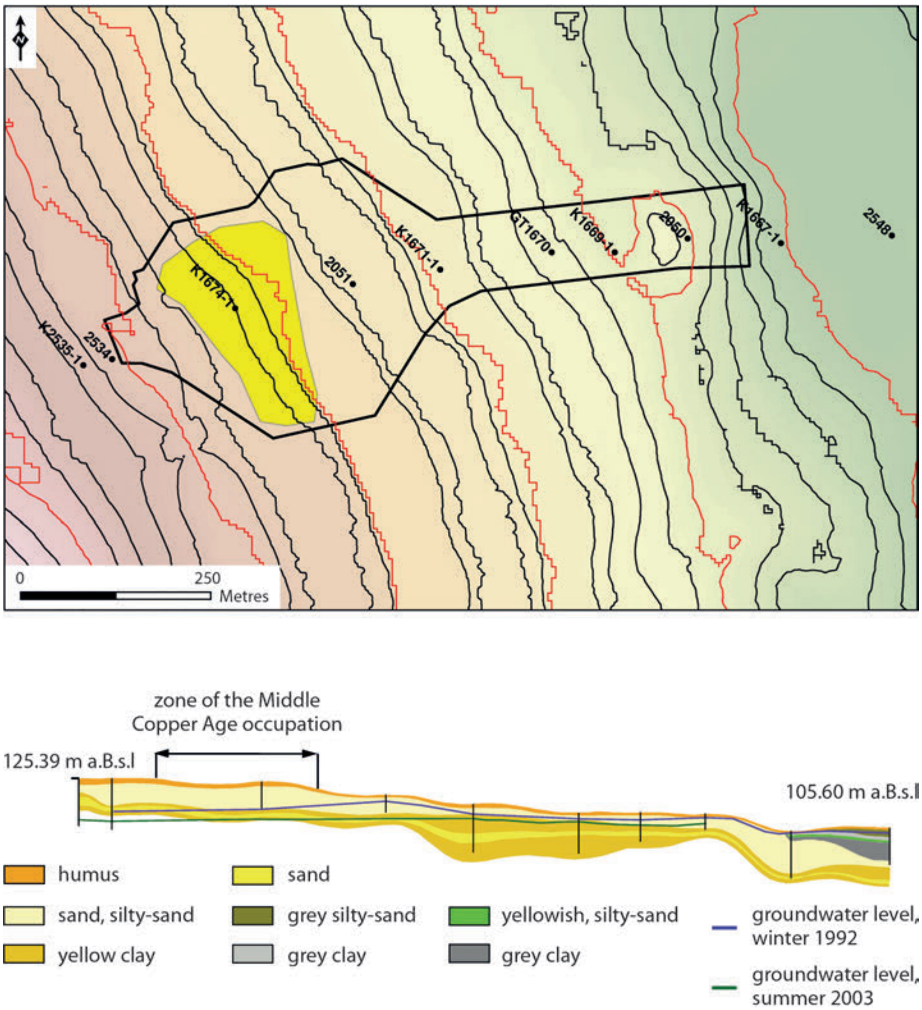

Fig. 9. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Middle Copper Age.

Based on the spatial distribution of the Middle Copper Age features, the other determining factors of the human occupation strategy must also be mentioned. It can be noted that the settlement's centre is located farther and above the altitude of the optimal hydrological zone. The water supply features, however, are positioned farther from the settlement features, directly in the zone that meets the criteria of the optimal hydrological zone, and therefore have the ideal groundwater level characteristics. It can be assumed that in certain periods, the settlement centres were located farther, but still on the economically feasible boundary of the optimal zone. However, no far-reaching conclusion can be drawn regarding the impact of environmental and cultural factors based on the data gained from the analysis of one single archaeological site. This requires a regional study of the settlements and a complex analysis of the period's settlement strategy.

Late Copper Age: Boleráz-Baden culture (3600–2900 BC)

The occupation zone of the Late Copper Age is concentrated on the horizontal plateau located at the lower section of the slope at 110 to 111 m a.B.s.l. There are no features of this period below 107 m a.B.s.l. *(Fig. 10)*. Among the finds of the different archaeological periods, the Late Copper Age material has been most fully analysed. Through the typological assessment of the ceramic finds, Szilvia Fábián was able to distinguish three different phases within the Late Copper Age occupation of the site, during which there were also structural changes in the settlement. These three, archaeologically distinct phases were later confirmed by the radiocarbon dates (Fábián / Serlegi 2009, 206–215; Serlegi et al. 2012, 140–142).

The earliest Boleráz occupation is characterised by a relatively dispersed settlement structure within the Late Copper Age occupation zone. The settlement features of

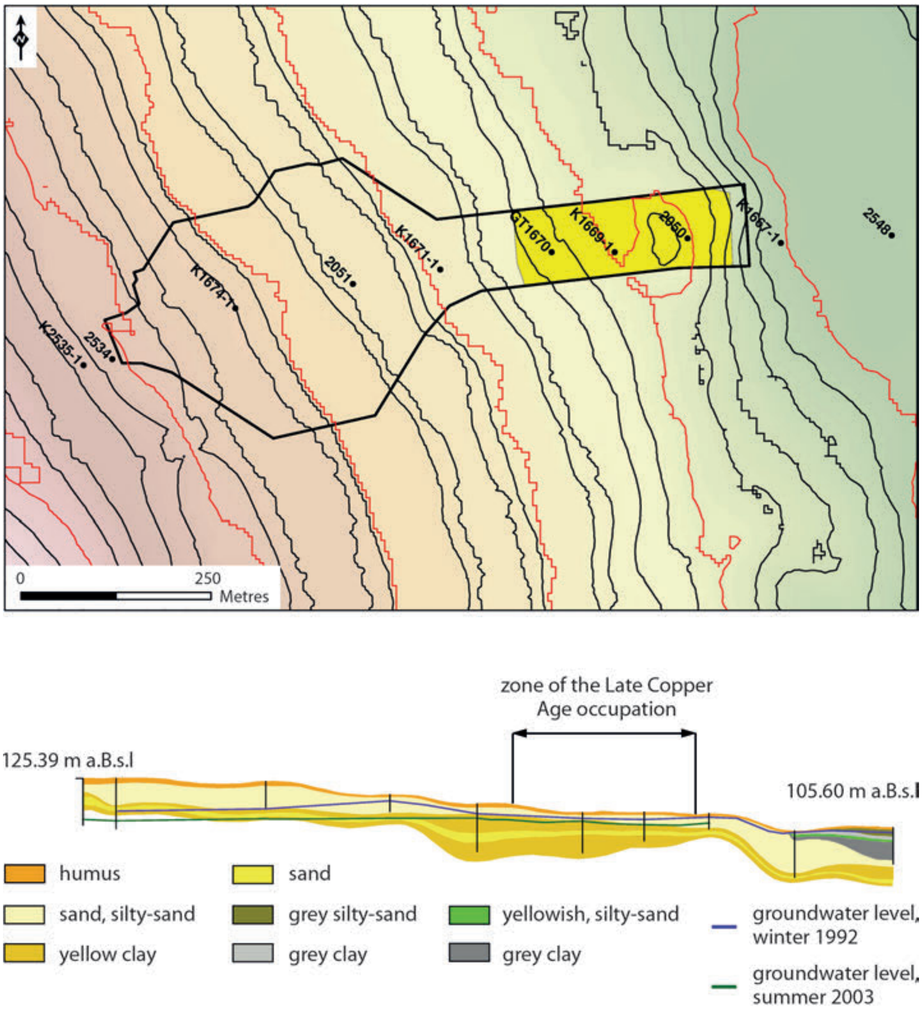

Fig. 10. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Late Copper Age.

the earliest phase can be found on lower altitude surfaces during the Late Copper Age. In the ensuing early classical Baden period, a settlement concentration can be noted across the excavated area, reflected by the greater density of settlement features on the horizontal plateau. During the late classical Baden period, this concentration process continued: the extent of the settlement became smaller and was restricted to the plateau *(Fig. 11)*.

Based on the observations regarding the settlement structure, a continuously rising groundwater level can be reconstructed, resulting in the horizontal diminution of the area suitable for occupation as well as of the centres of the subsequent settlements.

In order to examine the possible climatic changes regulating the rising groundwater level and to determine the climatic characteristics of this period, Painter's mussel shells *(Unio pictorum)* from significant features of the three occupation phases were submitted to stable isotope ($\delta^{18}O$) analysis (Barna 2009, 59–63; Demény et al. 2010, 87 f.; Schöll-Barna et al. 2012, 87–100; Serlegi et al. 2012, 144–146).

Relatively stable climatic conditions can be reconstructed for the Boleráz period. Based on the stable isotope analysis, the climate became more humid, wet, and extremely volatile during the transition between the Boleráz and the early classical Baden period, when the previously dispersed settlement structure starts to become more concentrated. The analysis of the mollusc shells also revealed that the humid climate of the early Baden period became similar to that of the Boleráz period by the end of the late classical period.

It can be assumed that during the Late Copper Age, the concentration of features within the assumed optimal hydrological zone was due to the effect of the changing surface water system and the increase of the groundwater level in its wake. These later alternated as a result of the climatic changes, which turned the area more humid and wetter. However, it is clearly observable that the settlement's occupants did not wholly abandon

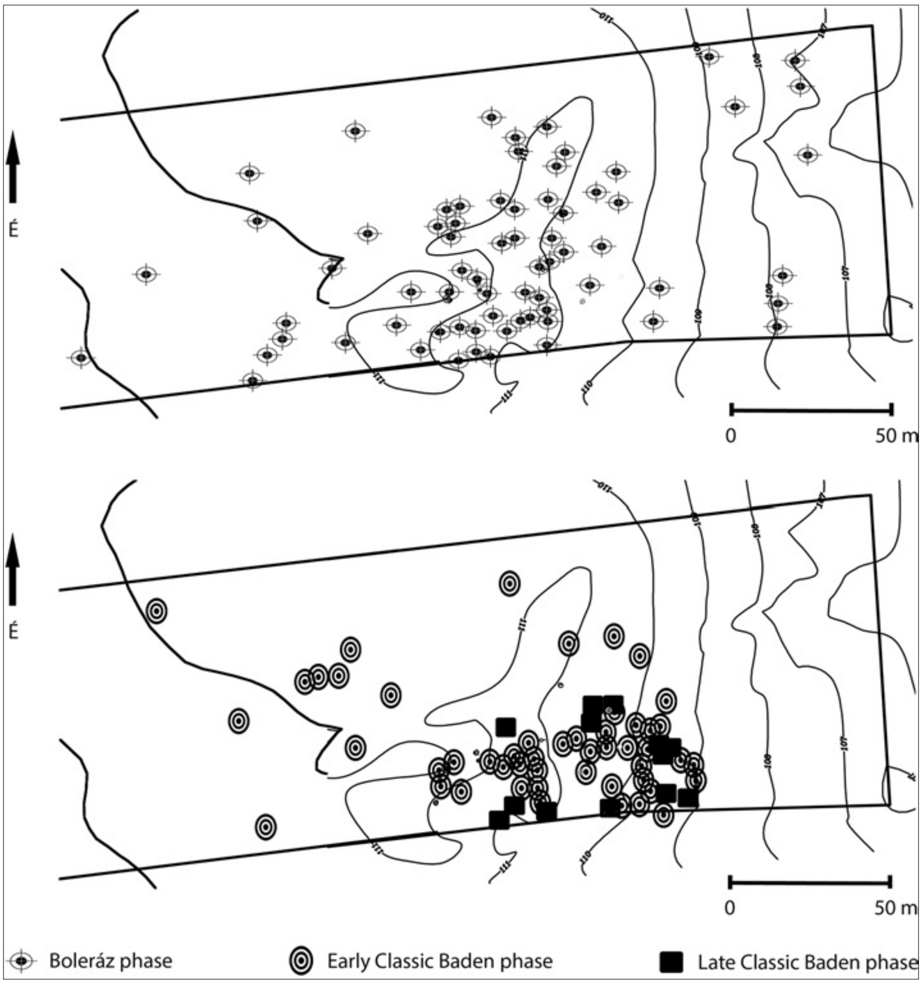

Fig. 11. Balatonkeresztúr-Réti-dűlő. Archaeological features in the occupation zone of the Late Copper Age belonging to the three different phases.

the area even under more extreme climatic conditions, indicating that even under significantly robust climatic changes, as shown by the stable isotope results for this period, the groundwater conditions in the area remain stable enough in the optimal hydrological zone.

Early and Middle Bronze Age: Somogyvár-Vinkovci, Kisapostag, and Encrusted Pottery cultures (2500/2400–1600/1500 BC)

The occupation zone of the Early and Middle Bronze Age cultures is located in the middle section of the hillside *(Fig. 12)*. Except for the Middle Copper Age, this is the period when no traces of occupation can be observed on the slope extending east of the horizontal plateau. Unfortunately, due to the current state of the archaeological assessment of the finds and the low number of excavated features, a detailed analysis of the features of this period was not possible. However, it must be noted that during the construction work after the completion of the preventive archaeological excavations, two additional Early Bronze Age pits were found in the central area of the Middle Copper Age occupation zone (Honti et al. 2007, 42–44). In addition, finds of the Early Bronze Age Somogyvár-Vinkovci and Kisapostag cultures were recovered from the fill of a few features of the Balatonkeresztúr–Kiserdei-dűlő archaeological site during a preventive excavation (site M7/S36), located at 130 m a.B.s.l. at a distance of several hundred metres west of the line of the motorway (Honti et al. 2004, 9 f.). It is impossible to determine on the basis of the currently available data whether or not the excavated features belong to the same settlement. However, it is an indication that the Early Bronze Age population established its settlement on the higher altitude surfaces where the groundwater level is at least 9 to 10 m below the surface. It cannot be assumed that any shift in the groundwater level at such a depth would have influenced the settlement features and the selection of the occupation area. Wells dating from this period are not known from the site. It is very likely that during the Early and

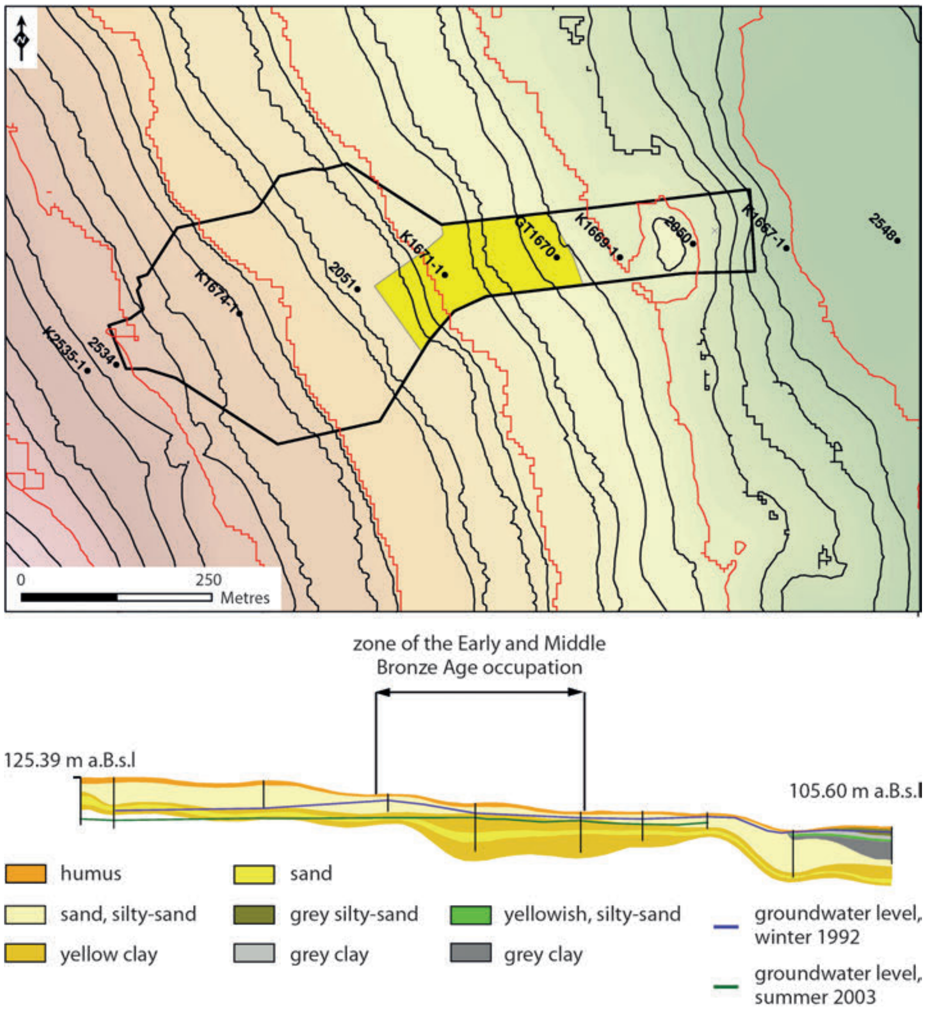

Fig. 12. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Early and Middle Bronze Age.

Middle Bronze Age, the settlement's water supply features were located near the boundary of the optimal hydrological zone, but the excavated area did not include this part of the settlement. Similar to the Middle Copper Age, the reasons for locating the centre of the Early and Middle Bronze Age occupation at such a high altitude could only be determined after a regional study, which would reveal the possible cultural reasons behind the occupation strategy of the period's communities.

Late Iron Age: La Tène C–D culture (4th century BC to 1st century AD)

The Late Iron Age occupation zone was observed in the entire lower section of the hillside within the site *(Fig. 13)*. This is the first period in which settlement features could be found across the entire section of the slope, reaching the boundary of the Nagyberek area. In this area, the model assumes the near surface location of the groundwater, which is underlined by the observations made during the excavation. Currently, no detailed assessment of the finds of this period is available. However, considering the Late Iron Age settlement structure of Balatonkeresztúr–Réti-dűlő, as well as the generally established climatic conclusions based on the dendrochronological analysis of this particular period, the following tentative conclusions can be drawn. Based on the features observed relatively low, below the lower boundary of the optimal hydrological zone at 105 m a.B.s.l., it can be assumed that the groundwater was permanently located at a low level on the hillside. This might indicate a prolonged drier and warmer climatic period. This climatic trend is underlined by the dendrochronological analyses of the Iron Age of the Carpathian Basin too. The so-called Pannonian oak chronology covers the period from 170 BC to AD 90, and the growth indices of the trees reflect an extremely dry and warm period (Grynaeus 2004, 93 f.). In the light of these data, a low groundwater level and reserved surface water regime can be reconstructed for this period, which could have led to a temporary expansion of the boundary of the optimal hydrological zone.

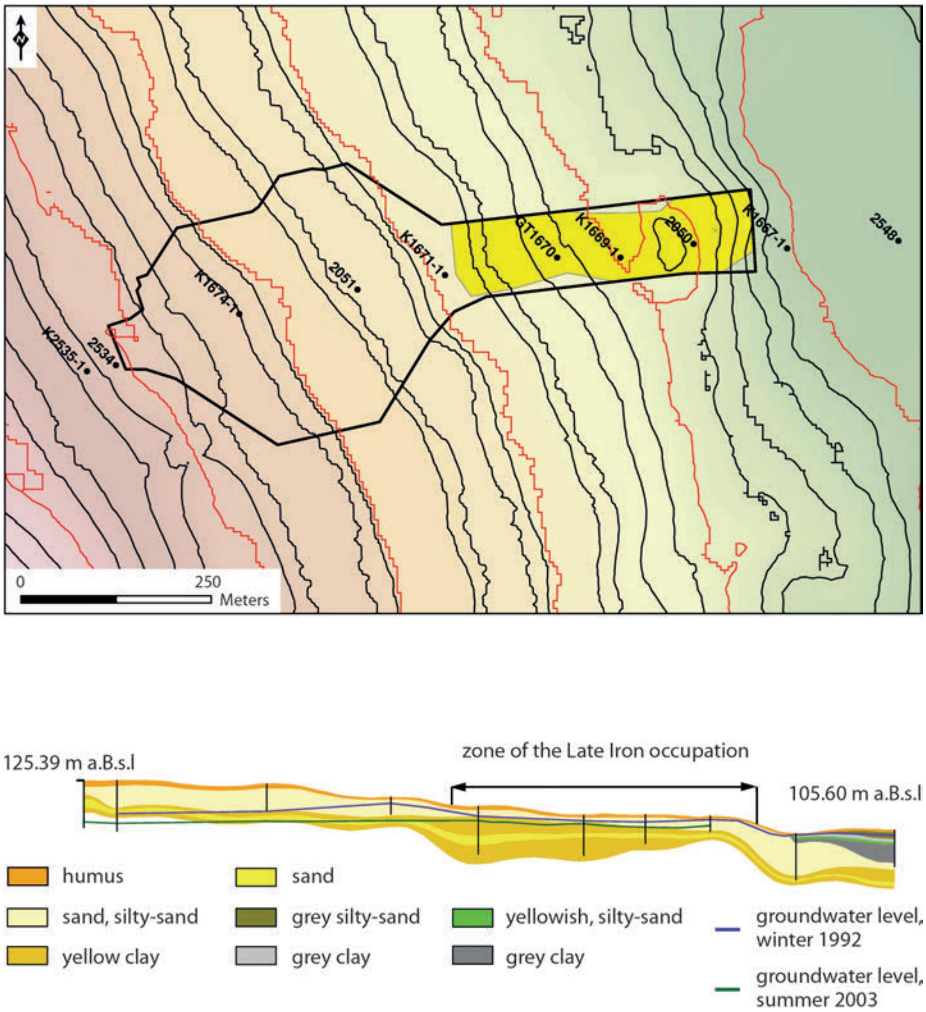

Fig. 13. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Late Iron Age.

Migration period (Langobard occupation, 6th century AD)

The occupation zone of the Migration period within the site was observed in the lowest section of the hillside, on the boundary with the Nagyberek area *(Fig. 14)*. Similarly to the Late Iron Age, low ground water data can be expected. During this period, settlement traces were excavated below the hypothesised boundary of the optimal hydrological zone in the lowest part of the slope. Essentially, the period's settlement features do not reach the optimal hydrological zone, which is approximately the horizontal plateau of the site.

Árpádian Age (10th to 11th centuries AD)

The occupation zone of the settlement that can be dated to the Árpádian Age is located on the horizontal plateau in the middle section of the hillside. Its boundary reaches the edge of the plateau to the east; its features do not occur under 110 m a.B.s.l. *(Fig. 15)*. The greater part of the settlement's centre is well-detectably located within the hypothesised optimal hydrological zone.

Medieval period (13th to 15th centuries AD)

The occupation zone of the Medieval village of *Cholta* overlaps with the territory of the Árpádian Age settlement. In the later period, the area is characterised by a significantly denser settlement structure and a higher concentration of features *(Fig. 16)*. The period's settlement features do occur under 110 m a.B.s.l., suggesting groundwater conditions similar to those of the Árpádian Age. There is no direct data on the destruction of the settlement; however, analogies to the phenomena observed at Balatonkeresztúr would suggest that the abandonment of the settlement can be associated with the impact of the Little Ice Age (LIA). Environmental changes during the

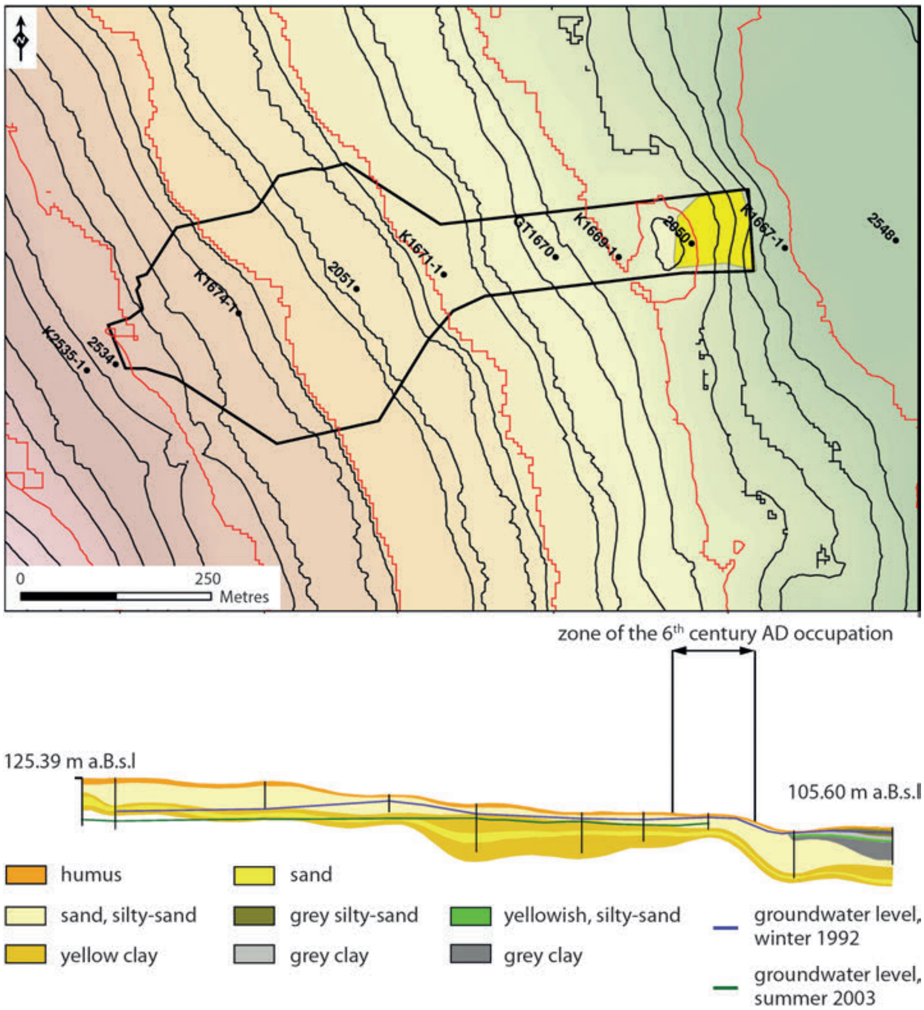

Fig. 14. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Migration Period (6th century AD).

LIA in the Lake Balaton area affected the groundwater levels, which most likely influenced the site's occupation strategies (Mészáros / Serlegi 2011, 215).

The relation between the static groundwater model and the location of the occupation zones during the examined archaeological periods

The results of the stratigraphic and static groundwater model constructed from the soil mechanics coring data and the location of the occupation zones of the different archaeological periods of the site show a good correlation. The results confirm the relation between the criteria of the optimal hydrological zone theory and one of the hydrology-related aspects of human occupation strategy. We may assert that the groundwater table, which was interpolated based on the record of the modern groundwater level data from the soil mechanics corings, does not show significant alternations at the horizontal plateau located at 110 to 111 m a.B.s.l., although more significant groundwater fluctuations can be noted in some sections of the hillside. The groundwater level remains at an ideal moderate depth on the plateau satisfying the criteria set against it.

The centre of six settlements (Late Copper Age, Early and Middle Bronze Age, Late Iron Age, Migration period, Árpádian Age, and the Medieval period) of the seven archaeological periods recorded at Balatonkeresztúr was mainly located in the optimal hydrological zone predicted by the model *(Fig. 17)*. However, some spatial variations can be identified between the settlement centres in the territory of the zone.

The settlements of the Middle Bronze Age are located on the highest altitude relief, on the upper boundary of the zone. The settlement traces of the Late Copper Age, the Árpádian Age, and the Medieval period can be found at roughly similar altitudes and extend across the entire territory of the zone. Archaeological features

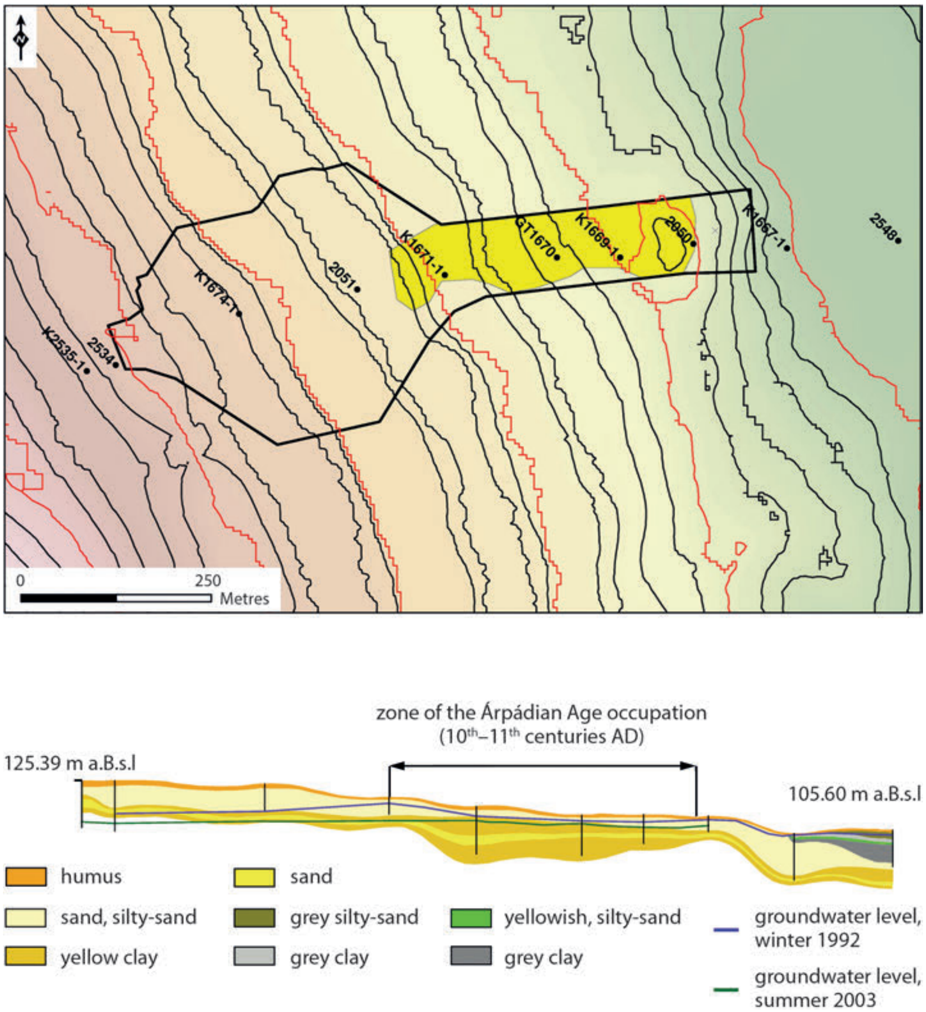

Fig. 15. Balatonkeresztúr-Réti-dűlő. The occupation zone zone of the Árpádian period (10th to 11th century AD).

associated with certain periods of the Late Copper Age could be observed at 108 m a.B.s.l on the hillside, which is below the lower boundary of the hypothesised zone. According to the period's internal chronology, these features represent the earliest, Boleráz period. In the second half of the Late Copper Age, as well as during the Árpádian Age and the Medieval period, the concentration of the settlements can be identified on the horizontal plateau at 110 to 111 m a.B.s.l.; in other words, these settlements were established in the area of the optimal hydrological zone. The features of the Árpádian Age and the Medieval period do not exceed the 110 m a.B.s.l. limit, which is the lower boundary of the zone. Yet, their features located west of the site are in line with the Bronze Age settlement features on the highest altitude surfaces. In this section, no traces of a Late Copper Age occupation were detected. The settlement features of the Late Iron Age and the 6th century AD can be found even on the steeper slope section of the hillside below the horizontal plateau. This is well below the lower boundary of the hypothesised optimal hydrological zone, already located near the Nagyberek area.

The single archaeological period with an occupation centre well beyond the boundary of the optimal hydrological zone, located on the highest altitude surfaces of the hillside, is the Middle Copper Age. The features of this period are located on a relief where the depth of the groundwater unequivocally reflects its impact on the features, under any environmental conditions. The location of the period's water supply features near the boundary of the optimal hydrological zone highlights the fact that the central part of the Balaton-Lasinja occupation was independent of the territory of the optimal hydrological zone. Based on the observations made at the Balatonkeresztúr–Kiserdei-dűlő site, this possibility also arises in the case of the Early Bronze Age.

Our observations indicate that with the exception of the Middle Copper Age, the central area of the settlements was always located in the area of the hillside,

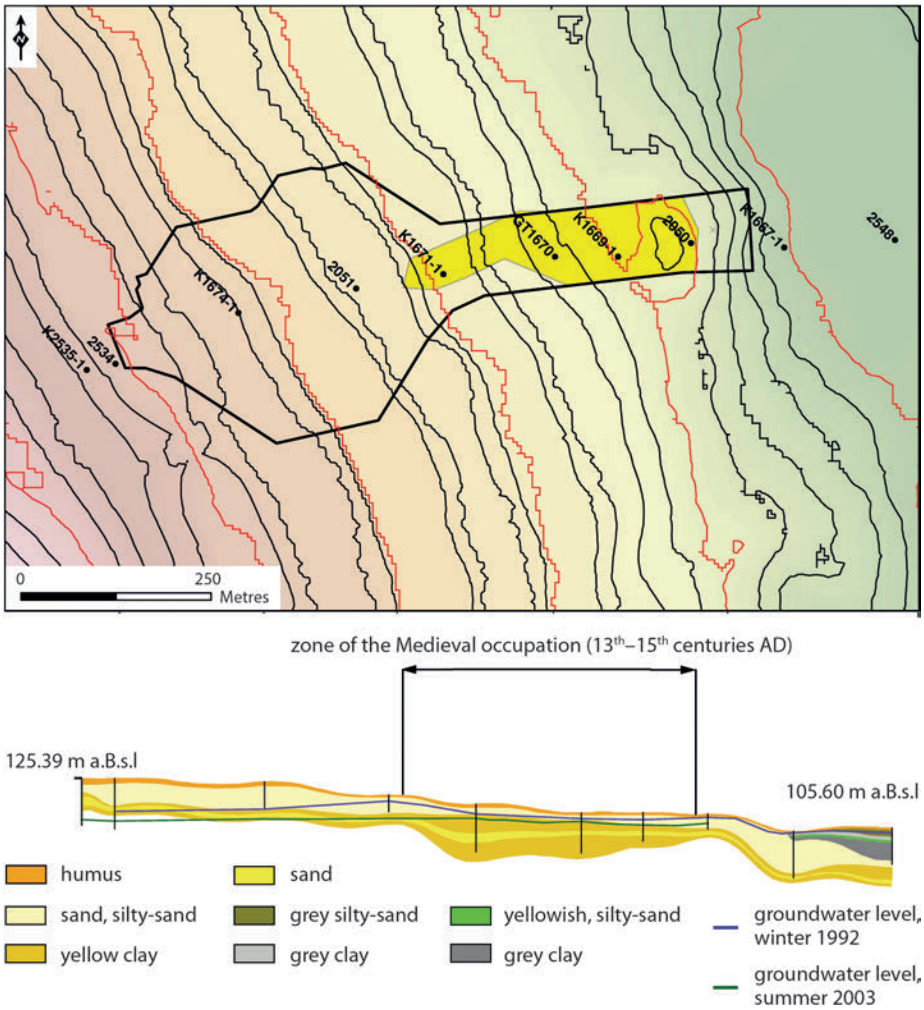

Fig. 16. Balatonkeresztúr-Réti-dűlő. The occupation zone of the Medieval period (13th to 15th century AD).

which is hypothesised by the model as the optimal hydrological zone.

The comparison of the conclusions drawn from the static groundwater model constructed from the data of the soil mechanics corings with the archaeological data undoubtedly support the decisive role of the optimal hydrological zone in the shaping of human occupation strategies. However, based on the model, only the criteria of the groundwater table characteristics of the optimal hydrological zone can be justified. The available data are unsuited to reconstructing the parameters of the optimal distance of the settlements from the water surface, which would undoubtedly provide further details on the hydrological aspects of human occupation strategies.

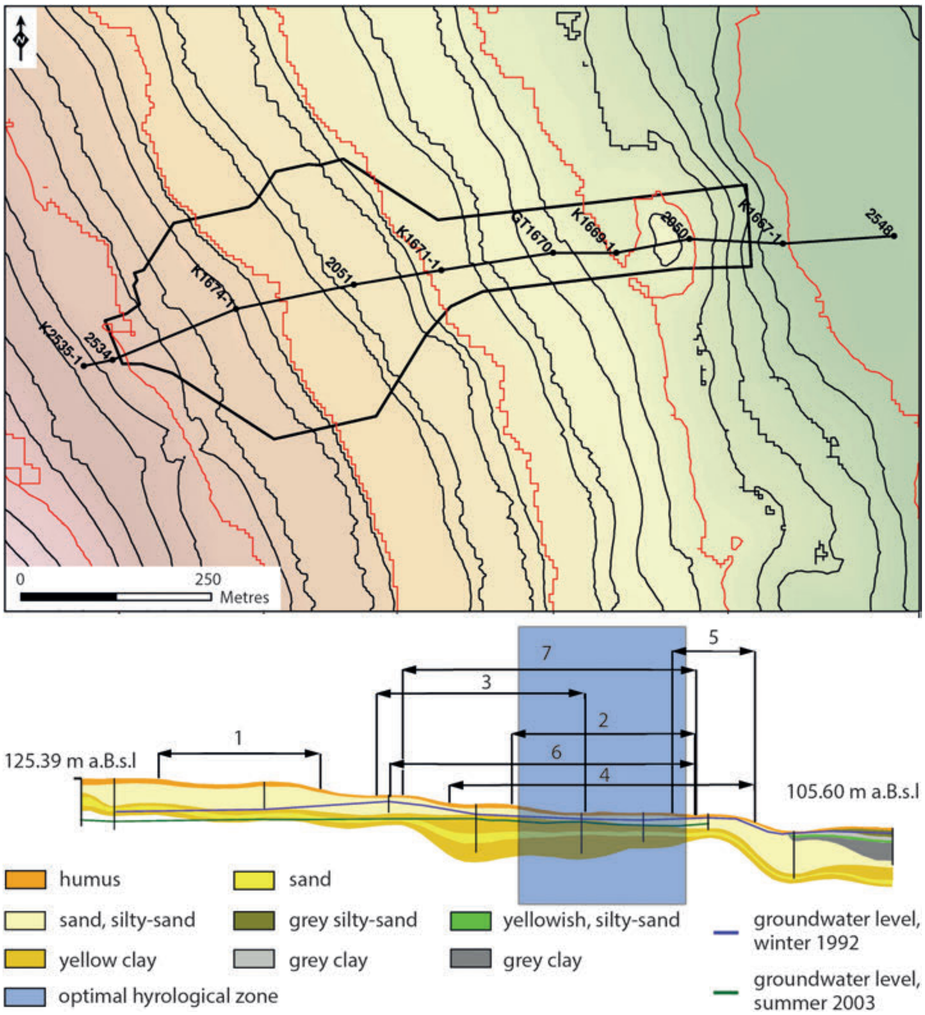

Fig. 17. Balatonkeresztúr-Réti-dűlő. The occupation zone of the different archaeological periods and the area of the optimal hydrological zone (blue).1 Middle Copper Age; 2 Late Copper Age; 3 Early and Middle Bronze Age; 4 Late Iron Age; 5 Migration period (6th century AD); 6 Árpádian period (10th to 11th century AD); 7 Medieval period (13th to 15th century AD).

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Abstract: Groundwater under scrutiny: A hydrological aspect of human settlement strategy in the vicinity of the southern shoreline of Lake Balaton

Hydrological conditions in the Carpathian Basin underwent a significant change in the wake of anthropogenic activities impacting the environment. The regulation and management of surface waters led to changes in the subsurface natural water systems. The depth and stability of the groundwater table are at least as important as the presence of surface water bodies among the parameters determining the locations suitable for human settlement. Discussed here are the effects of the relative groundwater table depth and its movement on human settlement, based on the insights provided by the comparative analysis of the data gained from the investigation of the multi-period archaeological site at Balatonkeresztúr-Réti-dűlő (site M7 / S35) and the static groundwater model constructed from the data provided by mechanical drillings and surveys ahead of the construction of the M7 motorway.

Zusammenfassung: Grundwasser auf dem Prüfstand: Ein hydrologischer Aspekt menschlicher Siedlungsstrategie im Nahbereich der südlichen Uferlinie des Balaton

Die hydrologischen Gegebenheiten im Karpatenbecken durchliefen erhebliche Veränderungen in Folge anthropogener Aktivitäten und ihres Einflusses auf die Umwelt. Die Regulierung und Steuerung von Oberflächengewässern führte zu Änderungen in den natürlichen unterirdischen Wassersystemen. Bei den Parametern, die entscheidend dafür sind, welche Plätze für die menschliche Besiedlung nutzbar sind, sind Tiefe und Stabilität des Grundwasserspiegels mindestens ebenso wichtig wie die Verfügbarkeit von Oberflächenwasser. In diesem Beitrag werden die Auswirkungen diskutiert, die die relative Tiefe des Grundwasserspiegels und ihre Veränderungen auf die menschliche Besiedlung hatten, auf der Grundlage der Erkenntnisse aus der vergleichenden Untersuchung der Daten, die aus der Erforschung des mehrperiodigen archäologischen Fundplatzes Balatonkeresztúr-Réti-dűló (Fundplatz M7 / S35) vorliegen, sowie auf Grundlage des statischen Grundwassermodells, das anhand von Daten aus Bohrungen und Surveys im Vorfeld des Baus der Autobahn M7 gewonnen wurde.

Absztrakt: A talajvíz tényező: az emberi megtelepedési stratégia hidrológiai szempontjai a Balaton déli partvonala mentén

Az elmúlt két évszázad antropogén eredetű természetátalakító folyamatai nagyban megváltoztatták a Kárpát-medence vízrajzi képét. A felszíni vizek rendezése magával vonta a felszín alatti természetes vízrendszerek megváltozását is. A felszíni vízfolyások mellett, a talajvíztükör mélysége és stabilitása legalább ugyan olyan fontos az emberi megtelepedés lehetséges helyét meghatározó paraméterek között. Jelen kutatás vizsgálati fókuszpontjában a talajvíztükör relatív mélységének és mozgáskarakterisztikájának emberi megtelepedésre gyakorolt hatása áll. A vizsgálatok alapja az M7 autópálya építését megelőző, Balatonkeresztúr-Réti dűlő (M7 / S35) több korszakú lelőhely településrégészeti adatainak és a kivitelezést megelőző talajmechanikai vizsgálatok eredményei alapján készült statikus talajvízmodell következtetéseinek összehasonlító elemzése.

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Fig. 1, 4–18: author. – *Fig. 2:* Gábor Timár. – *Fig. 3:* after data from the former Hungarian Ministry of Environmental Protection and Hydrology, graphics G. Serlegi and O. Wagner (RGK).

Angela Kreuz, Péter Pomázi, Anett Osztás, Krisztián Oross, Tibor Marton, Jörg Petrasch, László Domboróczki, Pál Raczky and Eszter Bánffy

Investigation of the plant macro-remains from four archaeological excavations at Fajsz-Garadomb and Alsónyék-Bátaszék in the Sárköz region and their comparison with the archaeobotanical record from other Hungarian Neolithic sites

Keywords: Hungary, Neolithic, agriculture, diet, cultural choice, archaeobotany

Schlagwörter: Ungarn, Neolithikum, Landwirtschaft, Ernährung, kulturbedingte Auswahl, Archäobotanik

Kulcsszavak: Magyarország, újkőkor, élelemtermelés, táplálkozás, kulturális értékválasztás, archeobotanika

Introduction

Following an intensive archaeological prospection in the years 2006–2008, the multi-period site of Fajsz-Garadomb in Hungary was excavated in the course of a research project supervised by Eszter Bánffy (then working in the Institute of Archaeology [RCH] of the Hungarian Academy of Sciences [HAS], Budapest) and Jörg Petrasch (Eberhard Karls Universität Tübingen, Ur- und Frühgeschichte und Archäologie des Mittelalters) funded by a grant from the German Research Foundation (DFG). This was the starting point of the first archaeobotanical investigations in the study area. The archaeobotanical samples from the excavations at Fajsz have been analysed as part of an MA thesis submitted to the University of Szeged (Pomázi 2010, tutored by the first author of the present paper). In the course of a subsequent research project focusing on Neolithic crop cultivation and land use in Hungary at the archaeobotanical department of the Landesamt für Denkmalpflege Hessen, hessenARCHÄOLOGIE (Wiesbaden), Péter Pomázi undertook the identification of the plant remains from another 22 Hungarian Neolithic sites, under the tutelage of the first author *(Tabs 1–2)*. The Landesamt für Denkmalpflege Hessen provided support for this archaeobotanical work since 2008, among others by facilitating sample preparation, the photographic documentation of the plant remains, and the archiving of the residues and plant remains with up-to-date standards. All raw data are stored in the *ArboDat* 2016 archaeobotanical database programme (based on Microsoft Access) in Wiesbaden, ensuring availability and access for future studies. Originally, the data was to be evaluated in a PhD thesis on these Neolithic plant remains at the Johannes Gutenberg-Universität Mainz. However, in May 2015, P. Pomázi left the institute in Wiesbaden to meet his other obligations in Hungary. Therefore, in agreement with him, the data evaluation was carried out by the first author of the present study.

Archaeobotanical material and method

As aptly noted by Kalicz et al. (2007, 20), the current state of archaeobotanical research on the Neolithic in Hungary makes it difficult to draw any final conclusions (Tempir 1964; see also Gyulai 2007; 2010). Therefore, the DFG project "Die Besiedlungsgeschichte der Siedlungskammer um Fajsz (Kom. Bács-Kiskun, Südungarn) in der Ältesten Bandkeramik" (2006–2010) as well as the excavations ahead of the construction of the Hungarian M6 motorway (Bánffy et al. 2010; 2014; Osztás et al. 2016, and further contributions in the same volume) provided an excellent opportunity to start

Archaeological dating	RTyp	Zust	Starčevo / Körös	Körös	LBK	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?	English Name	Deutscher Name
Excavation sites			**Sárköz:** **HU 1**, FAJSZ **HU 3** BSZÉK 5603/1 MT, **HU 6** BSZÉK 11	**HU 9** GORZSA 5, **HU 16** SARK	**Sárköz:** **HU 1** FAJSZ, **HU 2** BSZÉK 5603/1 56-út	**HU 4** SZEMELY, **HU 7** APC 1, **HU 11** RABAP, **HU 14** ZSENNYE	**HU 5** PTASK 1, **HU 8** HPAPI, **HU 10** MHEGYES, **HU 12** TBURA 5, **HU 16** SARK, **HU 17** VNAM, **HU 18** PPETRI, **HU 19** KANT, **HU 22** Büábr VII, **HU 23** Büábr XI/A	**Sárköz:** **HU 1** FAJSZ, **HU 2** BSZÉK 5603/1 56-út, **HU 6** BSZÉK 11	**HU 5** PTASK 1, **HU 15** URAI	**Sárköz:** **HU 1** FAJSZ	**Sárköz:** **HU 2** BSZÉK 5603/1 56-út, **HU 6** BSZÉK 11	**HU 5** PTASK 1, **HU 7** APC 1, **HU 11** RABAP, **HU 16** SARK, **HU 19** KANT		
Feature type(s)			Gr, SoBefu	Gr	Gr, Lgr	Gr, Lgr, Pfo, Gra, KöGrab	Gr, Lgr, Bru, KöGrab	Gr, Gra, KöGrab, SoBefu	Gr, Gra, KöGrab, SoBefu	Gr, Pfo, Koll	Gr	Gr, Pfo, Gra, Bru, KöGrab, BefuTyp?		
Sample type(s)			Eim, Gef	Eim, dir	Eim	Eim	Eim, dir	Eim	Eim	Eim	Eim	Eim		
Sample volume (litre)			147.15	235.01	334.5	456.6	1170.2	814	225.95	379	195	601		
Number of features			4	14	15	43	48	53	15	13	6	32		
Number of samples			7	22	20	58	139	72	20	23	15	56		
	RTyp	**Zust**											**English Name**	**Deutscher Name**
1 Riparian / Floodplain Vegetation														
Alisma plantago-aquatica	Em	vk					1						Water-plantain	Gewöhnlicher Froschlöffel
Chara spec.	Sa / Fr	vk										12	Stonewort	Armleuchteralge
Chara spec.	Sa / Fr	mi	1		25			3					Stonewort	Armleuchteralge
Eleocharis palustris agg.	Sa / Fr	vk					1					1	Common spike-rush	Gewöhnliche Sumpfbinse
cf. *Eleocharis palustris* agg.	Sa / Fr	vk								1			Common spike-rush	Gewöhnliche Sumpfbinse
Polygonum lapathifolium agg.	Sa / Fr	vk		2			1			1			Pale persicaria	Ampfer-Knöterich
Polygonum minus	Sa / Fr	vk		3						1			Small water pepper	Kleiner Knöterich
Potamogeton spec.	Sa / Fr	vk							26				Pondweed	Laichkraut
Rumex crispus / obtusifolius	Sa / Fr	vk	1	2			21						Curled / broad-leaved dock	Krauser / Stumpfblättriger Ampfer

Tab. 1. Compilation of the archaeobotanical results of the four Sárköz area excavations in comparison with further 22 Hungarian Neolithic sites. The results of features with mixed archaeological finds from different periods are entered in the *ArboDat* database as *ArchDat?* (for the abbreviations of the sites see *Tab. 2*; further abbreviations according to *ArboDat* 2016 see list of abbreviations).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
Trapa natans	Sa / Fr	vk	1	100			32		5				Water caltrop	Wassernuss
2 Grassland Vegetation														
Alchemilla vulgaris agg.	Sa / Fr	vk						1					Lady's mantle	Frauenmantel
Carex muricata agg.	Sa / Fr	vk					2						Prickly sedge	Stachel-Segge
Centaurea jacea s.l.	Sa / Fr	vk								1			Brown knapweed	Wiesen-Flockenblume
Cerastium cf. *arvense*	Sa / Fr	vk	3				1			1			Field mouse-ear chickweed	Acker-Hornkraut
Coronilla cf. *varia*	Sa / Fr	vk					4						Crown vetch	Bunte Kronwicke
Festuca spec.	Sa / Fr	vk					2						Fescue	Schwingel
Festuca / Lolium	Sa / Fr	vk								5			Fescue / ryegrass	Schwingel / Lolch
Fragaria vesca	Sa / Fr	vk							2				Wild strawberry	Wald-Erdbeere
Galium mollugo agg.	Sa / Fr	vk								1			Hedge bedstraw	Wiesen-Labkraut
Lotus corniculatus s. str.	Sa / Fr	vk										1	Bird's-foot trefoil	Gewöhnlicher Hornklee
Lychnis flos-cuculi	Sa / Fr	vk				1	5		1			1	Ragged-Robin	Kuckucks-Lichtnelke
Lychnis flos-cuculi	Sa / Fr	mi					4						Ragged-Robin	Kuckucks-Lichtnelke
cf. *Medicago lupulina*	Sa / Fr	vk								2			Black medick	Hopfenklee
Phleum pratense s.l.	Sa / Fr	vk		1		1	1			2	2		Purple-stem cat's-tail	Wiesen-Lieschgras
Polygonum aviculare agg.	Sa / Fr	vk		4			4	1		1			Knotweed	Vogel-Knöterich
Poa annua	Sa / Fr	vk	1			1	1						Annual meadow-grass	Einjähriges Rispengras
Poa spec.	Sa / Fr	vk					6					4	Meadow-grass	Rispengras
Silene vulgaris	Sa / Fr	vk										1	Bladder campion	Aufgeblasenes Leimkraut
Stipa spec.	Sa / Fr	vk										4	Feather grass	Federgras
Stipa spec.	Gr	vk	1	1		9	21		7			22	Feather grass	Federgras
Teucrium cf. *chamaedrys*	Sa / Fr	vk						1					Wall germander	Edel-Gamander
Trifolium pratense s.l.	Sa / Fr	vk								1			Red clover	Roter Wiesen-Klee
Trifolium cf. *pratense* s.l.	Sa / Fr	vk								2			Red clover	Roter Wiesen-Klee
Trifolium camp. / dub. / arv.	Sa / Fr	vk	2			2	6			1		2	Hop trefoil / suckling clover	Feld- / Kleiner / Hasen-Klee
cf. *Trifolium camp. / dub. / arv.*	Sa / Fr	vk								4			Hop trefoil / suckling clover	Feld- / Kleiner / Hasen-Klee
Trifolium spec.	Sa / Fr	vk					3	2		1			Clover	Klee
Verbena officinalis	Sa / Fr	vk					1						Vervain	Gewöhnliches Eisenkraut

Tab. 1. (continued).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
3 Ruderal Vegetation														
Bromus sterilis	Sa / Fr	vk										8	Barren brome	Taube Trespe
cf. *Bromus sterilis / tectorum*	Sa / Fr	vk						1					Barren brome / drooping brome	Taube / Dach-Trespe
Galium cf. *aparine*	Sa / Fr	vk					60			1			Goosegrass	Kletten-Labkraut
Hyoscyamus niger	Sa / Fr	vk		1			2	1	2			7	Henbane	Schwarzes Bilsenkraut
Malva sylvestris	Sa / Fr	vk				2							Common mallow	Wilde Malve
Nepeta cf. *cataria*	Sa / Fr	vk	1										Cat-mint	Gewöhnliche Katzenminze
Sambucus ebulus	Sa / Fr	vk	1		1		22					37	Danewort	Zwerg-Holunder
Sambucus ebulus	Sa / Fr	mi										1	Danewort	Zwerg-Holunder
Silene dioica	Sa / Fr	vk					2						Red campion	Tag-Lichtnelke
Sisymbrium spec.	Sa / Fr	vk								1			Rocket	Rauke
Torilis japonica	Sa / Fr	vk					1						Upright hedge-parsley	Gewöhnlicher Klettenkerbel
Urtica dioica	Sa / Fr	mi	1										Common nettle	Große Brennnessel
4 Ruderals / Segetals undifferentiated														
Atriplex / Chenopodium	Sa / Fr	mi	32	5		2	1		12			18	Orache / goosefoots	Melde / Gänsefuß
Chenopodium album	Sa / Fr	vk	384	16	7	84	1319	28	64	17	55	132	Fat-hen	Weißer Gänsefuß
Chenopodium album	Sa / Fr	mi					5		10				Fat-hen	Weißer Gänsefuß
Chenopodium hybridum	Sa / Fr	vk	1	2			7	4	4			1	Maple-leaved goosefoot	Unechter Gänsefuß
Chenopodium spec.	Sa / Fr	vk					2	1	1				Goosefoot	Gänsefuß
Chenopodium spec.	Sa / Fr	mi				843					1		Goosefoot	Gänsefuß
Echinochloa crus-galli	Sa / Fr	vk	8	2		2	15	1	4	1	10	5	Cockspur	Hühnerhirse
cf. *Echinochloa crus-galli*	Sa / Fr	vk					1					1	Cockspur	Hühnerhirse
cf. *Echinochloa crus-galli*	Sa / Fr	mi							1				Cockspur	Hühnerhirse
Lepidium spec.	Sa / Fr	mi							1				Pepperwort	Kresse
Portulaca oleracea s.l.	Sa / Fr	vk										4	Common purslane	Portulak s.l.
Silene alba	Sa / Fr	vk	2										White campion	Weiße Lichtnelke
Solanum nigrum	Sa / Fr	vk	4			1	5			1		4	Black nightshade	Schwarzer Nachtschatten
5 Crops														
Hordeum distichon / vulgare	Sa / Fr	vk	19	20			125	2	1	15		2	Barley	Kulturgerste undiff.
cf. *Hordeum distichon / vulgare*	Sa / Fr	vk					3			3			Barley	Kulturgerste undiff.

Tab. 1. (continued).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
Hordeum distichon / vulgare	Spi	vk	4				3						Barley	Kulturgerste undiff.
Panicum miliaceum	Sa / Fr	vk								230	2	11	Common millet	Echte Hirse
cf. *Panicum miliaceum*	Sa / Fr	vk								17			Common millet	Echte Hirse
Triticum aestivum s.l. / *durum / turgidum*	Sa / Fr	vk				1	1	1	1	6		11	Naked wheat	Nacktweizen
Triticum aestivum s.l. / *durum / turgidum*	Spi	vk				1	3					114	Naked wheat	Nacktweizen
Triticum cf. *aestivum* s.l. / *durum / turgidum*	Sa / Fr	vk					7			3		1	Naked wheat	Nacktweizen
Triticum dicoccum	Sa / Fr	vk		3	1	13	172	4	5	8		57	Emmer	Emmer
Triticum cf. *dicoccum*	Sa / Fr	vk	2	3		1	16		2	1	1	11	Emmer	Emmer
Triticum dicoccum	HSB	vk	196	249	55	587	6526	1181	160	87	4247	2540	Emmer	Emmer
Triticum cf. *dicoccum*	HSB	vk			5	16	66	68	19	4			Emmer	Emmer
Triticum dicoccum	Spi	vk					6	2			2	1	Emmer	Emmer
Triticum cf. *dicoccum*	Spi	vk					1						Emmer	Emmer
Triticum monococcum	Sa / Fr	vk	2	6	1	8	29	2	7	6	1	43	Einkorn	Einkorn
Triticum cf. *monococcum*	Sa / Fr	vk				1	8		1			1	Einkorn	Einkorn
Triticum monococcum	HSB	vk	274	112	203	913	1514	2911	154	349	4448	6643	Einkorn	Einkorn
Triticum cf. *monococcum*	HSB	vk	12	4	2	12	53	5	30				Einkorn	Einkorn
Triticum monococcum	Spi	vk					2					1	Einkorn	Einkorn
Triticum monococcum, 2-grained	Sa / Fr	vk					24	2		1		8	Einkorn 2-grained	Einkorn
Triticum cf. *monococcum*, 2-grained	Sa / Fr	vk					1		1				Einkorn 2-grained	Einkorn
Triticum aest. s.l. / *dur.* / *turg.* / *dicoccum*	Sa / Fr	vk					3				1	5	Naked wheat / emmer	Nacktweizen / Emmer
Triticum monococcum / dicoccum	Sa / Fr	vk	1	3	12	13	65	2	1	4	8	51	Einkorn / emmer	Einkorn / Emmer
Triticum monococcum / dicoccum	HSB	vk	386	819	501	1994	13422	19320	2114	1117	17656	7495	Einkorn / emmer	Einkorn / Emmer
Triticum dicoccum / spelta	Sa / Fr	vk					2			3			Emmer / spelt	Emmer / Dinkel
Triticum dicoccum / spelta	HSB	vk				1		1		2			Emmer / spelt	Emmer / Dinkel
Triticum spec., Spelzweizen	HSB	vk	2		7	1	2	552		136			Glume wheat	Spelzweizen

Tab. 1. (continued).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
Triticum spec.	Sa / Fr	vk	6	2		11	28	3	8	11	2	9	Wheat	Weizen undifferenziert
Cerealia indet.	Sa / Fr	vk	71	145	50	152	1846	126	70	105	66	466	Cereals	Getreide
Cerealia indet.	Spi	vk		3	2	4	301	46		4	88	91	Cereals	Getreide
Lens culinaris	Sa / Fr	vk		8		8	30	1	1	1	1	19	Lentil	Linse
cf. *Lens culinaris*	Sa / Fr	vk					1						Lentil	Linse
Pisum sativum	Sa / Fr	vk				1	10					3	Garden pea	Erbse
cf. *Vicia ervilia*	Sa / Fr	vk		1									Bitter vetch	Linsen-Wicke
Fabaceae (kult.)	Sa / Fr	vk					15						Pulses	Hülsenfrüchte kultiviert
Camelina sativa	Sa / Fr	vk								4			Gold-of-pleasure	Saat-Leindotter
Linum usitatissimum	Sa / Fr	vk					1						Flax	Gebauter Lein, Flachs
Linum usitatissimum	Sa / Fr	mi					5						Flax	Gebauter Lein, Flachs
Papaver somniferum	Sa / Fr	vk				3	2						Opium poppy	Schlaf-Mohn
6 Weeds of hoed fields and gardens														
Digitaria ischaemum	Sa / Fr	vk								2			Red millet	Faden-Fingergras
Digitaria cf. *ischaemum*	Sa / Fr	vk								1			Red millet	Faden-Fingergras
Setaria verticillata / viridis	Sa / Fr	vk				1	9		8		19	1	Lively / green bristle-grass	Quirlige / Grüne Borstenhirse
7 Weeds of cereal fields														
Agrostemma githago	Sa / Fr	vk										32	Corn-cockle	Kornrade
Anagallis arvensis	Sa / Fr	vk								2			Scarlet pimpernel	Acker-Gauchheil
Bromus cf. *arvensis*	Sa / Fr	vk		1						3			Field brome	Acker-Trespe
Bromus cf. *secalinus*	Sa / Fr	vk		1		1	45			14		20	Chess grass	Roggen-Trespe
Camelina spec. *microcarpa*	Sa / Fr	vk					3			1			Lesser gold-of-pleasure	Kleinfrüchtiger Leindotter
Galium spurium	Sa / Fr	vk	3	1	1	2	246		4	3		6	False cleavers	Saat-Labkraut
Galium cf. *spurium*	Sa / Fr	vk							1				False cleavers	Saat-Labkraut
Papaver dubium / rhoeas	Sa / Fr	vk	2										Long-headed / field poppy	Klatsch-, Saat-Mohn
Polygonum convolvulus	Sa / Fr	vk	6	5	1	17	164	9	2	2	42	31	Black bindweed	Winden-Knöterich
Scleranthus annuus s.str.	Sa / Fr	vk					1						Annual knawel	Einjähriges Knäuelkraut
Stachys annua	Sa / Fr	vk								3			Annual woundwort	Einjähriger Ziest
Vicia hirsuta	Sa / Fr	vk					10			1	1		Hairy tare	Rauhhaarige Wicke
Vicia hirsuta / tetrasperma	Sa / Fr	vk		1	1		2						Hairy / slender tare	Rauhhaarige / Viersamige Wicke
10 Deciduous Forests / Shrubbery														
Alnus cf. *glutinos*a	Sa / Fr	vk	1										Alder	Schwarz-Erle
Cornus mas	Sa / Fr	vk	2	6	12	5	54	164	3	62		6	Cornelian cherry	Kornelkirsche

Tab. 1. (continued).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
Cornus sanguinea	Sa / Fr	vk				1		1					Dogwood	Roter Hartriegel
Corylus avellana	Sa / Fr	vk		3	1	5	7	4	5		3	5	Hazel	Hasel
cf. *Pyrus pyraster*	Sa / Fr	vk				1							Wild pear	Wild-Birnbaum
Rubus spec.	Sa / Fr	vk									1		Blackberry / raspberry / dewberry	Brombeere, Himbeere, Kratzbeere
Sambucus nigra	Sa / Fr	vk			2		1					18	Elder	Schwarzer Holunder
Sambucus cf. *nigra*	Sa / Fr	vk				1		1					Elder	Schwarzer Holunder
Sambucus spec.	Sa / Fr	vk	4	1	6	5	37		4		12	9	Elder	Holunder
Sambucus spec.	Sa / Fr	mi	2					6					Elder	Holunder
cf. *Vitis sylvestris*	Sa / Fr	vk						1					Wild vine	Weinrebe
11 Varia														
Apiaceae	Sa / Fr	vk						1		1			Umbelliferous plants	Doldengewächse
Asteraceae	Sa / Fr	vk					1						Daisy family	Korbblütler
Avena spec.	Gr	vk			1		1	19		26			Oat	Hafer
Avena / Secale	Sa / Fr	vk							1				Oat / rye	Hafer / Roggen
Bromus spec.	Sa / Fr	vk	1										Brome	Trespe
Brassicaceae	Sa / Fr	vk					1	1		2			Cabbage family	Kreuzblütler
Brassicaceae	Sa / Fr	mi							1				Cabbage family	Kreuzblütler
Carex spec.	Sa / Fr	vk	2				1	1		1		1	Sedge	Segge bicarpellat
Caryophyllaceae	Sa / Fr	vk		1		1	2	1	1				Carnation family	Nelkengewächse
Caryophyllaceae / Chenopodiaceae	Sa / Fr	vk					83	1	5	2	1		Carnation / goosefoot families	Nelken- / Meldengewächse
Caryophyllaceae / Chenopodiaceae	Sa / Fr	mi	3		183			1			10		Carnation / goosefoot families	Nelken- / Meldengewächse
Cyperaceae	Sa / Fr	vk				3	2	1					Sedges	Sauergräser
Fabaceae	Sa / Fr	vk	1	2		5	158		2	7	1	17	Legumes	Hülsenfrüchte
cf. Fabaceae	Sa / Fr	vk								2			Legumes	Hülsenfrüchte
Galium spec.	Sa / Fr	vk					143	1	4	1			Bedstraw	Labkraut
Galium spec.	Sa / Fr	mi					1						Bedstraw	Labkraut
Hordeum spec.	Sa / Fr	vk	1				6						Barley undiff.	Gerste undiff.
Lamiaceae	Sa / Fr	vk	1				2						Labiatae	Lippenblütler
Lamiaceae	Sa / Fr	mi	15							3			Labiatae	Lippenblütler
Lathyrus / Vicia spec.	Sa / Fr	vk					6						Vetchling / tare	Platterbse / Wicke
Panicoideae	Sa / Fr	vk		2		4	9		2	1	34	4	Millet-like	Hirseartige
Panicoideae	Sa / Fr	mi					1						Millet-like	Hirseartige
Poaceae	Sa / Fr	vk	3	18	1	6	97	6	7	6	3	5	Grasses	Süßgräser

Tab. 1. (continued).

Archaeological dating			Starčevo /	Körös	LBK Körös	LBK	ALBK, Szakálhát	SOP, LENG	SOP, LENG, Tisza	BZ	ArchDat?	ArchDat?		
Polygonum convolvulus/ aviculare	Sa / Fr	vk		75	9	12	374	120	81	22	6	6	Black bindweed / knotgrass	Winden- / Vogel-Knöterich
Polygonum convolvulus/ dumetorum	Sa / Fr	vk					2		1	1		1	Black bindweed / copse-bindweed	Winden- / Vogel-Knöterich
Polygonum convolvulus/ dumetorum	Sa / Fr	mi					2		2				Black bindweed / copse-bindweed	Winden- / Vogel-Knöterich
Polygonum lapathifolium / persicaria	Sa / Fr	vk		2									Pale persicaria / red shank	Ampfer- / Pfirsich-blättriger Knöterich
Polygonum spec.	Sa / Fr	vk		4			1					2	Smartweed	Knöterich
Rumex spec.	Sa / Fr	vk		1									Dock	Ampfer
Polygonaceae	Sa / Fr	vk					4				4		Smartweed family	Knöterichgewächse
Rosaceae	Sa / Fr	vk				1	1						Rose family	Rosengewächse
Silene spec.	Sa / Fr	vk					1						Catchfly	Leimkraut
Solanaceae	Sa / Fr	vk					11					1	Nightshades	Nachtschattengewächse
Solanaceae	Sa / Fr	mi	1			3		2			1		Nightshades	Nachtschattengewächse
Vicia spec.	Sa / Fr	vk					1						Tare	Wicke
Viola spec.	Sa / Fr	vk	1										Violet	Veilchen
20 Other														
Indeterminata	Sa / Fr	vk	1	164		2	36	13	8	62		37	Unidentified seed / fruit	unbestimmte Samen / Früchte
Indeterminata	Sa / Fr	mi	13		161	771	31	2	1	1	20	25	Unidentified seed / fruit	unbestimmte Samen / Früchte
Indeterminata	Kap / Kapz	vk					1					1	Capsule fragment	Kapselfragment
Indeterminata	Veget	vk		6		3	601	5	4	14	1	34	Vegetative plant remains	vegetative Pflanzenreste
Indeterminata	Knos	vk				3	100	1	1		6	31	Buds	Knospen
Indeterminata	Do / St	vk								2			Thorn	Dorn / Stachel
Indeterminata	BGF	vk		7			100			42	6		Porridge / pastry / fruit	Brei / Gebäck / Fruchtfleisch
Indeterminata	Fisch	vk					1	10			14		Fish remains	Fischwirbel / schuppen
Indeterminata	Fisch	so	674	2079	1608	131	812	23035	352	407	403	397	Fish remains	Fischwirbel / schuppen
Indeterminata	Insek	mi	6										Insect remains	Insekten
Indeterminata	Knoz	so	16	49	25	60	151	83	19	30	26	63	Bone / teeth	Knochen / Zähne
Indeterminata	Kopr	vk	1	6	4	18	58	3		3	2	142	Coprolithe	Koprolithen, cf. Maus

Tab. 1. (continued).

Fig. 1. During the excavation of the Neolithic site near Fajsz-Garadomb, Bács-Kiskun county, a systematic archaeobotanical sampling was carried out by the excavators. The dry mineral soil conditions allowed charred or mineralised preservation of the plant remains (in the centre Eszter Bánffy and Péter Pomázi; 14th October 2007).

systematic archaeobotanical investigations in the Sárköz region for the first time. Of the four excavated sites in the Sárköz region, the samples comprise plant remains dating to the Neolithic and, although to a lesser extent, to the Bronze Age (the latter included here for the sake of completeness only). This study reviews and discusses the fully archived and assessed quantitative data with the *ArboDat* 2016 archaeobotanical database programme (for the latter, see Kreuz / Schäfer 2012).

All calculations are based on charred or mineralised plant material that was preserved under dry mineral soil conditions. The processing of the samples (wet sieving and sorting) was carried out at the Landesamt für Denkmalpflege Hessen, hessenARCHÄOLOGIE (Wiesbaden), and follows the methods described, e. g., in Jacomet / Kreuz (1999). Wet sieving was conducted with sieves of 1 mm to 0.5 mm mesh width. The reference collections and the archaeobotanical literature of the department in Wiesbaden were used for the species determination of the plant remains. The plant remains are stored as single species and are labelled with their project, feature, and sample numbers.

A total of 56 509 plant remains have been identified in the 137 samples collected from 91 archaeological features of the Sárköz region *(Tab. 1)*. The number of sites, features, samples, and the sample volumes vary strongly for the different time periods. Therefore, in the following, the archaeobotanical data are summarised according to the three major archaeological periods of the Neolithic in Hungary.

(1) Early Neolithic, after 5800 cal BC
Late Starčevo (Spiraloid B), late Körös: three excavation sites (HU 1 Fajsz, HU 3 and HU 6 Alsónyék), four features, seven samples;

(2) Middle Neolithic, c. 5500–4950 cal BC
Linerarbandkeramik culture (hereinafter LBK) (Bicske-Bíňa phase and LBK undifferentiated): two excavation sites (HU 1 Fajsz, HU 2 Alsónyék), 15 features, 20 samples;

(3) Late Neolithic, c. 4900–4500 cal BC
Sopot and Lengyel cultures: three excavation sites (HU 1 Fajsz, HU 2, and HU 6 Alsónyék), 53 features, 72 samples (see *Tab. 1*).

Project number	Abbreviation site	Site	Location	Easting	Northing	Excavation year
HU 1	FAJSZ	Fajsz	Garadomb	18.937807	46.402068	2007, 2008
HU 2	BSZÉK 5603 / 1	Alsónyék-Bátaszék	M6 TO 5603 / 1 56-út	18.705132	46.208121	2009
HU 3	BSZÉK 5603 / 1 MT	Alsónyék-Bátaszék	M6 TO 5603 / 1 Mérnöki Telep	18.702595	46.206970	2009
HU 4	SZEMELY	Szemely	M60 83	18.338697	46.024756	2007
HU 5	PTASK 2	Pusztataskony	Ledence	20.509958	47.460995	2009
HU 6	BSZÉK 11	Alsónyék-Bátaszék	M6 TO 11	18.701670	46.208639	2009
HU 7	APC 1	Apc	Berekalja 1	19.670949	47.802355	2009
HU 8	HPAPI 1	Hejőpapi	1	20.873172	47.918639	2009, 2010
HU 9	GORZSA 5	Gorzsa	V. Homokbánya	20.311681	46.334006	2009
HU 10	MHEGYES	Magyarbánhegyes	Boglyás-Lengés dűlő	20.939869	46.439658	2010
HU 11	RÁBAP	Rábapatona	Kós-domb	17.475372	47.657400	2011
HU 12	TBURA	Tiszabura	Bónis-hát	20.515383	47.449967	2009
HU 14	ZSENNYE	Zsennye	Kavicsbánya	16.817442	47.117678	2007
HU 15	URAI	Uraiújfalu	Alájáró-dűlő	16.997679	47.371613	2010
HU 16	SARKAD	Sarkad	59	21.440775	46.755975	2012
HU 17	VNAM	Vásárosnamény	Perényi tanyától D-re (M3 219)	22.253587	48.078001	2011
HU 18	PPETRI	Pócspetri	Bikaréti szivárgó (M3 212)	22.008021	47.907448	2011
HU 19	KANT	Kántorjánosi	Homoki-dűlő Ny-i pereme (M3 / 52+52d)	22.146671	47.952447	2010
HU 22	BÜÁBR VII	Bükkábrány	VII	20.726297	47.878250	2012
HU 23	BÜÁBR XI / A	Bükkábrány	XI / A	20.730569	47.883052	2012, 2013
Sum						

Tab. 2. Table of the archaeobotanically investigated Hungarian Neolithic sites.
All data are archived with the archaeobotanical database programme *ArboDat* 2016.

Archaeological Dating	Features	Samples	Sample volume (litre)	Excavator(s)	Institution
KÖR, LBK Bic, SOP, BZ	52	74	1049	Dr. Jörg Petrasch / Prof. Dr. Eszter Bánffy	Eberhard Karls Universität Tübingen / Institute of Archaeology of the Hungarian Academy of Sciences Budapest]
LBK HU, LENG, ArchDat?	30	46	604	Prof. Dr. István Zalai-Gaál / Anett Osztás	Institute of Archaeology of the Hungarian Academy of Sciences Budapest / Archaeosztráda Kft.[company of archaeological services, Budapest]
STAR_L	2	4	122.15	Prof. Dr. István Zalai-Gaál / Anett Osztás	Institute of Archaeology of the Hungarian Academy of Sciences Budapest / Archaeosztráda Kft.[company of archaeological services, Budapest]
LBK II-V HU, LBK HU	3	5	14.5	Zsolt Gallina / Krisztina Somogyi	Ásatárs Kft. [company of archaeological services, Kecskemét]
SZAK, TIS, Neol HU, ArchDat?	26	30	450	Prof. Dr. Pál Raczky / Dr. Katalin Sebők	Eötvös Loránd University, (ELTE), Budapest
STAR_L, LENG, ArchDat?	7	13	94.5	Zsolt Gallina / Krisztina Somogyi	Ásatárs Kft. [company of archaeological services, Kecskemét]
LBK Bic, LBK HU, LBK Not, LBK Zse, ArchDat?	37	69	813.5	Dr. László Domboróczki / József Danyi	Dobó István Vármúzeum, Eger [Museum, Eger]
ALBK	11	48	536	Miklós Makoldi	Herman Ottó Múzeum, Miskolc [Museum, Miskolc]
KÖR	7	15	171.51	Katalin Tóth / Tibor Paluch	Tornyai János Múzeum, Hódmezővásárhely [Museum, Hódmezővásárhely]
SZAK 2	2	21	65	Dániel Pópity	Field service for cultural heritage
LBK Not, ArchDat?	28	30	175.5	Péter Polgár	Xantus János Múzeum, Győr [Museum, Győr]
ALBK	2	2	34	Prof. Dr. Pál Raczky / Gábor Váczi	Eötvös Loránd University, Budapest
LBK Kes	1	3	1.6	Csilla Farkas	Savaria Múzeum, Szombathely [Museum, Szombathely]
LENG	2	6	4.95	Csilla Farkas / Réka Mladoniczky	Savaria Múzeum, Szombathely [Museum, Szombathely]
KÖR, ALBK 3, Neol HU, ArchDat?	6	9	55.45	Anita Vári / Gábor Bácsmegi	Munkácsy Múzeum, Békéscsaba [Museum, Békéscsaba]
ALBK 1, Neol HU	11	28	71.5	Katalin Kurucz	Magyar Nemzeti Múzeum (Hungarian National Museum)
ALBK	2	4	17.5	Katalin Kurucz	Magyar Nemzeti Múzeum (Hungarian National Museum)
ALBK, ArchDat?	5	6	41	Katalin Kurucz	Magyar Nemzeti Múzeum (Hungarian National Museum)
ALBK	2	5	42	András Kalli	Herman Ottó Múzeum, Miskolc [Museum, Miskolc]
ALBK	5	12	169	András Kalli	Herman Ottó Múzeum, Miskolc [Museum, Miskolc]
	241	**430**	**4532.66**		

Tab. 2. (continued).

Archaeological dating	Starčevo / Körös	LBK	ALBK, Szakálhát	SOP, LENG, Tisza	BZ	ArchDat?
Site(s)	**HU 1** FAJSZ, **HU 3** BSZÉK 5603 / 1 MT, **HU 6** BSZÉK 11, **HU 9** GORZSA 5, **HU 16** SARK	**HU 1** FAJSZ, **HU 2** BSZÉK 5603 / 1 56-út, **HU 4** SZEMELY, **HU 7** APC 1, **HU 11** RABAP, **HU 14** ZSENNYE	**HU 5** PTASK 1, **HU 8** HPAPI, **HU 10** MHEGYES, **HU 12** TBURA 5, **HU 16** SARK, **HU 17** VNAM, **HU 18** PPETRI, **HU 19** KANT, **HU 22** Büábr VII, **HU 23** Büábr XI / A	**HU 1** FAJSZ, **HU 2** BSZÉK 5603 / 1 56-út, **HU 5** PTASK 1, **HU 6** BSZÉK 11 **HU 15** URAI	**HU 1** FAJSZ	**HU 2** BSZÉK 5603 / 1 56-út, **HU 5** PTASK 1, **HU 6** BSZÉK 11, **HU 7** APC 1, **HU 11** RABAP, **HU 16** SARK, **HU 19** KANT
Charred concentration (piece / l) **all sites / all feature types**	8.3	6.2	23.4	44.6	6.2	56.2
Charred concentration (piece / l) **all sites / only pits**	8.3	7.5	24.1	54.9	14.4	63.7
Charred concentration (piece / l) **all feature types / only Sarköz area**	10.9	3.1		52	6.2	137

Tab. 3. Comparison of the concentration values of the charred plant remains for the different archaeological periods (Ecological Groups 1–7, 10–11; see *Tab. 1*).

In addition, further 23 samples from 13 archaeological features of the excavation at the HU 1 Fajsz site dated to the Hungarian Bronze Age (from 2200 cal BC onwards) are included here for the sake of the completeness of the Sárköz sites.

As mentioned in the above, supplementary to the archaeobotanical samples from the Sárköz excavation sites, we received additional archaeobotanical material for the research project from a further 19 Hungarian Neolithic sites, representing, among others, the Alföld Linearbandkeramik (hereinafter Alföld-LBK or ALBK) and the Szakálhát group of eastern Hungary *(Tabs 1–2)*. Additionally, material from two Romanian Neolithic sites has been evaluated, which is not included here. All in all, 79 plant species (Ecological Groups 1–7, 10) and 20 plant taxa (Ecological Group 11 Varia; *Tabs 1–2*) from 113 170 plant remains have been determined and are archived fully quantitatively with the archaeobotanical database programme *ArboDat* [1].

Today, the one-time occupation surface of Neolithic settlement sites is usually eroded. Therefore, predominantly features that in the past were dug into the ground are preserved. In the case of our investigation, the regularly sampled archaeological features are different kinds of pits, post-holes, ditches, and graves. At all sites, we are dealing with dry mineral soils with a preponderance of the charred preservation of the plant remains (e. g. as at the excavation at Fajsz; *Fig. 1*). Mineralised remains occurred in about 10 % of the features only and in very low quantities. The general archaeobotanical experience is that the remains of crop species are well preserved in a charred form due to their contact with cooking fires and hearths. Therefore, it is not surprising that, on the average, 94 % of all charred plant remains discussed here come from cereals, pulses, and the other crop plants *(Tab. 1)*.

Table 3 clearly illustrates the variability of the concentration values of the charred plant remains for the different archaeological periods. The concentration values are calculated for all charred plant remains of Ecological Groups 1–7, 11 of all sites and all feature types. They are also calculated for “only pit features” and for “all features from the Sárköz region”, respectively (for the latter, see the last line of *Tab. 3*). Remarkably, the values of the Sárköz sites partly mirror the general trend. The high values of the features with uncertain archaeological dating (ArchDat?) can in part be attributed to the higher amount of charred cereal chaff remains in the relevant samples. In fact, it is too early for a contextual interpretation of the existing quantitative data. If, for example, we

1 The assignation of archaeobotanical finds to modern phytosociological units, e. g. modern weed associations, often makes no sense, especially for earlier prehistoric periods. Instead, as an aid for the sorting of wild and cultivated species, taxa can be classified into so-called Ecological Groups, following their modern, natural main distribution. The Ecological Groups used here and from the *ArboDat* database programme are listed in *Tab. 1*.

Fig. 2. Historical map from the Sárköz area by Mihály Ruttkay 1763 (1 : 20 000) showing the surroundings of the archaeological site near Fajsz (orange square). Recognisable are the numerous meanders and fens in the marginal depression area of the river Danube to the east.

compare the concentration values of 1749 samples from 551 LBK features from Germany and Austria, which is 16.5 charred plant remains per litre (Kreuz 2012) with the LBK value of 3.1 pieces per litre from the Sárköz sites (based on 20 samples from 15 features, see *Tab. 1*), it is obvious that the more samples investigated in future, the better the archaeobotanical output and the potential for a differentiated interpretation.

The study area and the Neolithic landscapes

The study area is located in the alluvial Danube Valley, in a micro-region known as the Sárköz region. The landscape is bordered to the east by the sandy plains of the Danube-Tisza interfluve and to the west by the Mecsek Mountains and the hilly landscape of southern Transdanubia.

The excavation at Fajsz-Garadomb lays some 4 km east of the current Danube channel, at about 93 m a.s.l., which is 4 m higher than the modern river bed and thus rises above the floodplain with its yearly inundations. It seems very likely that this was the case in the Neolithic too, since according to our current knowledge, the former river channel ran deeper than today (Gábris / Nádor 2007). On the testimony of studies in the comparable areas of the Upper Rhine Valley and the German low mountain range, due to erosion the relief has been flattened up to 50 % including a considerable sedimentation in the river valleys during the Holocene (e. g. Thiemeyer 1987; Wunderlich 2000; Dambeck / Thiemeyer 2002; Dambeck 2005; Gábris / Nádor 2007; Kreuz et al. 2007). A similar development can be assumed for the Danube Valley in the Hungarian Plain too. Three other excavations around Alsónyék in the Sárköz region were located about 40 km south-west of Fajsz, about 10 km west of the Danube (for further geographic information, see, e. g., Somogyi 1961; Kosse 1979; Marosi / Somogyi 1990; Bánffy et al. 2014; Sümegi et al. in this volume).

The entire Danube Valley is characterised by the changeful development of the numerous rivers and streams and their abandoned channels and oxbow lakes (see also the topographical maps as well as Borsy et al. 1969, 237; Somogyi 1961; Sümegi 2001; Bánffy et al.

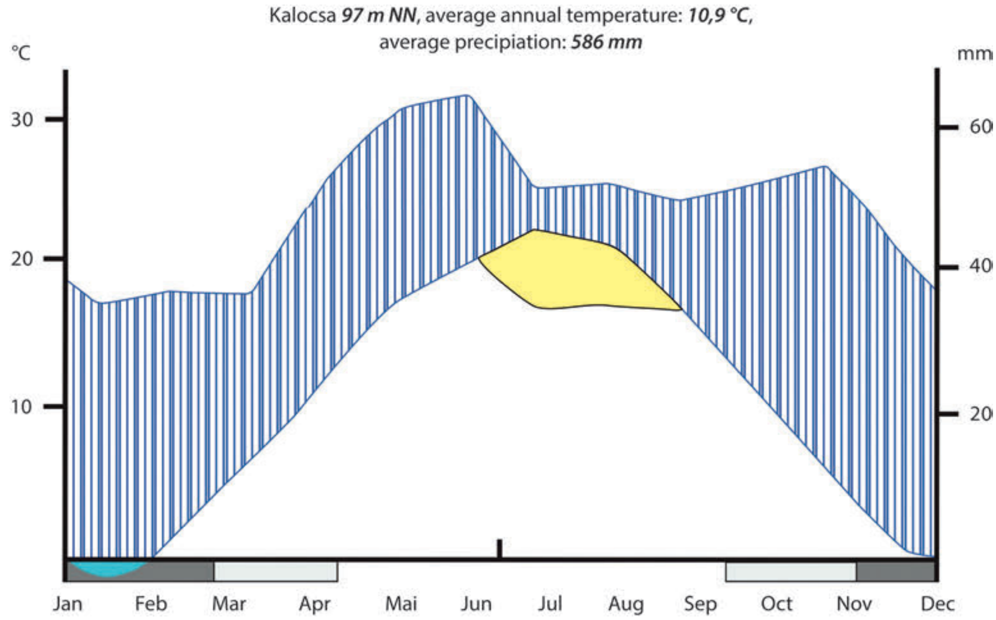


Fig. 3. Diagram illustrating the climate in the area of the modern town of Kalocsa, Bács-Kiskun county (from Walter / Lieth 1967). The decrease of the precipitation coincides with the highest temperatures in July (lower curve). Therefore, today there is a risk of summer drought.

2014; Osztás et al. 2016, fig. 2). Regrettably, the absolute dating of the oxbows is mostly still lacking and it is unknown until when they were small "lakes" in the landscape. On the other hand, former meanders can still be seen on the historic maps of the 18th century (*Fig. 2*; Ruttkay 1763 in Arcanum 2009). These historic maps show that at least part of the abandoned channels and oxbow lakes still contained water at that time. Moreover, on the testimony of the map, there were extended fens along the eastern edge of the Danube Valley in the year 1763, in the marginal depression area *(Randsenke)* of the river valley.

The fluvial sediments consisting of gravel, sand, clay, and loam are today overlain by up to 1 m thick loess sediments (Geological Map of Hungary, Máfi 2009; Sümegi 2001; 2003). Chernozem soils and brown soils developed during the Pre-Boreal from the late-glacial virgin soils under terrestrial conditions (Horvat et al. 1974, 41; 282–285; Stefanovits et al. 1999, 279–318; 409; for the development of chernozem soils see e. g. Schalich 1988; Schachtschabel et al. 1989; Semmel 1990). The entire Sárköz region and the areas of the other Neolithic sites included here are under agricultural use today and provided an excellent substrate for crop cultivation in prehistoric times.

The climate

Modern Hungary is located at the intersection of the Eastern European continental, the Western European oceanic, and the South European sub-Mediterranean climate zones (Pécsi / Sárfalvi 1962, 42; see also Sümegi et al. in this volume). The Sárköz region has a more continental, warm, and dry climate (*Fig. 3*; Walter / Lieth 1967, type nos 6–7). Currently, the annual average temperature around Kalocsa and in the Sárköz region is about 10.5–10.9 °C. The average temperature of the vegetation period is 17 °C. The period without frost lasts from April 5 until October 25. The temperature ranges from a maximum of 34.4 °C in summer to -15.5 and -16 °C in winter (Vadász 1969; Marosi / Somogyi 1990, 50). The annual average precipitation ranges from about 570 to 590 mm. Today, the area's environment can be characterised by a slightly arid tendency with the risk of summer drought (*Fig. 3*; Marosi / Somogyi 1990, 50).

The palaeoclimate records for the study period suggest a European climate having been characterised by warmer summers with higher rainfall than today, which seems to be a global tendency for the northern hemisphere (for details see Kreuz 2012, 49–56; contributions in Litt 2003). In sum, the Sárköz region quite certainly provided a favourable climate and very good soil conditions for prehistoric crop cultivation (Pécsi / Sárfalvi 1962, 46; Marosi / Somogyi 1990, 48–50). Considering the probably more humid climate in the mid- and later 6th millennium BC, summer droughts probably did not mean a major problem for the early farming communities settling there.

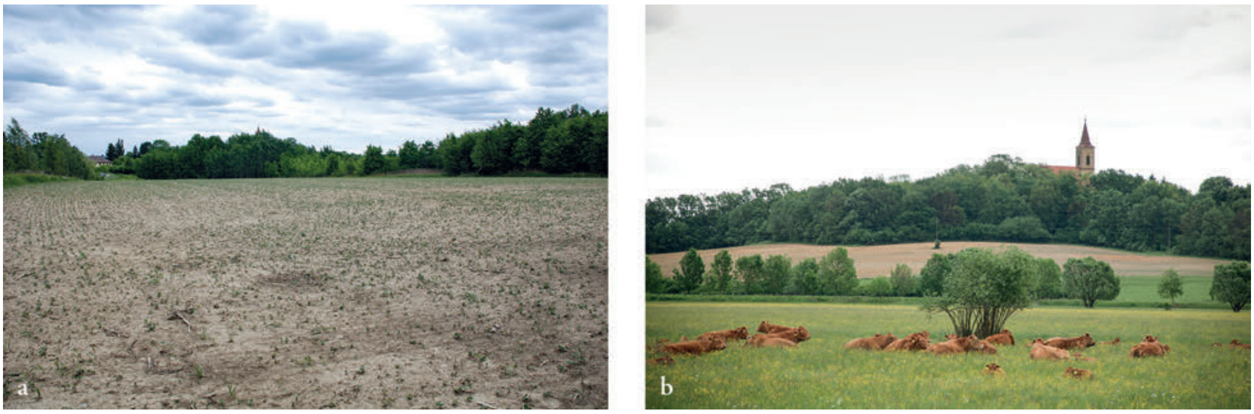


Fig. 4. A settlement dating to the "formative LBK" has been excavated in parts at the site Szentgyörgyvölgy-Pityerdomb, Zala county, by E. Bánffy (Bánffy 2004). a View to the west; due to the ecological conditions the sunflowers are not thriving well (16th May 2012). b Appropriate to the ecological potential of the landscape, the focus of agricultural use around the modern village is more on pasture and cattle breeding. The excavation was carried out behind the church tower.

The past vegetation

The natural vegetation cover provided the prehistoric ecological basis for the wild and domestic grazing and browsing animals as well as the potential for collecting herbs, nuts, berries, mushrooms, roots, and the like for human consumption. Regarding the ecological potential of the landscapes settled by the early farmers, the openness of the Neolithic woodland cover is an important, but still debated factor (e. g. Kreuz 2008a). Kosse (1979) reconstructed a forest-steppe for the Neolithic period in Hungary, forming a transition between woodland and steppe vegetation. Natural steppe vegetation is connected with summer droughts and an annual precipitation of ≤ 450 mm, resulting in a restricted groundwater table, constraining the growth of bigger trees (e. g. Walter 1968; Walter / Straka 1970). In fact, at present, a steppe-like vegetation covers the lowlands of central Hungary, e. g. the "alkali puszta" in the Hungarian National Park in the Hortobágy / Debrecen region east of the Tisza and the "sand puszta" of Bugac / Kecskemét in the sandy region of the Danube-Tisza interfluve. However, according to the current evidence, western Hungary probably did not have a steppe forcing climate during the 6th millennium BC (see also Bánffy / Sümegi 2012; see above, for further literature). In addition, this modern Pannonian salt and steppe vegetation probably is due to the considerable and artificial lowering of the groundwater level and increased evaporation as a consequence of the lack of a woodland cover (see also the discussion by Járai-Komlódi 2003, 49 f.; Kreuz 1990, 159–162, with further literature). Based on the 570–590 mm annual precipitation in the Sárköz region today and with the probably higher rainfall in Atlantic times, a natural steppe-like vegetation should have been restricted to dry stands, as to be expected on steep slopes or on sand dunes in the river valleys and in the Danube-Tisza interfluve. The possible indicator plants for such special stands are discussed below.

For a more detailed reconstruction of the vegetation and the question of the openness of the woodland pollen analytical studies in the Sárköz study area are needed. An interesting deposit can be found near Császártöltés on the eastern margins of the Sárköz Danube Valley *(Randsenke)*, c. 15 km east of Fajsz (Persaits et al. 2008; see also Sümegi et al. in this volume). Based on the ^{14}C dates, the pollen diagram probably spans the entire Early Neolithic, but it should be analysed more in detail for a sound interpretation, as, for example, herbs and grasses, and other potential anthropogenic indicators are lacking from the published profile diagram. The profile from the Kolon-tó site at Izsák, lying 50 km north-east of Fajsz, is dated to the Atlantic period by its biostratigraphy (Járai-Komlódi 1985). Unfortunately, this interesting profile lacks an absolute dating and thus its interpretation in the context of a vegetation reconstruction of the Neolithic runs into difficulties. In any case, as shown by the pollen analytical results of Járai-Komlódi (1966, 198; 1985; 2003, 50 f.) and Lóczy (1989), oak, elm, and lime species *(Quercus*, *Ulmus*, *Tilia* sp.*)* as well as hazel *(Corylus avellana)* were widespread in the former woodland of the Hungarian plain, accompanied – especially at higher altitudes – by beech *(Fagus sylvatica)* and hornbeam *(Carpinus betulus)*.

The map of the modern natural vegetation of Europe (Bohn et al. 2003) provides further clues for the Neolithic woodland distribution in Hungary. The map shows Pannonian steppe-oak forests (dominated by *Quercus robur*, with *Quercus cerris* and *pubescens* in minor quantities, alongside *Acer tartaricum*, *Fraxinus ornus*, etc.) alternating with small areas of herb-grass steppes and sand steppes in the Danube-Tisza interfluve as well

Fig. 5. Forest reserve near Kerecsend "A kerecsendi Berek erdő" (9th May 2012) showing a young mixed deciduous forest (Aceri tataricum-Quercetum) with four oak species *(Quercus robur*, *Quercus petraea*, *Quercus pubescens* as well as *Quercus cerris)*, ash *(Fraxinus excelsior* and *Fraxinus ornus)*, maple *(Acer tatarcicum* and *Acer campestre)*, elm *(Ulmus minor)*, and a shrub layer with sloe *(Prunus spinosa)*, hawthorn *(Crataegus monogyna)*, roses (*Rosa* species), spindle bush *(Euonymus europaeus)*, and cornelian cherry *(Cornus mas)*, etc.

as east and south of the Great Hungarian Plain (see also the description of the *Aceri tartarici-Quercion* in Horvat et al. 1974, 275–319). Further to the north-west, the woodland becomes denser, for example in the region around Lake Balaton and in the region of Pécs and the Mecsek Mountains as well as in the region between the Drava and the Sava (Bohn et al. 2003).

It is remarkable that the settlement sites of the formative LBK (Bánffy 2004; Oross / Bánffy 2009) in the Balaton region of Transdanubia are located in landscapes that had at the time probably been covered by darker forests with hornbeam *(Carpinus betulus)*, and beech *(Fagus sylvatica)*, which, due to the comparably less advantageous soils and climate (Bohn et al. 2003; for Pityerdomb, see *Fig. 4*), were in all likelihood not ideally suited for crop growing. Actually, at the LBK sites of Neckenmarkt, Strögen, and Rosenburg in Austria near the border to north-western Hungary, charcoal of beech and spruce *(Picea abies)* as well as charred fruits of hornbeam have been identified (Kreuz 1990). Before the Copper and Bronze Ages, beech and hornbeam did not spread further to the northern LBK distribution area, where spruce remained restricted to certain mountain areas (e. g. Lang 1994; Schäfer 1996; for the archaeobotanical finds of further wood species, etc., see below). Instead, in the Sárköz region of southern Hungary, the current state of research indicates a mixed deciduous woodland with a rich shrub layer as the dominant vegetation cover on the fertile chernozem soils in the 6th millennium BC (for the potential shrub spectrum, see Horvat et al. 1974, 360–363). One rare possible "relict" of mixed deciduous woodland of this type can be visited today in a nature reserve south of Eger near Kerecsend in northern Hungary *(Fig. 5)*.

The crop spectra within their archaeological context

During the entire Hungarian Neolithic period, there is evidence for eight crop species, which were most likely cultivated by the early farmers: barley *(Hordeum distichon / vulgare)*, free-threshing wheat *(Triticum aestivum s. l. / durum / turgidum)*, emmer *(Triticum dicoccum)*, and einkorn *(Triticum monococcum*; one- and two-grained varieties) among cereals, lentil *(Lens culinaris)* and pea *(Pisum sativum)* among pulses as well as flax *(Linum usitatissimum)* and opium poppy *(Papaver somniferum)* among oil / fibre plants (*Tab. 4*; e. g. Tempir 1964; Hartyáni / Nowáki 1975; Füzes 1990; 1991; Gyulai 2010; Kreuz et al. 2005; Kreuz 2007; 2008a; 2012; see also the compilation in Pomázi 2010).

Regarding the Early Neolithic Starčevo and Körös groups of the Sárköz region, archaeobotanical data from four features are available. In addition, 22 samples from further 14 archaeological features collected during excavations in the other regions have been analysed *(Figs 6–7; Tabs 1; 4–5*[2]*)*. The samples from the excavations at HU 1 Fajsz and HU 3 and HU 6 Alsónyék are the first analysed archaeobotanical samples of the Körös and Starčevo culture in the Sárköz region (representing the later spiraloid B phase), showing the good potential of systematic investigations in the future. The seven samples contained 19 grains and four rachis fragments of barley, two grains and 286 glume bases of einkorn, and two grains and 196 glume bases of emmer. The lack of further crop species that could be expected (see, e. g., Bogaard et al. 2007 for the Körös site at Ecseg-

2 *Tab. 5* is available as digital supplement only: https://doi.org/10.34780/confinia.v1i0.1000.

Archaeological period	Early Neolithic		Middle Neolithic			Late Neolithic		Bronze Age	
	Körös / Starčevo formative LBK		LBK	late LBK	ALBK, Szakálhát	SOP, LENG, Tisza		diverse phases	
Region	**Sárköz**	**HUN**	**Sárköz**	**HUN**	**HUN**	**Sárköz**	**HUN**	**Sárköz**	
Number of samples	**7**	**22**	**20**	**58**	**139**	**72**	**20**	**23**	
Cultivated crop species									**English names**
Hordeum distichon / vulgare	x	x			x	x	x	x	Barley
Triticum aestivum s.l. / durum / turgidum		x		(x)	x	x	x	x	Naked wheat
Triticum dicoccum		x	x	x	x	x	x	x	Emmer
Triticum monococcum	x	x	x	x	x	x	x	x	Einkorn
Panicum miliaceum								x	Common millet
Lens culinaris		x		x	x	x	x	x	Lentil
Pisum sativum				x	x				Pea
Linum usitatissimum					x				Flax
Papaver somniferum				x	x				Opium poppy
Camelina sativa								x	Gold-of-pleasure

Tab. 4. The cultivated crop species of the different archaeological periods and the Sárköz area in comparison with further Hungarian (HUN) Neolithic sites (explanations and references in the text).

falva in south-eastern Hungary) can be attributed to the still small database. The other investigated Körös sites also yielded barley, naked wheat, lentil, and bitter vetch (*Vicia* cf. *ervilia*; *Tab. 1*, sites HU 16 Sarkad and HU 9 Hódmezővásárhely; for naked wheat, see also Bogaard et al. 2007). Further evidence of emmer and an undifferentiated wheat species was identified from imprints on Starčevo pottery sherds and a figurine fragment from Kéthely, Dombóvár-Gunaras, and Mernye (surface finds; Füzes 1990, 1991; Bánffy 2004, 355–358).

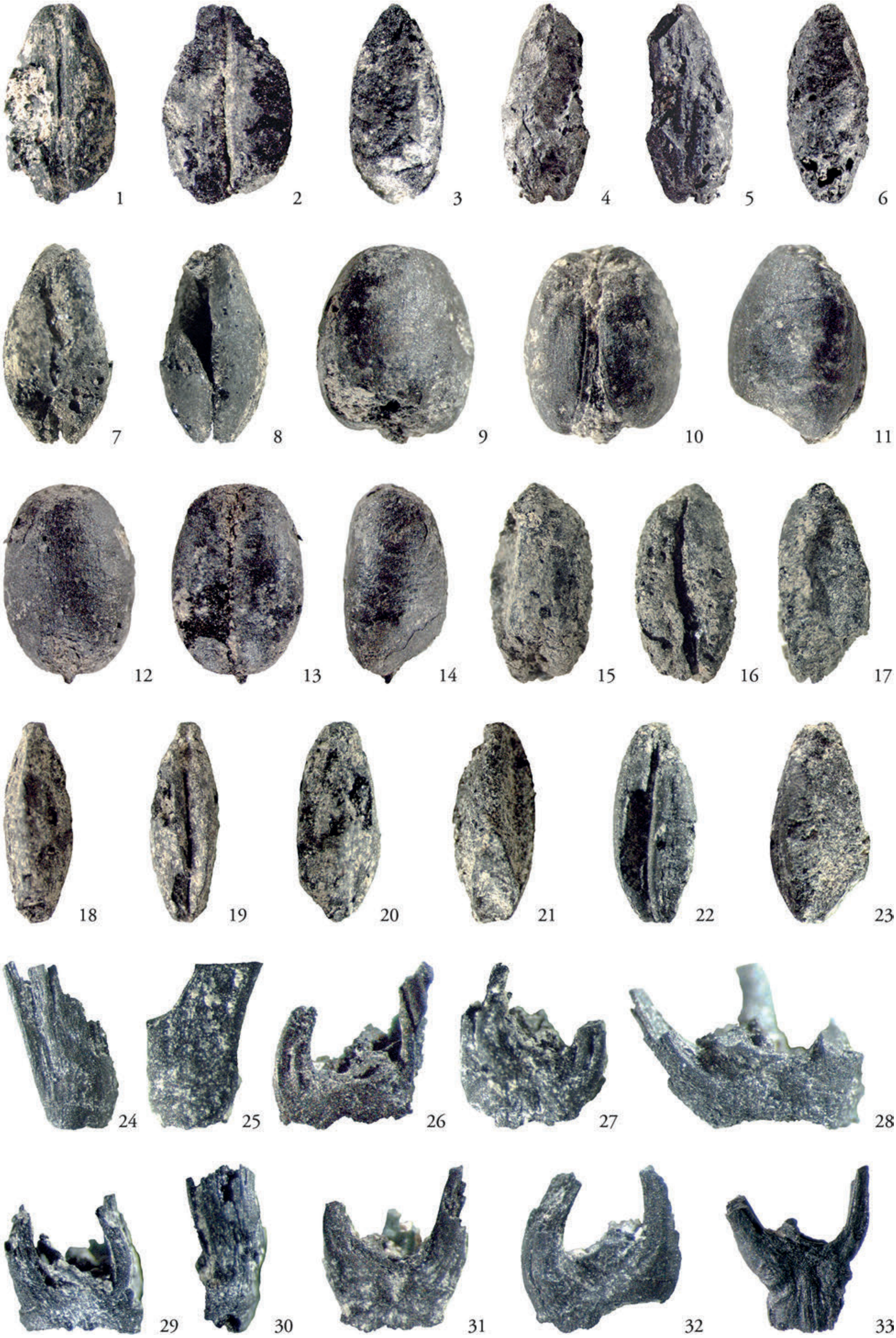
Regarding the LBK culture, einkorn (one grain, 205 glume bases) and emmer (one grain, 60 glume bases) have been found in the Sárköz region to date (for the botanical names of the crop species, see above and *Tab. 1*). Lentil and pea as well as opium poppy have been identified at the other investigated Hungarian sites of the younger LBK *(Fig. 7; Tabs 1; 4)*. Emmer, einkorn, pea, lentil, and flax are part of the regularly found spectrum at the earliest LBK sites in Germany and Austria as well. Opium poppy as the sixth species occurs from the Flomborn phase of the LBK onwards, arriving there from the western Mediterranean (Bakels 1982; Kreuz et al. 2005; Kreuz 2012).

Naked wheat and barley appear to have been adopted by the LBK farmers not before the end of the Bandkeramik period as deliberately cultivated crops[3]. They belong to the spectrum of the Neolithic farming systems of the subsequent Hinkelstein, Großgartach, and Rössen cultures in Germany and Austria (Kreuz 2012). Barley and naked wheat are cereals with higher yields compared to einkorn and emmer. On the other hand, they require more nitrogen input than hulled wheats, while naked wheat calls for much more careful weeding (e.g. Körber-Grohne 1988; Geisler 1991; Hydri Agri Dülmen 1993; Kreuz 2005, 134).

Remarkably, the initial situation in Transdanubia in north-western Hungary has been as follows: barley and naked wheat were part of the farming spectrum of the formative LBK, as evidenced by the Szentgyörgyvölgy-Pityerdomb site (Bánffy 2004, 313; 333; Berzsényi / Dálnoki 2005; Kreuz 2012, 138). The material culture of Pityerdomb was strongly influenced by the Starčevo complex (e.g. Bánffy 2004; Oross / Bánffy 2009; Bánffy et al. 2010, 48), and therefore the occurrence of naked wheat and barley, part of the crop spectrum of the Starčevo agricultural system, is not surprising. Unfortunately, no further archaeobotanical samples and data are available from the formative LBK sites in Transdanubia.

Strikingly, naked wheat and barley together with hulled wheats, lentil, pea, flax, and opium poppy have been found in samples from the Alföld-LBK and the Szakálhát group in eastern Hungary, which were in part

3 The two naked wheat finds from the site HU 7 Apc, features 763–764 and 779 (= LBK undifferentiated) comprise one rachis fragment and one grain. A ^{14}C date would be useful to confirm the absolute age of these single naked wheat finds.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contemporaneous with the western LBK culture. As for barley and naked wheat, their rejection by the western LBK farmers in contrast to the Alföld-LBK and Szakálhát groups, and the late Starčevo-Körös complex *(Tabs 1; 4)* was very probably a cultural decision, as proven by their later cultivation in all the former areas of the LBK distribution from the 5th millennium BC onwards (Hinkelstein, Großgartach, and Rössen cultures; Kreuz 2012). The reduction of the crop species diversity in the early LBK (Bicske-Bíňa phase) agrarian system following the formative phase was probably a consequence of a shift in agricultural emphasis, e. g. a greater emphasis on stockbreeding (for a discussion, see Kreuz 2012, e. g. 83–90 and tab. 9).

It is instructive to compare the crop spectra of various Hungarian Neolithic cultures with the corresponding archaeobotanical results of the areas settled earlier during the Neolithic further to the south and east of Europe, and beyond. Apart from cereals and flax, mentioned above, lentil, pea, chickpea, broad bean, bitter vetch, and grass pea belonged to the early crop spectrum of South-West Asia. Apart from broad bean, these spread westward to the Balkan Peninsula, arriving there in the centuries around 6000 cal BC (e. g. Kroll 1991; Marinova 2006; Fuller et al. 2011; Zohary et al. 2012; Reed 2015; González Carretero et al. 2017). Of these pulse species grown in the 6th millennium BC further to the north, only pea and lentil were integrated into the Neolithic agrarian systems of the different archaeological cultures in Hungary (Kreuz et al. 2005; Kreuz 2012). The solitary charred seed find of bitter vetch *(Vicia ervilia)* from the Körös site Hódmezővásárhely-Gorzsa (HU 9, sample 332–1) east of Szeged and the Tisza Valley of southern Hungary could well be a relic from the Balkan spectrum that "survived" as a weed among the cultivated pulses[4]. According to the archaeobotanical state of research, only after millennia did additional pulse species spread further to the north-west (e. g. bitter vetch and broad bean from the Bronze Age onward; Kreuz 2016).

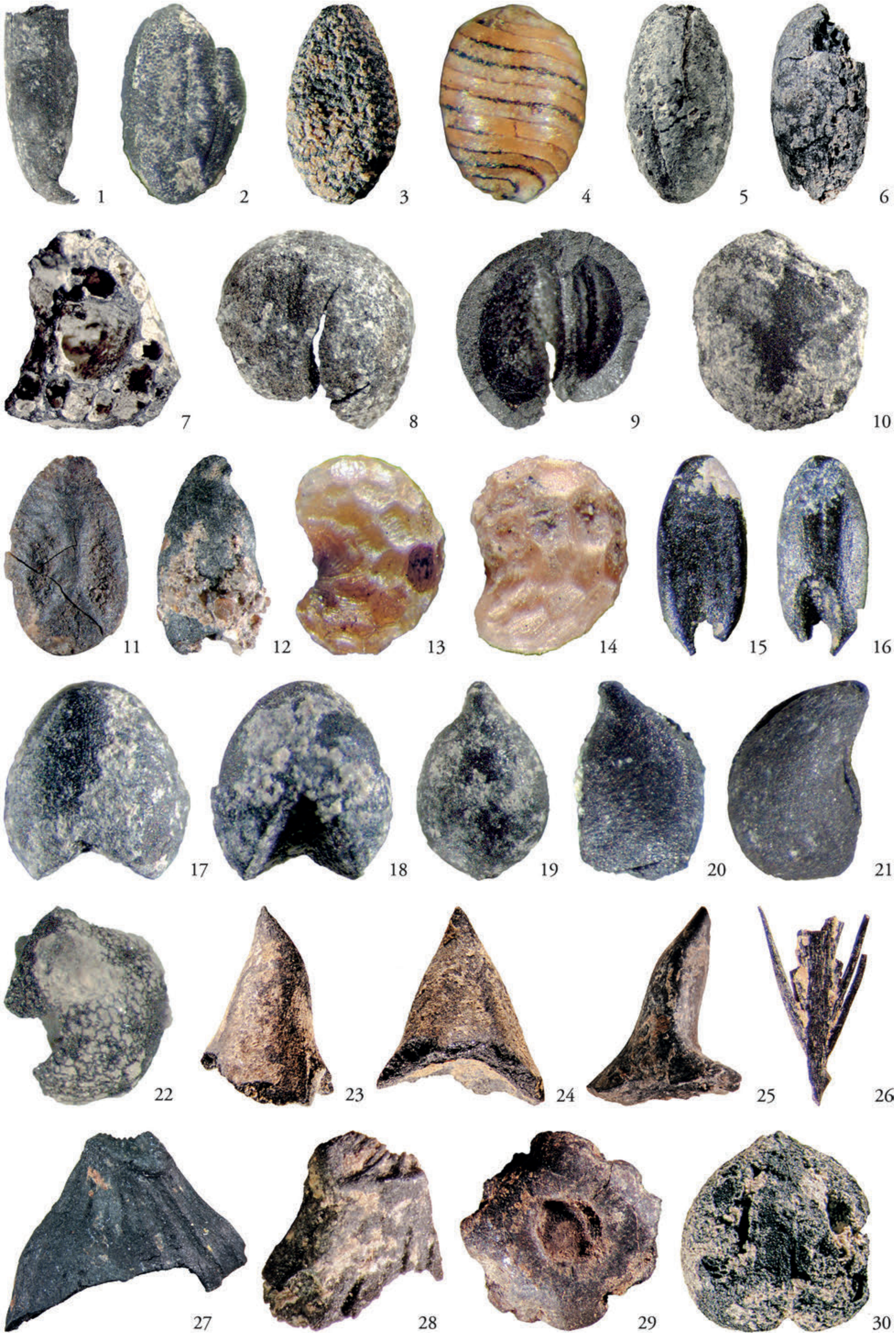
The reduction of the Neolithic pulse species spectrum during its spread to the north-west can be interpreted as a reflection of different cultural traditions in terms of the adopted agrarian systems and the diet (discussed in detail in Kreuz 2012; Kreuz / Marinova 2017; see also the cultivation experiment in Kreuz 2015, with pictures and further literature). For the Neolithic farmers of the neighbouring Balkan Peninsula, growing more pulse species probably acted as a kind of risk management to cope with the problem of summer droughts. In contrast, in the Hungarian Neolithic agrarian systems which apparently did not suffer from droughts, this would have caused additional work in the fields and more laborious processing, e. g. to make the poisonous pulse seeds of the *Vicia* and *Lathyrus* species edible (Kreuz 2015).

In the case of the Late Neolithic Sopot / Lengyel groups in the Sárköz region, we found an increase in the number of cultivated cereal species compared to the LBK system *(Tabs 1; 4)*[5]. This appears to be an analogous trend as could be noted in the more or less contemporaneous Middle Neolithic in Germany, possibly related to newly evolving demographic and social factors. As for the Bronze Age, represented by several phases at the HU 1 Fajsz site only, apart from barley, naked wheat, einkorn, emmer, and lentil, there is evidence for the two other typical crop species of the Metal Ages, namely gold-of-pleasure (*Camelina sativa*: four seeds) and foxtail millet (*Panicum miliaceum*: 247 grains) *(Fig. 7; Tab. 1)*. This further increase in the diversity of crop species can certainly be linked to the period's special economic and social developments (see also Kreuz 2016) that can, among others, be associated with the beginnings of metallurgy, as attested in other research areas as well.

◁ Fig. 6. Finds of plant remains from the Hungarian sites (see *Tab. 1*; for the abbreviations of the sites see *Tab. 2; l. length*). If not indicated differently the remains are preserved charred and belong to the site HU 1 Fajsz. 1–8 barley *(Hordeum distichon / vulgare)*: 1 grain ventral (l. 4.5 mm), feature 125, transect 125-1; 2–3 grain ventral, lateral (l. 4.1 mm), feature 46, transect 46-1; 4–6 grain dorsal, ventral, lateral (l. 5.6 mm), feature 46, transect 46-1; 7–8 grain dorsal, ventral (l. 6.1 mm), feature 126, transect 126-1; 9–14 naked wheat *(Triticum aestivum* s.l. */ durum / turgidum)*: 9–11 grain dorsal, ventral, lateral (l. 3.8 mm), feature 125, transect 125-1; 12–14 grain dorsal, ventral, lateral (l. 4.1 mm), feature 102, transect 102-1; 15–17 emmer *(Triticum dicoccum)*, grain dorsal, ventral, lateral (l. 5.9 mm), feature 126, transect 126-3; 18–23 einkorn *(Triticum monococcum)*: 18–20 grain dorsal, ventral, lateral (l. 3.8 mm), feature 183, transect 183-1; 21–23 grain dorsal, ventral, lateral (l. 4.1 mm), feature 46, transect 46-1; 24–28 emmer *(Triticum dicoccum)*: 24 glume base (l. 2.0 mm), feature 161, transect 161-1; 25 glume base (l. 1,65 mm), feature 165, transect 165-1; 26–28 spikelet fork: 26 (l. 1,8 mm), feature 173, transect 173-1; 27 (l. 1,7 mm), feature 165, transect 165-1; 28 (l. 1.3 mm), feature 161, transect 161-1; 29–33 einkorn *(Triticum monococcum)*: 29 spikelet fork (l 1.5 mm), feature 161, transect 161-1; 30 glume base (l. 2 mm), feature 161, transect 161-1; 31–33 spikelet fork: 31 (l. 1.5 mm), feature 167, transect 167-1; 32 (l. 1.55 mm), feature 165, transect 165-1; 33 (l. 1,9 mm), HU 3 feature 1501, transect 1501-1.

4 The cf. determination of *Vicia ervilia* is due to the small size and the singularity of the find; the shape of the seed is exactly the same as of bitter vetch.

5 At the current state of research, it is not possible to estimate the cultivation of pulses and oil / fibre plants.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The potential prehistoric weed species that grow together with the crops in the fields and are transported to the settlements together with the harvest can be assigned to the Ecological Groups “Weeds of cereal fields”, “Weeds of hoed fields and gardens”, “Ruderals”, and “Segetal Vegetation”, and in part possibly to “Grassland Vegetation” *(Tab. 1)*. The weed spectrum of the sites in the Sárköz region and beyond is still quite limited, possibly a reflection of the current state of research. As often experienced during other archaeobotanical investigations, there is a strong correlation between the number of investigated samples and the number of identified species (see also the concentration values mentioned above and the methodological remarks in the archaeobotanical overview of Neolithic Croatia by Reed 2015). At the moment, these first finds of potential weeds *(Tab. 1)* are too few to allow any conclusions with regard to field management, crop harvesting methods, etc.; the study of these important questions and aspects of Neolithic agriculture remains a task for future archaeobotanical investigations (for a discussion, see Kreuz / Schäfer 2011; Kreuz 2012). Given the fertile soils and the assumed weather conditions during the Neolithic, shifting cultivation seems unlikely – instead, permanent fields on terrestrial soils can be expected. Moreover, manuring by grazing animals after harvest combined with crop rotation should have been sufficient for the nutrient regime of the cultivated crops (Kreuz 2012, 91–111). Finds of charred coprolites occurring together with the crop finds indicate that the storages of cereals and pulses were frequented by mice in all periods *(Tab. 1)*.

◁ Fig. 7. Finds of plant remains from the Hungarian sites (see *Tab. 1*; for the abbreviations of the sites see *Tab. 2; l. length*). 1 cornflower *(Centaurea cyanus)*, fruit (l. 3.3 mm), feature 46, transect 46-1; 2 gold-of-pleasure *(Camelina sativa)*, seed (l. 1.4 mm), feature 125, transect 125-1; 3 elder *(Sambucus* cf. *nigra)*, pip (l. 2.7 mm), HU 6 feature 3806, transect 3806-1; 4 stonewort *(Chara* spec.*)*, mineralised oogonium (l. 0.7 mm), HU 6 feature 3802, transect 3802-1; 5–7 cornelian cherry *(Cornus mas)*: 5 pit (l. 10.7 mm), feature 43, transect 43-1; 6 pip (l. 11.9 mm), feature 189, transect 189-3; 7 fragment internal view (l. 3 6 mm), feature 173, transect 173-1; 8–9 dogwood *(Cornus sanguinea)*, pip, fragment external, internal view (l. 3.5 mm), feature 189, transect 189-3; 10 lentil *(Lens culinaris)*, seed (l. 2 mm), feature 31, transect 1; 11–12 flax *(Linum usitatissimum)*: 11 seed (l. 3.2 mm), HU 17 feature 476, transect 476-2; 12 seed (l. 2.65 mm), HU 1 feature 542, transect 542-1; 13–14 opium poppy mineralised seed *(Papaver somniferum)*: 13 (l. 0.92 mm), HU 10 feature 7, transect 7-7; 14 (l. 0.9 mm), HU 10 feature 7, transect 7-3; 15–16 red millet *(Digitaria* cf. *ischaemum)*, fruit ventral, dorsal (l. 1 mm), feature 43, transect 43-8; 17–18 common millet *(Panicum miliaceum)*, fruit ventral, dorsal (l. 1.7 mm), feature 102, transect 102-1; 19 hudson *(Polygonum minus)*, fruit (l. 1,65 mm), feature 125, transect 125-1; 20 lady’s mantle *(Alchemilla vulgaris* agg.*)*, fruit (l. 1 mm), HU 3 feature 92, transect 92-1; 21 silver-weed *(Potentilla anserina)*, fruit (l. 0.95 mm), HU 3 feature 1501, transect 1501-1; 22 black nightshade (*Solanum nigrum*), seed (l. 1.15 mm), feature 125, transect 125-1; 23–29 water caltrop *(Trapa natans)*: 23–25 spike fragments, 23–24 frontal, lateral (l. 6.3 mm), HU 5 feature 252, transect 252-1; 25 (l. 8,4 mm), HU 9 feature 333, transect 333-2; 26 appendix (l. 1.8 mm), HU 5 feature 38, transect 38-2; 27 shell fragment (l. 9.2 mm), HU 27 feature 1, transect 1-1; 28 shell fragment (l. 4.3 mm), HU 9 feature 333, transect 333-1; 29 shell fragment (l. 5.3 mm), HU 5 feature 252, transect 252-1; 30 wild vine *(*cf. *Vitis sylvestris*), pip (l. 3.9 mm), feature 71, transect 71-2.

Useful plants from the wild

Some of the most characteristic traits of the flat Hungarian Plain are the (former) meanders and oxbow lakes of the rivers bordered by hardwood alluvial forests, scrubland, and reed vegetation as well as the chernozem soils and brown soils that developed from loess or fluvial sediments under terrestrial conditions *(Fig. 8)*. As mentioned above, in prehistoric times the latter were probably covered by thermophilous mixed deciduous broad-leaved forests with *Quercus robur*, *Quercus cerris* and *pubescens*, *Acer tataricum*, *Fraxinus ornus*, *Carpinus betulus*, etc. (see also, e. g., Kerner von Marilaun 1916; Horvat et al. 1974). Depending on their position relative to the water level, the areas in the river valleys provided an attractive potential for pasturing, hunting, fishing, and (outside the floodplains) crop cultivations during all prehistoric periods. Actually, finds of water plantain *(Alisma plantago-aquatica)*, stonewort *(Chara* sp.*)*, common spike-rush *(Eleocharis palustris)*, pale persicaria *(Polygonum lapathifolium)*, hudson *(Polygonum minus)*, pond weed *(Potamogeton* sp.*)*, curled / broad-leaved dock *(Rumex crispus / obtursifolius)*, water caltrop *(Trapa natans)*, alder *(Alnus* cf. glutinosa), and ragged-robin *(Lychnis flos-cuculi) (Tab. 1)* suggest the exploitation of riparian or floodplain vegetation areas and the on-site disposal of the according plant remains by the Neolithic farmers, herders, and perhaps their domestic animals. This is attested by the archaeozoological finds of diverse fish species, Eurasian coots *(Fulica atra)*, mallards *(Anas platyrhynchos)*, and mute swans *(Cygnus olor)* in the Starčevo features of the Sárköz region (Nyerges / Biller 2015, 2).

Water caltrop is a floating aquatic plant *(Fig. 9)*, growing in warmer areas of Europe in standing or little-moving shallow and nutrient-rich water, such as, e. g., the numerous Hungarian oxbow lakes. It produces edible fruits rich in starch, ripening from September to October (Oberdorfer 1990). The fruits can be roast-

Fig. 8. Today, due to the area-wide agricultural use the Hungarian lowland is characterised in particular by two types of vegetation cover: fields (to the left) on the chernozem and brown soils developed out of loess or fluviatile sediments under terrestrial conditions, and meadows (puszta) on sandy and alkaline soils, here sand dunes. In addition, the edges of channels and former oxbow lakes are marked e. g. by shrubbery of alder and willow (here in the background). Photo near Kisköre, Heves county, in the Tisza Valley (9th May 2012).

ed to improve their taste and to make them preservable for longer, which was probably the reason for their continuous on-site charred preservation *(Fig. 7)*.

Interestingly, *Trapa natans* occurs in the samples from Körös, Alföld-LBK, and Late Neolithic sites (see also, e. g., Bogaard et al. 2007 for the Körös site at Ecsegfalva; Gyulai 2010), but is lacking from all the 78 samples recovered from six Hungarian LBK settlements *(Tab. 1)*. The LBK distribution area in Germany and Austria, where *Trapa* has been and still is a native plant too (e. g. Gams 1927; Behre 1970; Lang 1994), yielded no finds on the settlement sites either (Kreuz 2012), even though the taxon can be easily identified from the archaeobotanical point of view, e. g. by the charred fragments of its fruit spikes *(Fig. 7)*. Obviously, irrespective of its wide natural distribution during the Neolithic, the use of *Trapa* in human diet in Central Europe is restricted to certain regions such as the Hungarian Plain and the Alpine foreland (for the latter, see Karg 2006, with further literature), where it has been continuously used up to modern times.

The regular occurrence of fat-hen *(Chenopodium album)* could be an indication of the use of its starch-rich fruits for human nutrition as well (e. g. Knörzer 1971; Kroll 1990; Behre 2008). Other plants that were quite certainly collected in the wild – providing important vitamins and nutrients – include the nuts and fruits of cornelian cherry *(Cornus mas)* and hazelnut *(Corylus avellana)* as well as dogwood *(Cornus sanguinea)*, wild strawberry *(Fragaria vesca)*, wild pear *(Pyrus pyraster)*, wild blackberry / raspberry / dewberry *(Rubus* sp.*)*, black elder *(Sambucus nigra),* and wild vine *(*cf. *Vitis sylvestris)*. Interestingly enough, in contrast to the LBK finds further to the north-west, sloe is absent among the Hungarian Neolithic plant remains: no LBK, Starčevo or Körös finds until now *(Tab. 1)*. It appears to have been unpopular among these Hungarian Neolithic communities, perhaps owing to its special taste.

The regular occurrence of cornelian cherry remains in the samples of all prehistoric periods from Hungarian sites is interesting for the vegetation reconstruction of the mixed oak forests (see above). The small cornelian cherry tree is part of the natural South-East European open and light dry forests on nutrient and base rich soils, which are characteristic for the northern Mediterranean downy oak region (*Flaumeichengebiet*; Oberdorfer 1990; *Figs 7; 10*). The evidence of awn fragments and grains of feather grass *(Stipa* sp.*)* is likewise remarkable since this species grows in a steppe like vegetation on sand dunes, steep slopes, etc., or under dry summer conditions. In combination with the species group of "Grassland Vegetation" and the collected fruits, recurrent finds

Fig. 9. a–b The water caltrop *(Trapa natans)* is well recognisable by its leaf rosettes floating on the water, here at a former Tisza meander near Mártély north of Szeged (13th May 2012). b–c The ripe fruits are floating on the water surface and have been washed up in quantities at the shore of the oxbow lake.

Fig. 10. One of the collected plants typical for the Neolithic of Hungary and the countries adjacent to the south and east is the thermophile shrub or small tree cornelian cherry *(Cornus mas)*. The shining red longitudinal edible fruits ripen from August onwards and supply among others vitamin C and B (13th October 1994, Botanical Garden of Frankfurt; see also *Fig. 7*).

of *Stipa* awns *(Tab. 1)* are probably an indication of open stands in the woodland area of the Sárköz region and in the lowlands of the Hungarian Plain, in contrast to e. g. the Balaton hinterland settled by the formative LBK (see above, as well as the examples in TMLFUN 2013). This is confirmed by the archaeozoological results: the hunted wild species comprise, among others, species preferring forest glades and open woodland such as hare *(Lepus europaeus)*, badger *(Meles meles)*, red fox *(Vulpes vulpes)*, beaver *(Castor fiber)*, and buzzard *(Buteo buteo)*. On the other hand, the finds of feather grass should not be over-interpreted, given that it has been found in LBK features of Nieder-Eschbach / Frankfurt am Main and Eitzum / Schöppenstedt, south of the Harz range, as well (both in Germany), where a steppe like zonal vegetation was unlikely during the Neolithic (Kreuz 2012).

Other useful wild plant species have also been found on the Hungarian Neolithic sites: these include medicinal plants for healing purposes such as lady's mantle *(Alchemilla vulgaris* agg.*)*, henbane *(Hyoscyamus niger)*, and common mallow *(Malva sylvestris)* (*Tab. 1*, Ecological Groups 2–3). It seems likely that the knowledge of wild plants, of their characteristics, and possible use was widespread in all prehistoric periods, as supported by the rich ethnographic evidence from native societies all over the world (Kreuz 2012, 116–119).

Differences in Neolithic subsistence and diet

The two most important innovations in Early Neolithic subsistence practices were crop cultivation and animal breeding. The use of the crops is not merely a question of their nutritional value. Considering the different cereal, pulse, and oil plant species, new dishes and new tastes appeared (Kreuz 2009; 2012, 112–130). For example, cereals are rich in carbohydrates and very filling, but in addition, they also enabled the baking of "real" breads for the first time, that were less perishable than soups and stews and were also suitable for storage and transport. Besides, cereals can be used for the production

Fig. 11. As an example for the aquatic resources used in Neolithic times, some (a) mussel and (b) fish remains from the Körös site near Hódmezővásárhely, Csongrád county, situated east of Szeged and the river Tisza (HU 9 Gorzsa 5 HB 2009, sample 345–1).

of alcoholic beverages. The pulses provided the farmers with vegetable protein and new types of healthy and filling meals, as did the flavoursome oil plants.

Despite the insufficient state of archaeobotanical research, we can nevertheless assess, with all due caution, that the crop growing system of the Alföld-LBK, comprising a larger crop spectrum than the western early LBK, including naked wheat and barley *(Tabs 1; 4)*, has greater affinities with the (south-) eastern Balkans (for the latter, see Kreuz et al. 2005; Kreuz / Marinova 2017). This is also reflected, for example, in differences in house architecture (Bánffy 2004), burial traditions (Kalicz / Makkay 1977; Oravecz 1998 / 1999), and different archaeological finds such as stone artefacts (e. g. Biagi / Starnini 2010), bone spoons (spatulas) (e. g. Beldiman / Sztancs 2011; Tóth 2012; Vitezović 2016a; 2016b), and clay figurines / idols (e. g. Becker 2009; 2011), which differ substantially from the western LBK. For example, the bone spoons made from large ungulate metapodials were widespread in the Near East and Anatolia and abundant in the entire Starčevo-Körös-Criș and Alföld-LBK distribution area in Hungary as well, reflecting a cultural affiliation between the latter regions. In contrast, they are lacking from among the LBK settlement finds further to the north-west, pointing again to different cultural habits and another culinary identity there.

The other serious innovation of Neolithic subsistence and diet is represented by the introduction of the domestic animals cattle, sheep, goat, and pig to a regionally varying extend. The use of meat alone probably was no reason to start livestock farming, as meat could have been procured from hunted animals as well. Instead, a new element gained from domestic cattle, goats, and sheep was the creation of milk products, whose use has been repeatedly proven by the residue analysis of pottery fragments from refuse pits (e. g. Dudd / Evershed 1998; Craig 2002; Craig et al. 2005; Helmer et al. 2007; Vigne / Helmer 2007; Evershed et al. 2008; for the Neolithic Sárköz region, see the discussion in Nyerges / Biller 2015, 3; Balasse et al. 2017; Ethier et al. 2017). To avoid any misunderstandings, the consumption of fresh milk in larger quantities is a modern habit. Instead, in prehistoric periods, a variety of milk *products* can be expected, judging from the rich ethnographic evidence from native societies. These could include dry curd, yogurt, and cheese products, easy to prepare, store, and transport (see the preparation experiments in Kreuz 2008).

The use of dogs and specialised shepherds would have made it possible to graze larger herds even at greater distances from the permanent settlements. In addition to the referring pollen analytical record and the archaeological finds, evidence for transhumance has been yielded by isotope investigations in the lower mountain areas of Germany as well (Bentley et al. 2002; for examples for the LBK, see Price et al. 2006; Knipper / Price 2009; for the Michelsberg culture, see Kreuz et al. 2014, 91–95).

The current archaeozoological state of research includes evidence for a variable emphasis on stockbreeding by the different Hungarian Neolithic archaeological cultures, judging from the assumed correlation between the archaeological bone samples recovered from settlement sites and the species preferences of Neolithic farmers. Whereas the LBK farmers had a focus on cattle breeding and sometimes pig, the Körös farmers of south-eastern Hungary apparently preferred sheep / goat herding (based on 12 Körös sites by Bartosiewicz 2012, with further papers in the same volume; Domboróczki 2010, tabs 2 and 3, assessment by I. Vörös; Domboróczki et al.

Period	Early Neolithic	Middle Neolithic	Middle Neolithic	Late Neolithic	Bronze Age	Early Neolithic
Archaeological culture	**Starčevo / Körös**	**LBK**	**ALBK, Szakálhát**	**SOP, LENG, Tisza**	**BZ**	**LBK Germany / Austria**
Site(s)	**HU 1** FAJSZ, **HU 3** BSZÉK 5603 / 1 MT, **HU 6** BSZÉK 11, **HU 9** GORZSA 5, **HU 16** SARK	**HU 1** FAJSZ, **HU 2** BSZÉK 5603 / 1 56-út, **HU 4** SZEMELY, **HU 7** APC 1, **HU 11** RABAP, **HU 14** ZSENNYE	**HU 5** PTASK 1, **HU 8** HPAPI, **HU 10** MHEGYES, **HU 12** TBURA 5, **HU 16** SARK, **HU 17** VNAM, **HU 18** PPETRI, **HU 19** KANT, **HU 22** Büábr VII, **HU 23** Büábr XI / A	**HU 1** FAJSZ, **HU 2** BSZÉK 5603 / 1 56-út, **HU 5** PTASK 1, **HU 6** BSZÉK 11 **HU 15** URAI	**HU 1** FAJSZ	37 sites in Germany and Austria
Feature type	Gr	Gr, Lgr	Gr, Lgr	Gr	Gr	Gr, GrKo, Lgr, GrIn
Sample type	Eim, dir, Gef	Eim	Eim, dir	Eim	Eim	Eim
Sample volume (litre)	346.66	603.6	1125.7	799.45	144.5	25593.2
No. of features	14	32	44	49	10	488
No. of samples	25	51	132	68	11	1520
Fish remains	**7.5**	**2.9**	**0.7**	**26.4**	**1.8**	**0.002**
Water plants	**0.3**	**0.04**	**0.05**	**0.04**	**0.02**	**0.004**

Tab. 6. Comparison of the concentration values of fish and plant remains of the Ecological Group 1 "Riparian and shallow water vegetation" differentiated for the prehistoric periods and regions. Concentration values in piece per litre. The values in which the site HU 1 Fajsz has been involved should be higher because the fish remains have not been counted in detail, but entered as 1 per sample, that means as presence / absence only.

2010; Kovács et al. 2010; see also Bökönyi 1974; 1981; 1984; Benecke 2006; Greenfield / Jongsma 2008; Nyerges 2013). This is ecologically surprising, as the open forests in the hinterland of the Körös sites would have provided ideal pastureland for cattle too. In contrast, a dominance of cattle has been demonstrated for the Early Neolithic of parts of Bulgaria and Romania (Benecke / Ninov 2002; El Susi 2008; 2011). Archaeozoological investigations of the Hungarian Starčevo sites are restricted to the excavation at Alsónyék in the Sárköz region (Nyerges / Biller 2015, 2; fig. 2) and Lánycsók (Bökönyi 1981) situated about 20 km to the south. Therefore, the stock breeder activities in this area remain open to discussion. Three further Starčevo sites with archaeozoological finds are situated in the region of the Vojvodina (Donja Branjevina and Golokut; BLAŽÍC 1985; 2005) and the Banat (Starčevo; CLASON 1980). They revealed low numbers of identified specimen as well. An enlarged bioarchaeological database would be helpful for testing the hypothesis of cultural choices determining differences in agricultural emphasis on crop growing and stock breeding.

Regularly occurring fish, mussel, and snail remains in the sieving fractions of all the Hungarian Neolithic samples (examples in *Fig. 11*) point to the continuous tradition of their consumption as an additional important source of animal protein[6]. However, as shown in *Table 6*, fish remains are rather rare in the archaeobotanical sieving residues of the LBK settlements in Germany and Austria. Again, this is interesting in terms of regionally different dietary habits, as the use or rejection of aquatic resources such as *Trapa natans*, mentioned in the above, could be an indication of regional diversity in culinary traditions.

6 The numerous fish remains from the different archaeobotanically investigated sites could not be determined until now. Fish specialist Dr Heidemarie Hüster Plogmann (IPNA Basel [Switzerland]) has kindly examined one sample with fish remains from Fajsz to gain an impression of the archaeozoological material and to estimate the effort needed for the scientific analysis. In her view, it is well preserved, with a huge variety of different species, ranging in dimension from 10 cm length to very big specimens. The different fish species were not only fished in different biotopes, but also, by necessity, with different fishing equipment, ranging from fish traps and fishing rods to fishnets and harpoons. In the case of the examined sample, the fish remains were certainly leftovers of meals, as the finds consist mainly of fish vertebrae and bear traces of digestion (kind information Dr Heidemarie Hüster Plogmann by e-mail to the first author, 01.11.2010). Fish remains from the Lengyel graves at Alsónyék-Bátaszék (HU 2, HU 6) have been identified as originating from wels catfish *(Silurus glanis)*, northern pike *(Esox Lucius)*, and carp species (Cyprinidae) (Nyerges / Biller 2015, 6).

Concluding remarks

Archaeobotanical investigations have been carried out in the context of an archaeobotanical research project focusing on Neolithic agriculture and land use in Hungary. The results from 22 archaeological excavation sites have been collected and archived with the archaeobotanical database programme *ArboDat* 2016. The synthesis presented here is based on the determinations of 113 996 botanical remains sorted out from 459 samples originating from 261 archaeological features. 4558.41 litres of sediment have been processed and 99 plant taxa were determined. The plant material has been archived at the Landesamt für Denkmalpflege Hessen, Wiesbaden.

Based on the available dataset, the Neolithic site catchment in the Sárköz region can be reconstructed as a region well suited for early agriculture. The farmers settling in the region found fertile soils for their fields and the probable climatic conditions were highly favourable for crop cultivation and other agrarian activities. The deciduous forests provided timber, collectable herbs, roots, fruits, nuts, etc., as well as hunting ground. The floodplain areas of the river valleys offered rich nourishment for the livestock, but also indirectly for the inhabitants through hunting and fishing, etc., as proven by the archaeobiological finds.

It is an old research question whether local Mesolithic groups were engaged in the Neolithic transformation process during its spread from the Near East to West-Central Europe. In fact, the extent of the differences between the legacy of the western early LBK farmers and those of the neighbouring southern and eastern farming communities suggest that a Mesolithic population of Transdanubia in north-western Hungary, influenced by the material culture of the Starčevo complex, was involved in developing a creative new strategy of LBK agrarian subsistence in the mid-6th millennium BC (for a discussion, see, e.g., Bánffy 2004; Kreuz 2012, chapters 6 and 9, with further literature; Oross / Bánffy 2009).

Archaeobotanical research provides important insights into former daily life with its underlying cultural and in part ecologically induced choices. On the other hand, more archaeobotanical research based on fully quantitative data is needed for an even better understanding of the on-site display of plant remains within different site and feature types of the different Hungarian Neolithic archaeological cultures and periods. We are looking forward to the results of further interdisciplinary investigations of these exciting subjects with all their fascinating facets in future.

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Digital supplement

Table 5 is available as digital supplement via iDAI.publications / books: https://doi.org/10.34780/confinia.v1i0.1000.

List of abbreviations

agg. = *aggregatio*
ALBK = Alföld Linearbandkeramik
ALBK 3 = Late ALBK
ArchDat? = uncertain archaeological dating
Bef. = feature
BGF = porridge / (flat) bread / pulp
Bru = well
BZ = Bronze Age
cf. = *confere*
dir = directly taken plant remains
Do / St = thorn / prickle
Eim = bucket / bag
Fisch = fish remains
Gef = vessel content
Gra = ditch
GrKo = pit complex
Gr = pit
GrIn = pit in pit complex
HSB = glume base
HUN = Hungary
indet. = indeterminate
Insek = insect remains
Kap / Kapz = capsule / capsule dent
Knos = bud
Knoz = bones / teeth
KöGrab = inhumation
KÖR = Körös
Koll = colluvium
Kopr = coprolite
kult. = cultivated
LBK = Linearbandkeramik
LBK Bic = Bicske-Bíňa (LBK I)
LBK Not = Notenkopf (LBK II)
LBK Kes = Keszthely (LBK III)
LBK Zse = Zseliz (LBK IV–V)
LBK HU = Hungarian LBK undifferentiated
LENG = Lengyel
Lgr = pit alongside house
l = litre
mi = mineralised
Neol HU = Hungarian Neolithic undifferentiated
Pfo = poste hole
RTyp = plant remains type
Sa / Fr = seed / fruit
Siedl = site
s. l. = *sensu latu*
so = other conservation
SoBefu = other type of feature
SOP = Sopot
Spi = rachis segment
STAR_L = Late Starčevo
SZAK 2 = Late Szakálhát
TIS = Tisza Culture
Veget = vegetative remains
vk = charred
Zust = preservation state

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Abstract: Investigation of the plant macro-remains from four archaeological excavations in the Sárköz area around Fajsz-Garadomb and Alsónyék-Bátaszék and a comparison with the archaeobotanical results from further Hungarian Neolithic sites

Archaeobotanical investigations have been carried out in the context of an archaeobotanical research project concerning Neolithic agriculture and land use in Hungary. The results from 22 archaeological excavation sites of the Starčevo, Körös, (formative) Linearbandkeramik (LBK), and Alföld-LBK have been collected and archived with the database programme *ArboDat* 2016 at the Landesamt für Denkmalpflege Hessen in Wiesbaden (Germany). The results are discussed and compared with the archaeobotanical data from 551 LBK features from Germany and Austria. The available data give a hint for differences in subsistence and diet of the Hungarian Neolithic archaeological cultures.

Zusammenfassung: Untersuchungen an pflanzlichen Makroresten aus vier archäologischen Ausgrabungen in der Sárköz-Region nahe Fajsz-Garadomb und Alsónyék-Bátaszék und ein Vergleich mit den archäobotanischen Ergebnissen weiterer neolithischer Fundplätze Ungarns

Im Rahmen eines Forschungsprojektes zur neolithischen Landwirtschaft und Landnutzung in Ungarn wurden archäobotanische Bestimmungen von 22 Fundstellen der Starčevo, Körös, (formativen) Linearbandkeramik (LBK) und Alföld-LBK am Landesamt für Denkmalpflege Hessen in Wiesbaden (Deutschland) durchgeführt und mit dem Datenbankprogramm *ArboDat* 2016 erfasst. Die erarbeiteten Ergebnisse werden diskutiert und mit den archäobotanischen Daten von 551 bandkeramischen Befunden aus Österreich und Deutschland verglichen. Die Daten verweisen auf kulturspezifische Unterschiede hinsichtlich der bäuerlichen Subsistenz und der Ernährung neolithischer Gesellschaften Ungarns.

Absztrakt: Növényi maradványok vizsgálata Sárközi lelőhelyeken Fajsz-Garadombról és Alsónyék-Bátaszékről, további magyarországi újkőkori lelőhelyek botanikai anyagával összevetve

Egy, a magyarországi újkőkorban végbement mezőgazdasági és termőföld-használati folyamatokat kutató projekt keretében archeobotanikai kutatásokat végeztünk. A 22 lelőhelyről származó mintákat, amelyek a Starčevo, a Körös és a dunántúli és alföldi formatív-korai Vonaldíszes Kerámia népének kultúrájába (LBK) sorolhatók, a Landesamt für Denkmalpflege Hessen in Wiesbaden (Németország) *ArboDat* 2016 adatkezelő programjának segítségével gyűjtöttük és archiváltuk. A tanulmányban ismertetett eredményeket 551 ausztriai és németországi LBK-mintával összevetve értékeljük. Adataink a magyarországi neolitikum különböző életmódbeli és táplálkozási hagyományaira világítanak rá.

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