Doctoral School of Geosciences

The late Quaternary environmental history of the Hortobágy landscape

A Hortobágy késő negyedidőszaki környezettörténete

PhD Thesis

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SZEGED, 2024

“DEEP IS THE WELL OF THE PAST. SHOULD WE NOT CALL IT BOTTOMLESS?”
Joseph and His Brothers
Thomas Mann

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Chapter 1: Introduction and aims

1.1. Origin and development of alkaline landscapes

The origin and spatio-temporal evolution of lowland alkaline areas in the Carpathian Basin, including the alkaline grassland-wetland mosaics of the Hortobágy area has been a subject of continuous debate among various groups of Hungarian natural scientists for almost a century (Molnár & Borhidi, 2003a). According to the view of the most influential group of botanists, alkalinization is considered to be mostly the outcome of the late 19th century flood protection and drainage measures in the area of the Great Hungarian Plain. The alternative view, which has been in the minority for decades, is that these measures have only secondarily extended the coverage of primary alkaline areas, where the process of alkalinization goes back much further in the evolution of the natural landscape (Molnár & Borhidi, 2003b).

In order to fully understand the origin of alkaline landscapes, one must be acquainted with the causes of the process. The concept of alkalinization differs among the various groups of scientists. Geoscientists, soil scientists and experts in agriculture generally refer to the accumulation of primarily sodium salts (sodium-carbonates and bicarbonates, $Na_2CO_3.10H_2O$) in the near surface, leading to the emergence of saline and alkali soils (Arany, 1956; Scherf, 1935; Sigmond, 1906, 1934; Szabolcs, 1961; Treitz, 1898, 1917, 1925; Várallyay, 1967; Várallyay, 1993, 1999). Botanists, on the other hand, refer to the presence of saline or salt-preferring and salt-resistant alkaline plants when they talk about the process of salinization (Borbás, 1886; Kerner, 2004; Rapaics, 1916). The importance of sodium excess and sodium accumulation in the process of alkalinization in the case of the alkaline soils of the Great Hungarian Plain was first highlighted by *Sámuel Teschedik* in the early 19th century (Teschedik, 1804). Therefore, as a first step, it is necessary to examine where the material yielding the salts of alkali elements (mainly sodium) comes from.

Sodium accumulation in alkaline areas has been initially attributed to plant matter decay (Muraközy, 1902; Sigmond, 1923). This assumption is rather controversial since plants incorporate sodium from some other source. Thus the alkaline and halophilous plants inhabiting the salt lakes, salt steppes and marshes cannot be considered as primary sources of sodium. Sodium is present in various forms in these habitats: dissolved in groundwater or attached to the surface of soil colloids. It may also appear in solid form in deposits precipitated from saline soils, saline lakes or marshes (Bernátsky, 1905; Szendrei & Tóth, 2006; Tóth et al., 2001). Therefore, alkaline elements, primarily sodium as a main driver of the emergence of alkaline soils can derive from various sources. In this context it is important to highlight what Hungarian scientists thought of potential primary sodium sources in the evolution of alkaline areas. *József Szabó*, a Hungarian geologist working during the second half of the 19th century, was the first to state that alkaline salts derive from the weathering of sodium present in minerals from the volcanic rocks surrounding the basin (Szabó, 1864). He interpreted the presence of the so-called "white muddy soil" found in the alkaline meadows of Heves County, in the valley of the Laskó creek, as the weathering by-product of rhyolite tuff. Another view by *Jenő Kvassay* connected sodium sources to the Tertiary salt deposits of surrounding mountains, whose weathered material reached the centre of the basin via fluvial transport (Kvassay, 1876). Conversely, *Károly Galgóczy* pointed out the local Tertiary marine salt deposits buried by younger, quaternary fluvial sequences as potential alkaline and sodium sources for the alkalinization of the Great Hungarian Plain (Galgóczy, 1876-1877). Researchers working on the topic later on used some of these initial hypotheses or a combination of them in their works regarding sources of sodium. Nevertheless, as early as 1930, a consensus was reached stating that alkaline salts derived from the weathering of near-surface rocks and minerals of the Great Hungarian Plain after having been transported into their present location via fluvial and aeolian means (Arany, 1934; Endrédy, 1941; Inkey, 1895; Kreybig, 1944; Sigmond, 1906; Sümeghy, 1937; Székyné

Fux & Szepesi, 1959). Results of extensive geochemical studies and salt source modelling dated to the second half of the 20th century corroborated the assumptions regarding the origin of alkaline elements for alkali salts (Sümegi, 1989, 1997; Sümegi, Molnár, & Szilágyi, 2000; Szöőr, Sümegi, & Balázs, 1991; Tóth et al., 2001). Erosion of the surrounding mountain belt, primarily of carbonated and siliceous rocks provided material for the Quaternary sequences of the Great Hungarian Plain (Molnár, 1960, 1964, 1965, 1967, 1973; Sümegi, 1989, 1997, 2004b, 2005; Timár, Sümegi, & Horváth, 2005). However, the presence of bedrock material providing sources of alkaline elements cannot grant salinization or alkalinization alone. An interaction of the groundwater with the bedrock is necessary for the appearance of Ca2+, Mg2+, Na+, HCO3- and Cl- ions (Fórizs, 2003; Scherf, 1935; Sümegi, 1989, 1997; Székyné Fux & Szepesi, 1959; Szöőr, Sümegi, & Balázs, 1991; Várallyay, 1967). The nature of this interaction is determined by the hydrogeology and geomorphology of a given area.

Extensive isotope studies on aquifers of alkaline landscapes have univocally proved that potential salt sources are dominantly connected to the shallow, local upwellings of the groundwater (Deák, 1974, 1975; Fórizs, 2003; Sümegi, 1997; Tóth et al., 2001) in contrast to former theories which linked the process to upwellings from deeper deposits or gas exhalation along faults and fractures. Thus, the higher dissolved salt content and high alkalinity of the alkaline landscapes of Hortobágy derive from the chemical weathering and dissolution of the Quaternary bedrock (Sümegi, 1989; Székyné Fux & Szepesi, 1959; Tóth et al., 2001), rather than from the older, buried salt deposits found at greater depths of the basin.

Based on available data, local upwelling or discharge zones of the groundwater (Fórizs, 2003; Fórizs, Tóth, & Kuti, 2006; Tóth et al., 2001) connected to interdune depressions (Mucsi, 1963), abandoned, infilled riverbeds or the margin of the floodplains (Kovács, Szatmári, & Rakonczai, 2006; Rakonczai, 2006; Rakonczai & Kovács, 2006) support alkalinization, generating the hydro-geological and geomorphological prerequisites of the process. The height of the groundwater table is fundamentally influenced by the local morphology (Mados, 1943; Szabolcs, 1957). The local morphological endowments (Strömpl, 1931), as well as the perched depth of the groundwater table (Mados, 1943), i.e. relative elevational differences, are important components of the system yielding alkalinization (Mados, 1943; Strömpl, 1931; Szabolcs, 1957). These elevational differences are quite pronounced along the margins of the floodplain as well as those of abandoned, infilled riverbeds (Kovács, Szatmári, & Rakonczai, 2006; Rakonczai, 2006; Rakonczai & Kovács, 2006). Therefore, it is not surprising that the highest degree of alkalinization is observed along the margin of these natural depressions (Stefanovits, 1963). These areas favour the rapid emergence of a groundwater table critical for the initiation of alkalinization (Kerényi, 2003). On the other hand, precipitation of alkaline salts at the surface and in the near-surface deposits is hampered by a permanent upwelling of groundwater, where continuous flushing removes dissolved salts and elements. However, evaporation of groundwater with high dissolved salt content, together with rainfall in natural discharge areas with no surface runoff, can bring about alkalinization. Such processes are characteristic in particular in the southern part of the alkaline landscape of Hortobágy.

Upwelling of dissolved salts is driven by local discharge areas found in front of local recharge areas. It is also influenced by the development and nature of the capillary fringe found above the groundwater table, which is controlled by the cyclical fluctuations of groundwater, insolation, surface vegetation cover, morphology and microclimatic endowments (Sümegi, 1997). Capillary drive is an important component of alkalinization, as it enables the upwelling of salt-rich groundwater against gravity as well. This ensures a constant or temporarily link between the sodium-rich groundwater and the near-surface aqui-systems present in alkaline soils, salt lakes and salt marshes. In areas, where the groundwater table is deeper than two meters, capillary lift cannot bring up waters rich in dissolved salts and sodium to the surface, hampering alkalinization (Mados, 1943).

The nature of the capillary rise and the emergence of a capillary fringe are largely influenced by the climatic endowments of the Carpathian Basin. Dynamic fluctuations in the groundwater table were characterized by three maxima connected to precipitation peaks occurring during the spring snowmelt, early summer and early fall periods preceding the 19th century flood control measures. Among the various components influencing the climate, high continentality with a frequency of 30-40 % at the centennial scale plays the most important role in creating capillary action responsible for alkalinization (Karuczka, 1999; Lóczy, 1910; Pálfai, 1989, 1993, 1994; Réthly, 1933; Szelepcsényi et al., 2009a, 2009b). As a result of high continentality, the occurrence of intense droughts in periods between major floods mainly confined to the second half of the summer favours the emergence of a capillary fringe in the uppermost one or two meters of soil.

Thus the highly variable climate of the Carpathian Basin, characterized by highly alternating wet and dry periods driven and controlled by the intensity of continentality is a major asset to alkalinization. On one hand, it contributes to the development of the capillary fringe fostering the upward movement of sodium-rich waters in soils and fosters the emergence of oversaturated waters in alkaline salts via enhanced evaporation in potential discharge areas on the other.

Alkaline habitats cover an area of ca. 10,000 km^2 in several parts of the Great Hungarian Plain including the Danube-Tisza and the Körös-Maros interfluves (Sajó & Trummer, 1934), where, according to the analysis presented above, alkalinization can be considered as an outcome of the unique interplay of geology, geomorphology, hydrogeology and climate of the Carpathian Basin (Sümegi, Molnár, & Szilágyi, 2000). The landscape of Hortobágy is the largest coherent occurrence of salt accumulation in Hungary and in Europe, covering an area of ca. 2300 km^2 (Figure I.1), with the domination of different subtypes of alkaline solonetz soils, covered by the wetland-grassland mosaic of alkaline habitats, which form a complete series from the driest plant associations at the higher geomorphological surfaces - through the wet meadows - down to the shallow alkaline marshes (Borhidi, 2003).

(For the Hortobágy, having the largest contiguous coverage of alkaline soils, it would be worth considering adjusting the boundaries of the landscape unit (Dövényi, 2010; Marosi & Somogyi, 1990) to the occurrence of the corresponding genetic soil types in the AGROTOPO Database of the Centre for Agricultural Research (AGROTOPO), i.e. to the distribution of different solonetz soils in the region. However, this is beyond the scope of this dissertation.)

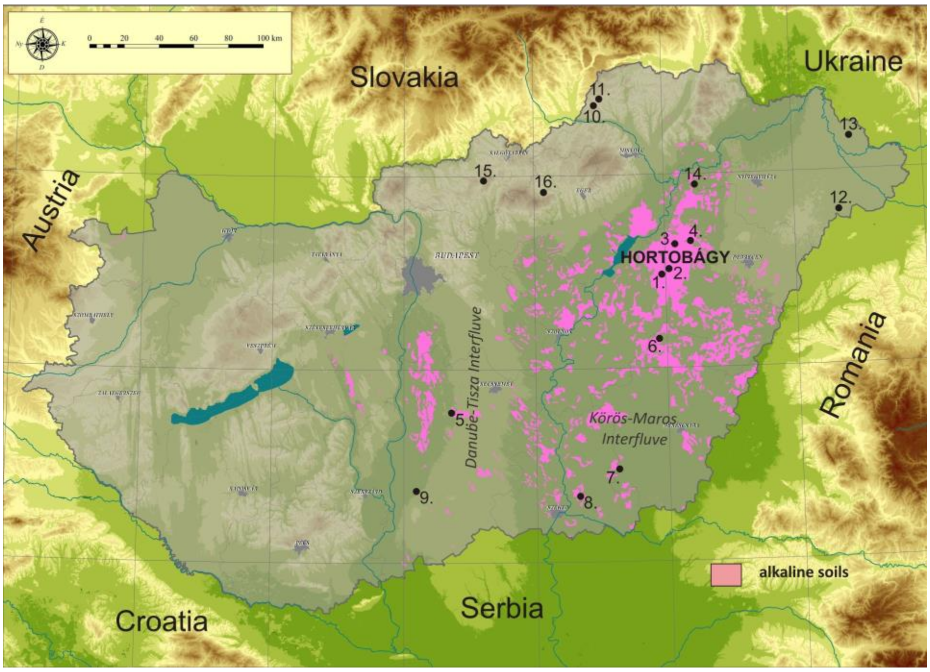

Figure I.1. Distribution of salt accumulation areas in Hungary. Location of undisturbed core points in Hungary.

1 = Kunkápolnás marsh, Kunmadaras; 2 = Halas Basin, Hortobágy; 3 = Pap-ere, Hortobágy; 4 = Fecske meadow, Balmazújváros; 5 = Lake Kolon, Izsák (Sümegi et al., 2011); 6 = Lake Kiri, Ecsegfalva (Willis, 2007); 7 = Lake Fehér, Kardoskút (Sümegi et al., 1999); 8 = Pana-hát, Maroslele (Sümegi, Persaits, & Gulyás, 2012); 9 = Hajós (Jakab, Sümegi, & Magyari, 2004); 10 = Kis–Mohos, Kelemér (Willis et al., 1997); 11 = Nagy–Mohos, Kelemér (Magyari et al., 2010); 12 = Bátorliget fen, Bátorliget (Willis et al., 1995); 13 = Nyírjes fen, Csaroda (Sümegi & Törőcsik, 2010); 14 = Sarló-hát, Tiszadob (Magyari et al., 2010); 15 = Nádas Lake, Nagybárkány (Sümegi & Törőcsik, 2010); 16 = Nyírjes Lake, Sirok (Gardner, 1999).

It is no coincidence that the first multi-disciplinary and comprehensive investigations making a consistent application of a methodology and meeting international standards, i.e. pollen and plant macrofossil analysis on undisturbed samples with reliable absolute chronologies were initiated in the landscape of the Hortobágy at the end of the 20th century (Figure I.2.)

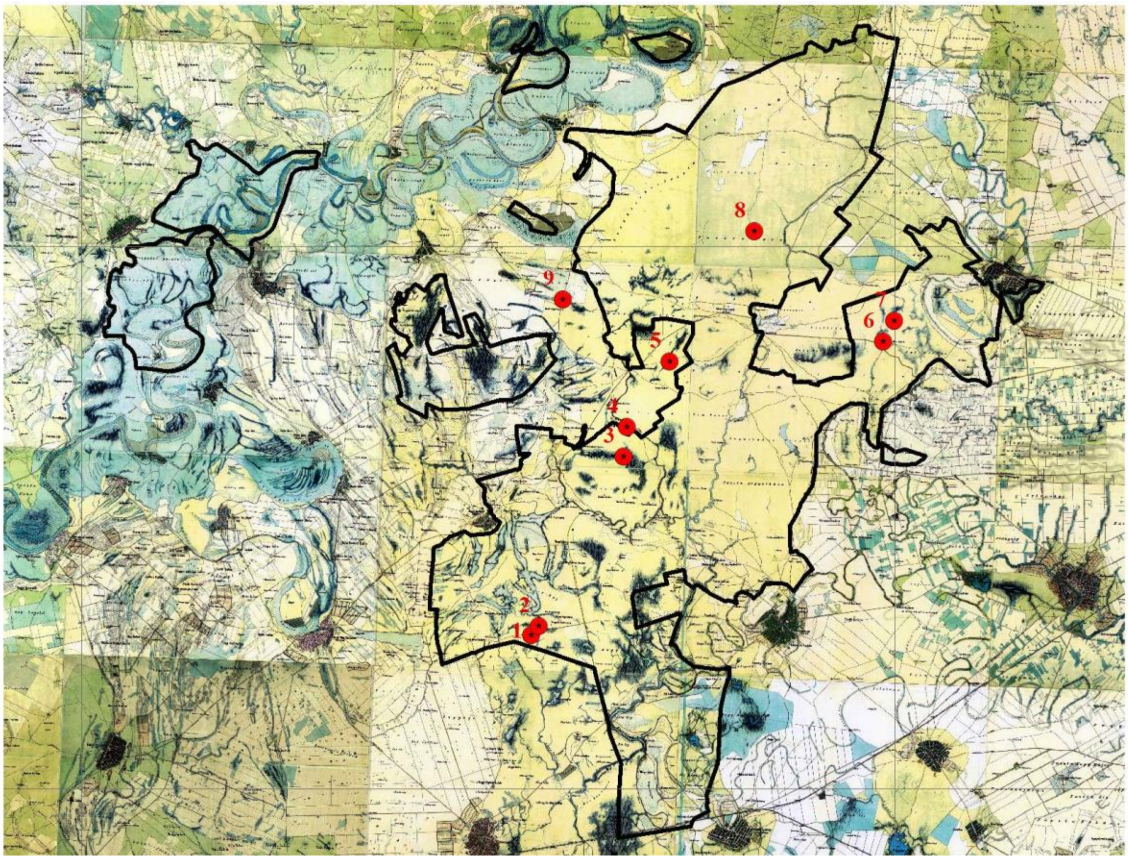

Figure I.2. Map of the Hortobágy National Park and its surroundings prepared before the major river regulations and creation of fishponds (II. military mapping survey) with the location of the undisturbed core points.

1. Ecse mound at Karcag/Kunmadaras (Yamnaja culture burial hill); 2 Kunkápolnás marsh near Kunmadaras with the analyzed paleochannel (Róna basin); 3. Halas Basin (paleochannel); 4. Faluvég mound (Yamnaja culture burial hill); 5. Kungyörgy Lake (paleochannel); 6. Szálka mound (Yamnaja culture burial hill); 7 = Fecske meadow (paleochannel); 8. = Pap-ere (paleochannel); 9. Csípő mound (Yamnaja culture burial hill).

1.2. Scientific and conservation importance of kurgans (burial mounds)

Loess steppes are considered to be one of the rarest and most fragmented habitat types of the Eurasian steppe and forest steppe zones. They are estimated to have once extended from Mongolia to the Danube delta (Bohn, Zazanashvili, & Nakhutsrishvili, 2007) over an 8–13 billion km2 area before human agricultural and industrial activities have begun (Wesche & Treiber, 2012). Various studies, primarily botanical in scope, have proved that the Pannonic forest steppe of the Great Hungarian Plain in the Carpathian Basin is part of this zone (Borhidi, 1956; Molnár & Borhidi, 2003a, 2003b; Molnár et al., 2012; Zólyomi, 1957, 1969; Zólyomi &

Fekete, 1994) that was cut off by the uplift of the Carpathians, as a result of which it has developed as a detached habitat island (Molnár & Kun, 2000). This once vast natural ecosystem has mostly been ruined or transformed (Szirmai, Czóbel, & Nagy, 2005) by the network of settlements, roads, and railroads, increasing agricultural activity, particularly the highly motorized and chemically enhanced intensive crop farming and animal husbandry. The most dramatic changes have taken place in the Ukraine, where only 5%–10% of the indigenous steppe and forest steppe vegetation has subsisted within this vegetation zone (Sudnik-Wójcikowska & Moysiyenko, 2013). Similar human encroachment and its effects have taken their toll in Kazakhstan, where 90% of the former steppe has been turned into arable land, since the announcement of the Virgin Lands Campaign movement in the 1950s (Rachkovskaya & Bragina, 2012).

The same anthropogenic processes have influenced the transformation of the Pannonian forest steppes and loess steppes developed in the Great Hungarian Plains for the past 100–150 years (Deák et al., 2015; Molnár et al., 2014). Therefore, Hungarian nature conservancy and particularly the national park directorates situated in the Great Plains play a significant role, also from an international perspective (Dengler et al., 2014), in the conservation of primary forest steppe and steppe areas, as well as in the extension and reconnection of habitat fragments based on the existing network of protected areas (Balázs, 2006). This nature conservation task is particularly difficult in the case of loess steppes, since they predominate in chernozem soils, while these highly fertile areas have long been cultivated as croplands (Kelemen et al., 2010; Török et al., 2011). This is the main reason for the existence of the few remaining examples of Pannonic forest steppe and loess steppe habitats in the Great Plains, mostly sustained in ditch slopes, balks, as well as on burial and watch mounds (Balázs & Kustár, 2012; Bede et al., 2014; Bede et al., 2015; Csathó, 2009; Csathó et al., 2015; Deák et al., 2015; Penksza et al., 2011; Tóth, 1998; Zólyomi, 1969).

These mounds have a one ha surface area on average (Deák et al., 2016; Deák et al., 2015), and despite their small size they play a pivotal role in the conservation of the steppe and forest steppe biota, because their botanical and zoological assets can be particularly diverse. This property can be attributed to the very structure of these mounds, i.e., their pyramidal shape with rather steep slopes. These steep, conic slopes were difficult or impossible to plough, and depending on their exposure, very diverse microhabitats and diverse microclimatic conditions have developed on them (Sudnik-Wójcikowska et al., 2011; Vona & Penksza, 2004).

Burial mounds are the most important objects of nature conservation efforts aiming at the restoration of the original vegetation and soil conditions, since they were built on the natural ground surface, and the earth around the burial site was used as building material (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007). Thus, contemporary soil types can be studied in the building strata of the mounds (Bede et al., 2014). Beyond the pedological research, by the careful study of plant remains, primarily pollen and phytoliths (Sümegi, 2001, 2002) (Persaits et al., 2008; Persaits & Sümegi, 2011, 2015; Persaits, Sümegi, & Törőcsik, 2014) it is possible to reconstruct the vegetation of the area within the period of the construction. This research can yield very precise data on the soil conditions and vegetation before and during the construction of the mounds in the heart of the Carpathian Basin. As the soil beneath these earth-pyramids has not developed any longer (Demkin et al., 2014; Kashirskaya et al., 2010; Khomutova et al., 2007; Lomov et al., 2017), the study of the natural original soil can reveal the soil conditions before the mounds were constructed.

The date of origin of the mounds has been an important question since the early period of Hungarian archaeological excavations. Not only did the mounds vary, but also the time of their construction ranged within a wide period of time. The Hungarian term “kunhalom” (meaning “Cumanian mound”) (Gárdonyi, 1893, 1914; Gyárfás, 1870; Győrffy, 1921; Horvát, 1825; Jerney, 1851) is highly problematic, since this is the umbrella term for all types of mounds without consideration of their function or date of origin (Barczi et al., 2009; Dani & Horváth, 2012; Pető & Barczi, 2011; Tóth & Tóth, 2003; Tóth, 2006). This term persisted despite archaeologists' warnings of the problems and misunderstandings it has caused, both in chronology and functional classification, since this term denotes Late Neolithic and Middle Bronze Age tells, Late Copper and Early Bronze Age kurgans, as well as Iron Age burial mounds, and burial mounds of Scythian, Sarmatian, Hungarian, and Cumanian origin. As *János Makkay* (1964) has pointed out, regardless of their function whether tells, burial mounds, watch and border mounds, cultic mounds, they are all labelled as "kunhalom."

There have been assumptions (Bede et al., 2014; Bede et al., 2015), before this study, that the Ecse Mound had been built by communities of the Pit Grave (Yamnaja) Culture (Gimbutas, 1980; Merpert, 1974; Rassamakin, 1994), considering the similarities in shape, orientation, and stratigraphy of this earth-pyramid, and the comparative geomorphological research of other mounds in the Hortobágy region (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013). Findings and data from this artificially piled layer correlate with the radiocarbon data from 80 to 100 samples from the East European Plains, as the infiltration of the Pit Grave (Yamnaja) Culture to the Carpathian Basin from there took place in several waves; they define the third wave, or the beginning of the so-called classic phase, i.e., Horizon A (Morgunova & Khokhlova, 2006, 2013).

Without accelerator mass spectrometry (AMS) or radiocarbon data, it is impossible to identify the culture of origin, since mounds were built in the Great Hungarian Plain throughout millennia, including in the area studied, by various cultures and peoples, like Scythians, Sarmatians, early Hungarians, and later Cumans (Tóth & Tóth, 2003; Tóth, 2006). Mounds were built in the Hortobágy and its broader region as early as 3300 BC (first appearance of the peoples of the Pit Grave Culture) until as late as the 15th century, which is a 4,900- to 5,000-year timespan.

Archaeological research papers rarely report on the fact of which nature conservationists are well aware of, i.e., that early archaeological excavations and research projects took a toll on the mounds, leading to either their full or partial disintegration in most cases. Several of the archaeological sites were left without reconstruction (their central part dug up, transacted and the soil deposited beside the mound). What all these excavations share in common is that the soil was not filled back. The reconstruction of these mounds would require a systematic program requiring substantial financial resources (Bede & Czukor, 2015).

This issue can only be tackled if the initial phase of each study includes stratigraphic and chronological analyses, so that the very function and age of the mound are revealed (Sümegi, Bede, & Szilágyi, 2015a). Following up on *Prof. Zoltán Borsy*'s observations (Borsy, 1968), the first such examinations were carried out on the section of the "Őrhalom" at Sárrétudvari (Sümegi, 1992), and on the "Szálkahalom," Hortobágy, by drilling and sampling (Sümegi, 1988). These pilot studies have led to the elaboration of a methodology of mound research (Sümegi, 2001, 2002, 2003).

Microstratigraphic sampling, sedimentological, geo-chemical, petrographic, and malacological analyses were the primary source of information guiding the methodology development. Samples were taken from the archeological excavation transects (by the archaeologist *Ibolya Nepper Módy* of the Őrhalom nearby Sárrétudvari, as the excavation trenches and illegal earth extraction made mapping and core drilling precise and easy. In addition, samples for radiocarbon analyses were collected from this same site to determine the age of specific strata (Sümegi, 1992, 2004a). The development of the methodology continued, and additional Neolithic and Bronze Age tells (Sümegi, 2009, 2013; Sümegi et al., 1998; Sümegi et al., 2002; Sümegi et al., 2013b), and kurgans of the Hortobágy were involved (Sümegi & Szilágyi, 2011;

Szilágyi et al., 2013), including the Ecse Mound (Szilágyi, Náfrádi, & Sümegi, 2019; Szilágyi et al., 2018).

1.3. Scientific background for the conservation management of the Hortobágy National Park

The changes triggered by the industrial revolution some three hundred years ago have already resulted in such a major climate shift and pollution that industrial society itself, humanity and the majority of the species that make up the Earth's biosphere, and their future, are at risk (Kerényi, 1995; Meadows et al., 1972). Human impacts are now so strong and profound that they have caused considerable changes in the geological strata, even in the geological time scale (Berardelli, 2008; Ruddiman, 2003, 2005). The scale of these human-induced environmental changes is so great that the International Commission on Stratigraphy (ICS), following a decision of its assigned working group on 30 August 2016, named the period from the first atomic bomb on 16 July 1945 the “Anthropocene”, based on a proposal by Nobel Prize-winning chemist *Paul Crutzen* (Crutzen & Stoermer, 2000; Lewis & Maslin, 2015). This new geological age and the challenges it poses for all of us has prompted earth and biological scientists to work together and form research teams, especially in areas where environmental and ecological problems have required knowledge of past changes to inform current and future conservation and sustainability strategies.

One such priority area is the issue of national parks (Sahney, Benton, & Ferry, 2010). The International Union for Conservation of Nature and Natural Resource (IUCN), defines national parks (= category II protected areas) as large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, where the primary objective of site management is the protection of natural biodiversity along with its underlying ecological structure and supporting environmental processes (Dudley, 2008). The need to support ecological processes as a priority task is no longer a static approach, but it raises the question of the time horizon of the ecological systems in the area, what should a management activity in a national park protect, especially in today's human-influenced world?

One of the key cornerstones of the management regime of an IUCN Category II national park is the identification of the ‘original’ biota of the given protected area, where ‘original’ means the natural flora and fauna before significant landscape-level changes caused by human activities, such as the cutting and fragmentation of contiguous forests and the conversion of natural grasslands to cropland, have occurred. Likewise, the first question asked by nature-loving visitors to national parks is usually about the 'pristine', 'unspoilt' ecological system of the site, wherever it may be in the world. By 'original' or 'pristine', they usually mean the state of the site before the agricultural or Neolithic revolution, after which the main landscape-forming and landscape-altering activities of man, such as plant cultivation and animal husbandry, began (Barker, 2006).

More important than answers to such questions is the fact that the strategic and specific management objectives of a protected area can only be determined by understanding the evolution of the land surface and vegetation and its successive use by different human cultures over time.

The first and still the largest national park of Hungary, the Hortobágy National Park was established 50 years ago in the north-eastern part of the country, in the Great Hungarian Plain. Most of the park area was dominated by different kinds of alkaline soils covered by mosaics of grassland-wetland vegetation complexes. The designation of the 52,000 ha area as a national park was followed by several international designations, such as the UNESCO Biosphere

Reserve, Ramsar Convention and the Natura 2000 network of the European Union. In 1999, the *Hortobágy National Park – the Puszta* site was inscribed on the World Heritage List of UNESCO as a cultural landscape, as it maintains intact and visible traces of its traditional land-use forms over several thousand years, and illustrates the harmonious interaction between people and nature. The park has been enlarged several times over the last half century and now extends over 80,000 hectares.

According to the prevailing academic views at the time of the foundation of the Hortobágy National Park there were two major human activities that significantly changed the original character of the flat landscape of the Hortobágy region. The first one was supposed to be, like in other lowland areas of Europe, the cutting down of forests to create pastures for grazing domestic animals, mostly cattle and sheep. In the first and still the only monograph of the Hortobágy National Park (Béres, Bodó, & Jakucs, 1976) the secondary character of the alkaline grassland-wetland mosaics was assumed as a starting point for the future management of the grassland-wetland mosaics of the Park. The potential vegetation map published in this monograph by Jakucs (Jakucs, 1976) suggested the dominance of hard and softwood gallery forests enclosing ancient alkaline grassland patches during the Early Neolithic period in the Hortobágy region. However, according to a recent critical source analysis, the presence of continuous forests in the Hortobágy region was assumed on the basis of the misinterpretation of a royal charter issued in the mid-15th century (Molnár, 2009). Based on this source the presence of extensive woodlands was presumed for the period preceding the flood control measures. Thus extensive deforestation and desiccation was blamed to initiate alkalinization. However, *Zsolt Molnár* was the first to point out that no information was given regarding the presence of woodlands in the Hortobágy area in the referred charter.

The second significant human intervention that was supposed to play an important role in the significant extension alkaline areas was the landscape scale change of the water regime of the Hortobágy by the major river regulation and drainage works started in the mid-19th century. This assumption is contradicted by descriptions of naturalists, such as *Pál Kitaibel* (Lőkös, 2001) and *Robert Townson* (Townson, 1797), indicating the presence of alkaline soils and vegetation in large areas before the start of hydroregulation measures in the Hortobágy region. These observations are also supported by the relevant map sheets of the first military mapping survey of Hungary and their description (Pók, 1994), undertaken in the second half of the 18th century. In addition, the presence of endemic plant species in the Hortobágy National Park, which occur exclusively in alkaline habitats, also indicates a much earlier appearance of such vegetation in the region (Lesku & Molnár, 2007). The most obvious representative of such species is *Plantago schwarzenbergiana*, which inhabits alkaline habitats in Hungary, Romania and Ukraine and is abundant in the southwestern, strictly protected part of the Hortobágy National Park called Kunkápolnás marshland. The CORINE Land Cover GIS database of the European Union (2018, 100-meter resolution) indicates the dominance of natural grasslands in the Hortobágy National Park (Figure I.3) and even with the relatively low resolution, places covered by the typical alkaline plant-less or mostly single-plant associations *Camphorosmetum annue* and *Puccinellietum limosae* are distinguished as “sparsely vegetated areas”.

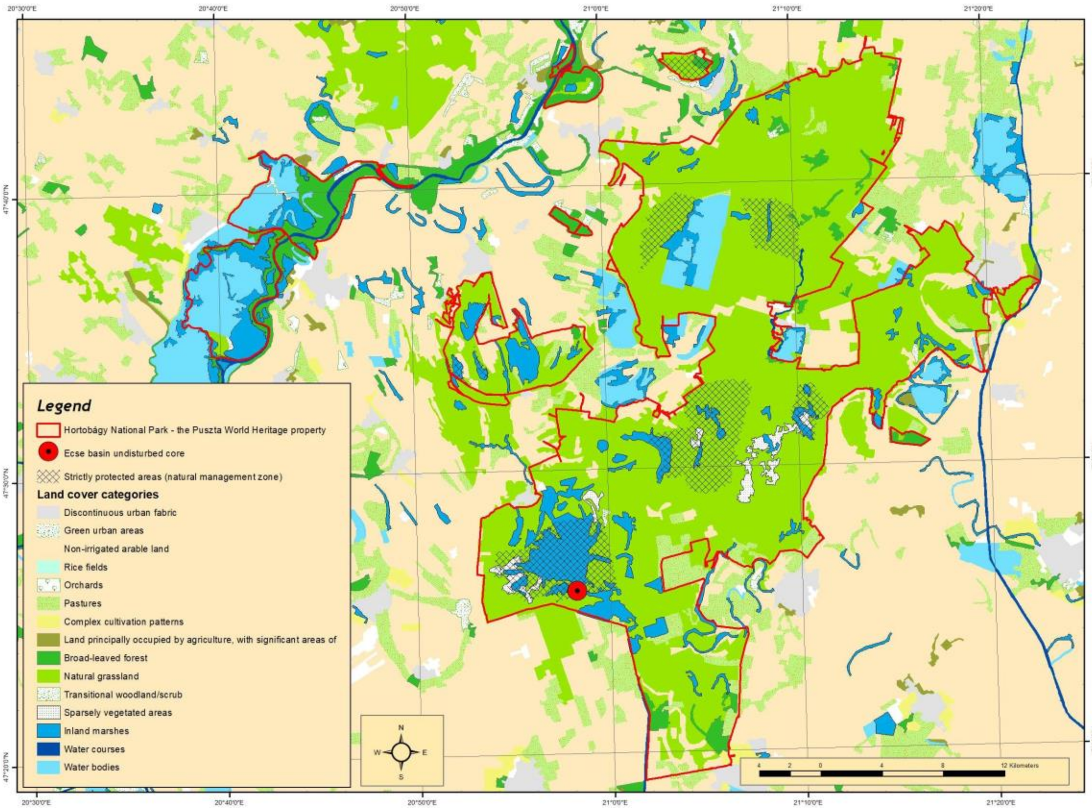

Figure I.3. CORINE Land Cover map of the Hortobágy National Park – the *Puszta* World Heritage property (2018).

Although one of the most important questions about the historicity of salt accumulation near the surface and accumulating in soils is whether the environment adapted to excess sodium developed before or after hydroregulations, naturalist travellers' descriptions (Lőkös, 2001; Townson, 1797) and the sporadic research data from the second half of the 19th century before river regulation (Boros & Bíró, 1999; Dapsy, 1869; Molnár, 2009; Sümegi & Boros, 2013) indicate that salt accumulation in soils and a biota adapted to the saline environment had already developed in the northern part of the Trans-Tisza region (the area east of the River Tisza) before the hydroregulation measures (Molnár, 1996, 2003, 2007, 2008, 2009; Molnár & Bíró, 1997).

Theoretical considerations based on these foundations have completely excluded the possibility of alkalinisation during the glacial periods, claiming that environmental conditions on the Hungarian Lowlands were not favourable for the process (Miháltz, 1947), hence the presence of glacial alkaline deposits, or signs of prehistoric alkalization were not assumed and searched for in the Great Hungarian Plain until 1988, when a multi-proxy paleoecological study of an undisturbed core series from the eastern margin of the Hortobágy landscape succeeded in identifying an alkaline paleosol horizon dated between 30-40,000 years beneath the glacial loess deposits (Sümegi, 1989, 2001, 2003; Szöőr, Sümegi, & Balázs, 1991, 1992). Subsequent analyses revealed the presence of minerals typical of alkaline soils, such as gypsum, polyaluminates and amorphous silica gel, supporting the assumptions established in the field (Sümegi, 1989, 1997; Szöőr, Sümegi, & Balázs, 1991, 1992). These data provided consistent evidence that conditions favourable to alkalinization may have developed during the last glacial cycle dated to MIS3 as part of an intense brief interstadial warming, the Dansgaard-Oeschger cycle (Sümegi, 1989). Cores taken from Bronze Age burial mounds also revealed the presence of buried chernozem and alkaline soils in the study area in the Early Holocene (Sümegi, 1989; Sümegi & Szilágyi, 2011).

1.4. Objectives, research questions and the structure of the dissertation

The main objective of my thesis is the identification of the milestones of the late Quaternary environmental history of the Hortobágy landscape through a multi-proxy study and analysis of a complete fluvial cycle, dating back to 50,000 years in the largest wetland-grassland mosaic habitat complex of the Hortobágy National Park, the Kunkápolnás marsh system (Szilágyi et al., 2024).

In my dissertation I look for answers for the following key questions:

1. Are the alkaline (solonetz) soils of the Hortobágy of primary or secondary origin?
2. How the water regime of the Hortobágy landscape developed and functioned until the hydroregulation measures started in the mid-19th century?
3. What were the major stages of vegetation changes of the area over the last 50,000 years, particularly with regard to the occurrence of alkaline habitats?
4. How much did human activity change the landscape of Hortobágy in the second half of the Holocene?
5. What lessons can be learned from environmental history and landscape change for conservation management?

The dissertation is structured as follows[1]:

- Chapter 2 provides an overview about the methodology applied and materials used during the research activities.
- Chapter 3 includes a multi-proxy study of the environmental history and the related vegetation development of the Hortobágy landscape through an interdisciplinary analysis of an undisturbed core sequence from one of the former riverbeds of the Kunkápolnás marsh system, with detailed information about the geochronology, sedimentology, pollen macrobotanical and malacological data of the sample. Furthermore, on the basis of these data, suggestions are made for the future conservation management of the Hortobágy National Park – the Puszta World Heritage Site and for the inscription of this property on the World Heritage List on the basis of natural criteria in addition to the two existing cultural ones.
- In Chapters 4 and 5 the results of a pilot study are described, which could serve as an example for a larger scale scientific programme for the objective studying of kurgans by the means of undisturbed core sampling, as other methods used for such purposes could hardly provide a sound basis for a comparative analysis of the environmental history and construction phases of burial mounds.
- Chapter 6 includes the discussion of the results of the three publications,
- In Chapter 7 the conclusions and the description of the new scientific results are described.

After a summary both in English and Hungarian, the dissertation concludes with the acknowledgments and an integrated list of references.

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[1] Chapters 3-5 include my first-authored publications in accordance with the rules of the doctoral school.

Chapter 2: Materials and methods

Since previous studies generally included only a part of the alkaline landscape development over time (Sümegi, 1997; Sümegi, Bodor, & Törőcsik, 2005, 2006; Sümegi, Molnár, & Szilágyi, 2000), I have selected an area for sampling where the entire sequence of changes and development process of the alkaline landscape could be captured. This place was found in the southern part of the Kunkápolnás marshland area, in the territory of Kunmadaras town (Figure II.1).

Figure II.1. Google Earth image of the Kunkápolnás marsh system with the location of the undisturbed core points.

This area was highly appropriate for the study, as it allows both a detailed analysis of a core sequence of a former riverbed (Róna Basin) and an undisturbed kurgan (burial mound called Ecse Mound) built by people of the Pit Tomb (Yamnaja) culture (Figure II.2), where the two sampling points are only a few hundred metres apart (Figure II.3).

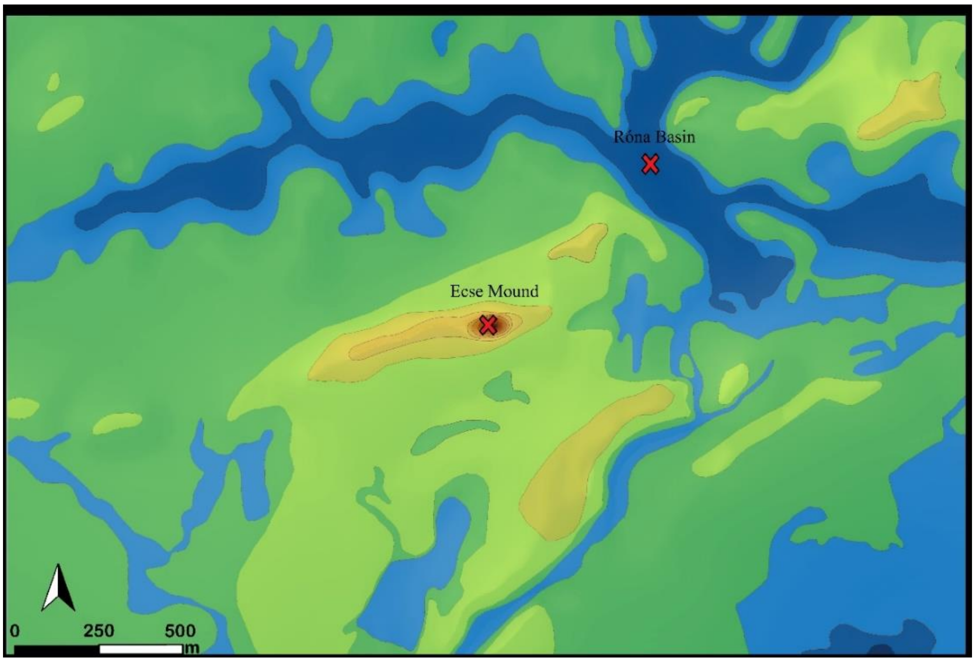

Figure II.2. Digital elevation model of the study area with the location of the undisturbed core points

Figure II.3. Drone photo of the study area with the location of the undisturbed core points

Samples were taken by undisturbed core drilling both from the Ecse Mound and the Róna Basin, The overall sampling and processing procedure was based on the international Quaternary paleoecological method of Birks & Birks (Birks & Birks, 1980).

2.1. Ecse mound

For the Ecse Mound sediment types were determined and described on the field using the Troels-Smith system (Troels-Smith, 1955), internationally accredited for paleoecological works. Both wet and dry colors were determined (Munsell, 2000).

Measuring magnetic susceptibility (MS) has proved to be one of the best methods to yield reliable stratigraphic data in case of studies of mounds (Bede et al., 2014; Bede et al., 2015; Sümegi, 2012, 2013; Sümegi, Bede, & Szilágyi, 2015a). Samples were taken at 2–4-cm intervals. Prior to the start of the measurement, all samples were crushed in a glass mortar after weighing. Then samples were cased in plastic boxes and dried in air in an oven at 40°C for 24 hr. Afterwards, magnetic susceptibilities were measured at a frequency of 2 kHz using an MS2 Bartington magnetic susceptibility meter with a MS2E high resolution sensor (Dearing, 1994). All the samples were measured three times and the average values of magnetic susceptibility were computed and reported.

The grain size composition of sedimentological samples was carried out using the laser-sedigraph method. First the samples were pre-treated with 1 M HCl and H2O2 to remove CaCO3 and organic content respectively. A more detailed description of the pre-treatment process is given by Konert and Vandenberghe (Konert & Vandenberghe 1997). All the samples were measured for 42 intervals between 0.0001 and 0.5mm using an Easy Laser Particle Sizer 2.0 and Fritsch sieves in Szeged (Hungary). For LOI examination sub-samples were taken at every 2–4-cm intervals and the loss on ignition method was applied, commonly used for the analysis of the organic and carbonate content on calcareous sediments (Dean 1974).

Six shell samples were submitted for radiocarbon dating taken from major stratigraphic units for AMS ^{14}C dating measurements (Szilágyi, Náfrádi, & Sümegi, 2019; Szilágyi et al., 2018), which were done in the internationally referenced AMS laboratory of Seattle, WA, USA.

Preparation of the samples and the actual steps of the measurement followed the methods of (Hertelendi et al., 1989; Hertelendi, Sümegi, & Szöőr, 1992; Molnár, Janovics, et al., 2013). Shells were ultrasonically washed and dried at room temperature. Surficial contaminations and carbonate coatings were removed by pre-treatment with weak acid etching (2% HCl) before graphitization. Conventional radiocarbon ages were converted to calendar ages using the software OxCal 4.2 (Bronk Ramsey, 2009) and the most recent IntCal13 calibration curve (Reimer et al., 2014). Calibrated ages are reported as age ranges at the 2-sigma confidence level (95.4%). A U_Sequence age-depth model was constructed for the upper part of the sequence representing the actual mound via Bayesian modelling using OxCal (Bronk Ramsey, 2009). As these layers were artificially built up we may presume a relatively uniform deposition rate related to the events of mound formation. In our models we used an U_Sequence model assuming strictly uniform deposition for the anthropogenic stratigraphic horizons.

2.2. Róna Basin

The undisturbed core-drilling site was located at the edge of the Kunkápolnás marsh complex and in the middle of a backfilled embankment across one of the paleochannels of the swamp. The embankment was constructed in 1958, and the surrounding area was used as a bombing range and had human-disturbed surfaces, in particular, thousands of bomb craters. However, the embankment protected the underlying stratigraphic sequence, therefore the most complete data set possible from the sedimentary assemblage accumulated up to the beginning of the Neolithic could be used for our paleoecological study. The sampling site corresponds to the abandoned and infilled paleochannels fringing the open vegetation of the alkaline grasslands.

Samples were taken in winter to avoid possible pollen contamination, and they were subjected to sedimentological, geochemical, palynological, malacological, plant macrofossil and ^{14}C chronological analyses.

The core was subsampled at 2 cm/4 cm intervals for pollen analysis. Samples of 1 cm^3 were obtained using a volumetric sampler and processed for pollen analysis (Berglund, 1986). Some pollen samples were analyzed using the Zólyomi–Erdtman $ZnCl_2$ method, which is the most commonly used method in Hungary (Zólyomi, 1952), as this method provides better results than others for oxbow lake sediments (Magyari, 2002). A known amount of exotic pollen was added to each sample to determine the concentration of identified pollen grains (Stockmarr, 1971). To ensure a statistically manageable sample size, at least 300 grains per sample were counted (excluding exotics) (Maher, 1972). Charcoal abundance was determined using the point count method (Clark, 1982). Tablets with known Lycopodium spore content (from Lund University, Lund, Sweden) were added to each sample to calculate pollen concentrations and accumulation rates. Pollen types were identified and modified according to Moore et al. (Moore, 1991), *Hans-Jürgen Beug* (Beug, 2004), *Radka Kozáková* and *Petr Pokorny* (Kozáková & Pokorný, 2007), supplemented by examinations of photographs by *Maurice Reille* (Reille, 1992, 1995, 1998) and reference material held in the Hungarian Geological Institute in Budapest. The analysis of local pollen zones and the statistical interpretations were carried out with the Psimpoll software package (version 4.26) created by *Keith David Benneth* (Bennett, 2005). For macrobotanical studies, QLCMA analyses (Barber, 1994; Sugita, 1994) were used. For the quarter-malacological analyses, the methods, assessments, and recent distribution data of *Vojen Ložek* (Ložek, 1964), *Bruce Wilfred Sparks* (Sparks, 1964), *Witold Pawel Alexandrowicz* (Alexandrowicz, 2004; Alexandrowicz, 2014), *Endre Krolopp* (Krolopp, 1965, 1973, 1983), and *Francisco Welter-Schultes* (Welter-Schultes, 2012) were applied, and the samples were pooled at 16 cm intervals to achieve a minimum of 100 per sample.

It must also be acknowledged that watersheds in floodplains subject to recurrent flooding receive large amounts of so-called “alien” pollen from distant areas, which greatly distorts the final pollen spectrum (Fall, 1987; Hall, 1989). Consequently, these paleochannels are far from being ideal pollen traps. The extent of “pollen pollution” is highly dependent on the depth and extent of flooding and the vegetation of the flooded area, which can distort the reconstruction of local and regional vegetation. To control and limit the potential bias as much as possible, our work used the analysis of plant macrofossils that provide information on vegetation that has been destroyed and preserved in situ. In this way, elements of the previously in situ flora could be separated from potential regional and extra-regional elements. Paleovegetation can be reconstructed from pollen data using several approaches. For our purposes, the key goal was to assess the extent to which the surrounding landscape and region were occupied by forest–steppe or steppe, as opposed to a closed forest (Magyari et al., 2010). In my work, the so-called biomization method (Prentice, 1996) was used, complemented by an indicator taxa approach to infer the potential local presence of steppe (Magyari et al., 2010; Magyari, 2011).

Chapter 3: Late Quaternary paleoecology and environmental history of the Hortobágy, an alkaline steppe in Central Europe

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Diversity: 16(1) p. 67 (2024)
DOI: 10.3390/d16010067

Abstract

Hungary's first national park was created in 1973 in the Hortobágy area to protect Europe's largest contiguous steppe area with its flora and fauna. The Hortobágy National Park - the Puszta was inscribed on the UNESCO World Heritage List as a cultural landscape in 1999. The park's outstanding importance is due to the predominantly non-arboreal steppe vegetation, home to a unique bird fauna, and the alkaline and chernozem soils with a complex, mosaic-like spatial structure. In addition, the landscape of the Hortobágy has a pastoral history stretching back thousands of years. Several hypotheses have been put forward, which suggest that the alkaline soils and the habitats that cover them were formed as a result of human activities related to river regulation that began in the second half of the 19th century. However, paleoecological and paleobiological studies over the last 30-40 years have pointed to the natural origin of the alkaline steppes, dating back to the end of the Ice Age. For thousands of years human activities, in particular grazing by domestic animals, hardly influenced the natural evolution of the area. Drainage of marshy and flooded areas began in the 19th century, and the introduction of more and more intensive agriculture, had a significant impact on the landscape. This paper aims to describe the past natural development of this special alkaline steppe ecosystem, with particular reference to the impacts of past and present human activities, including conservation measures.

3.1. Introduction

One of the most important cornerstones of the management system of an IUCN cate-gory II national park is the identification of its “original” vegetation, where original means its natural flora and fauna prior to significant changes caused by humans at the landscape level, such as cutting down and fragmenting continuous forests and turning natural grasslands to arable land. The first and still largest national park in Hungary was established 50 years ago in the eastern part of the country in the Great Hungarian Plain. Most of the park area is dominated by different kinds of alkaline soils covered by mosaics of grassland–wetland vegetation complexes (Video S1). According to the prevailing academic views at that time, there were two major human activities that significantly changed the original character of the flat landscape of the Hortobágy region. The first one was supposed to be, like in other lowland areas of Europe, the cutting down of forests to create pastures for grazing domestic animals, mostly cattle and sheep. In the first and still only monograph on Hortobágy National Park (Béres, Bodó, & Jakucs, 1976), the secondary character of the alkaline grassland–wetland mosaics was assumed to be a starting point for the future management of the grassland–wetland mosaics of the park. The potential vegetation map published in this monograph by Jakucs (Jakucs, 1976) suggested the dominance of hard and softwood gallery forests enclosing ancient alkaline grassland patches during the Early Neolithic period in the Hortobágy region. However, according to a recent critical source analysis, the presence of continuous forests in the Hortobágy region was assumed on the basis of a misinterpretation of a royal charter issued in the mid-15th century (Molnár, 2009).

The second significant human intervention that was supposed to play an important role in the significant extension of alkaline areas was the landscape-scale change in the water regime of Hortobágy caused by major river regulation and drainage works started in the mid-19th century. This assumption is contradicted by descriptions of naturalists, such as Kitaibel (Lőkös, 2001) and Townson (Townson, 1797), indicating the presence of alkaline soils and vegetation in large areas before the start of hydroregulations in the Hortobágy region. These observations are also supported by the relevant map sheets and their description of the first military mapping survey of Hungary (Pók, 1994), undertaken in the second half of the 18th century. In addition, the presence of endemic plant species in the Hortobágy National Park, which occur exclusively in alkaline habitats, also indicates the much earlier appearance of such vegetation in the region.

The most obvious representative of these species is *Plantago schwarzenbergiana* (Figure III.1), which inhabits alkaline habitats in Hungary, Romania, and Ukraine and is abundant in the southwestern part of the Hortobágy National Park, called Kunkápolnás marsh, the study area of the present paper (Figure III.2).

Figure III.1. *Plantago schwarzenbergiana* in alkaline grassland (photo: Balázs Lesku).

The CORINE Land Cover GIS database of the European Union (2018, 100 m resolution) indicates the dominance of natural grasslands in Hortobágy National Park (Figure III.2), and even with a relatively low resolution, places covered by the typical alkaline plant-less or single-plant association *Camphorosmetum annue* are distinguished as "sparsely vegetated areas".

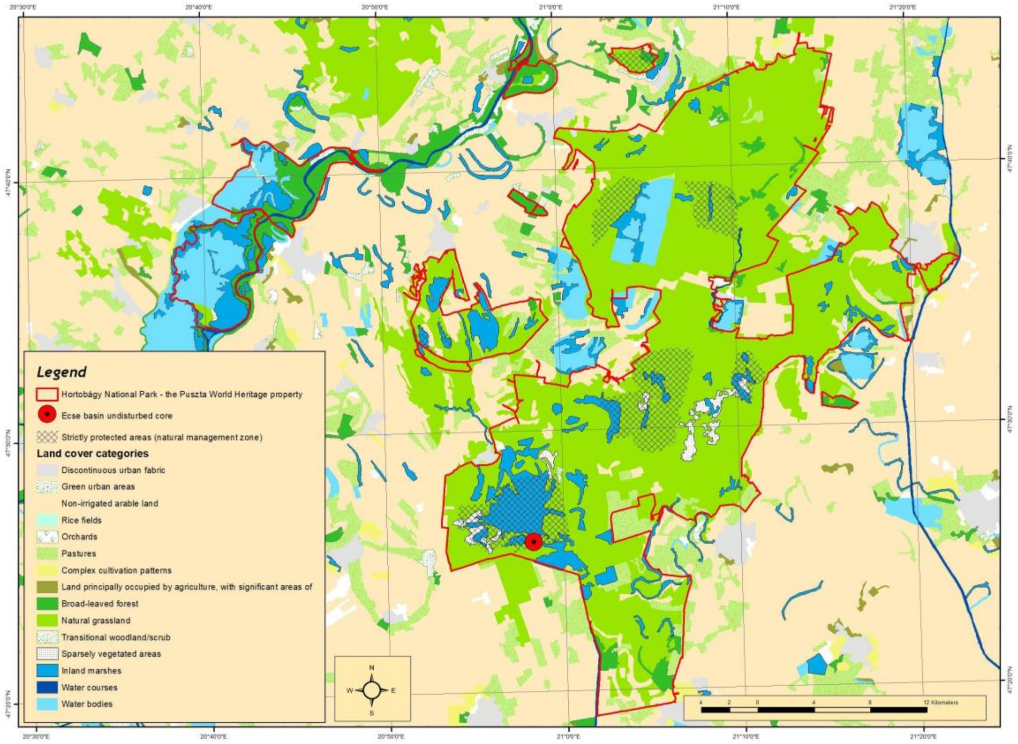

Figure III.2. CORINE Land Cover map of the Hortobágy National Park—the Puszta World Heritage property (2018).

Archaeological data can also contribute to understanding the development of a landscape. However, the number of archaeological sites actually found within the boundaries of the Hortobágy landscape is rather low, most probably because the area was suitable for arable cultivation only in small, loess-covered patches (Mesterházy, 2005), and the continuous vegetation cover, maintained by grazing land use over several millennia, prevented archaeological remains from being brought to the surface. In addition, there is no summary study systematically processing the basic data from the few archaeological sites actually located within the Hortobágy landscape. Paleolithic, Mesolithic material has not been found in the Hortobágy area, and the oldest Neolithic culture is the Alföld Linear Pottery (Nagy, 1998) culture (5330–4940 BC: (Hertelendi et al., 1995)), but its appearance is related mainly to the neighbouring Tisza Valley (Sherratt, 1982, 1983). Likewise, the known Late Neolithic archaeological sites are predominantly associated with the Tisza River valley and Pleistocene, loess-covered residual surfaces (Raczky & Anders, 2006, 2016). The most surveyed archaeological level is the Late Copper Age/Early Bronze Age—Pit Grave (Yamnaja) culture, which left visible traces on the surface in the form of burial mounds (kurgans) (Dani & Horváth, 2012; Horváth, 2011; Horváth et al., 2013; Zoltai, 1938). Several waves of this culture have been modelled in the Carpathian Basin (Gazdapusztai, 1968), and data have been reported from radiocarbon analysis of kurgans in the wider region between 3300 and 2600 BC (Ecsedy, 1979; Gerling et al., 2012; Tóth et al., 2018). In fact, this can be considered the first productive farming culture to appear in the whole Hortobágy region (Deák et al., 2016). Unfortunately, archaeological data from the later periods to the Hungarian Conquest (9–10th centuries AD) are scattered (Faragó et al., 2022; Masek, Serlegi, & Vágvölgyi, 2019), and most of them are not actually located in the Hortobágy landscape but rather in the surrounding, cultivated areas. The absence of data on Iron Age cultures related to the large pastoral peoples of Eastern Europe (Mezőcsát culture, Scythians) is striking, as the data available so far (Gerasimenko, Yurchenko, & Zaytsev, 2013; Kemenczei, 2001) suggest that Hortobágy could have been an ideal habitat for these cultures. Small medieval villages (destroyed during the Ottoman conquest) are also prominent and easily recognizable archaeological objects (Mesterházy, 1974; Módy, 1973, 1995/1996, 1998; Zoltai, 1925), as they were located on or close to the surface.

According to an alternative view, the process of alkalinization dates back much further in natural landscape evolution, and the contemporary measures regulating the water regime could only extend the coverage of already-existing alkaline areas of primary, natural origin. First of all, the geological, hydrogeological, geomorphological, and climatic basis of the alkalinization process had to be clarified, which required the collection and analysis of all the data and information regarding the origin of sodium salts; the chemical processes and climatic characteristics responsible for their accumulation in the close to surface soil levels; and the role of the unique geomorphology in the development of the grassland–wetland mosaic landscape of the Hortobágy region (Sümegi et al., 2013). Geological and paleontological evidence suggests that salt accumulation may have been caused by specific climatic and environmental conditions (Sümegi & Szilágyi, 2010).

Although one of the most important questions about the historicity of salt accumulation near the surface and accumulating in soils is whether the environment adapted to excess sodium developed before or after hydroregulation; travellers' descriptions and sporadic research data from the second half of the 19th century before river regulation (Boros & Bíró, 1999; Dapsy, 1869; Molnár, 2009) indicate that salt accumulation in soils and a biota adapted to the saline environment had already developed in the northern part of the Trans-Tisza region before the hydroregulation measures (Molnár, 1996, 2003, 2007, 2008, 2009; Molnár & Bíró, 1997). One of the major problems in understanding the historical aspect of alkalinization in the Carpathian Basin is that the source of alkalinization has not been correctly identified by researchers. In addition, theoretical considerations based on these foundations have completely excluded the possibility of alkalinization during the glacial periods, stating that the environmental conditions

in the Hungarian Lowlands were not favourable for the process (Mih
áltz, 1947); hence, the presence of glacial alkaline deposits and signs of prehistoric alkalization were not assumed and searched for in the Great Hungarian Plain until 1988, when a multi-proxy paleoecological study of an undisturbed core series from the eastern margin of the Hortobágy, which was obtained via multiproxy paleoecology, succeeded in identifying an alkaline paleosol horizon dated between 30-40,000 years beneath the glacial loess deposits (Sümegi, 2001). Subsequent analyses revealed the presence of minerals typical of alkaline soils, such as gypsum, polyaluminates, and amorphous silica gel, supporting the assumptions established in the field (Sümegi, 1997). These data provided consistent evidence that conditions favourable to alkalization may have developed during the last glacial cycle, dated to MIS3, as part of intense, brief interstadial warming: the Dansgaard–Oeschger cycle (Sümegi, 1989). Cores taken from Bronze Age burial mounds have also revealed the presence of buried chernozem and alkaline soils in the study area in the Early Holocene (Szilágyi, Náfrádi, & Sümegi, 2019).

Since previous data and studies generally included only a part of the salt landscape's development over time (Sümegi, Bodor, & Törőcsik, 2005), we searched for a region for sampling where the whole sequence of changes and the complete evolution of the salt landscape could be captured. This place was found in the Kunkápolnás Marshland area, in the territory of Kunmadaras Town.

3.2. Materials and methods

Alkaline habitats cover an area of ca. 10,000 km^2 in several parts of the Great Hungarian Plain, including the Danube–Tisza and the Körös–Maros Interfluves. The area of Hortobágy is the largest coherent occurrence of these habitat types in Europe, covering an area of ca. 2300 km^2 (Figure III.3). The first national park in the Carpathian Basin was established here in 1973 and was followed by several international designations, such as the UNESCO Biosphere Reserve, the Ramsar Convention, and the Natura 2000 network of the European Union. In 1999, the Hortobágy National Park—the Puszta was inscribed on the World Heritage List of UNESCO as a cultural landscape, as it maintains intact and visible traces of its traditional land use forms over several thousand years and illustrates the harmonious interaction between people and nature.

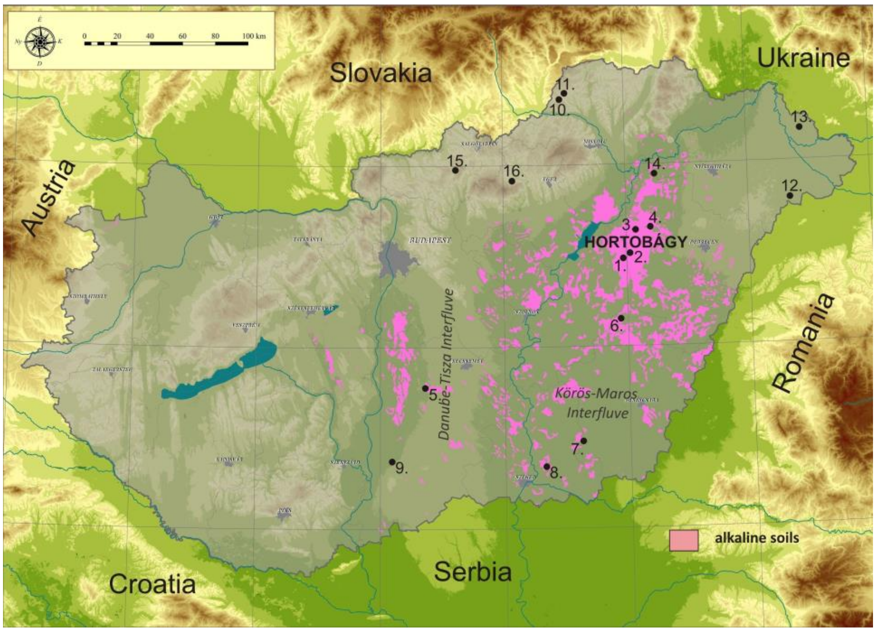

Figure III.3. Distribution of salt accumulation areas in Hungary and the location of undisturbed core points in Hungary

1 = Kunkápolnás marsh, Kunmadaras; 2 = Halas Basin, Hortobágy; 3 = Pap-ere, Hortobágy; 4 = Fecske meadow, Balmazújváros; 5 = Lake Kolon, Izsák (Sümegi et al., 2011); 6 = Lake Kiri, Ecsegfalva (Willis, 2007); 7 = Lake Fehér, Kardoskút (Sümegi et al., 1999); 8 = Pana-hát, Maroslele (Sümegi, Persaits, & Gulyás, 2012); 9 = Hajós (Jakab, Sümegi, & Magyari, 2004); 10 = Kis–Mohos, Kelemér (Willis et al., 1997); 11 = Nagy–Mohos, Kelemér (Magyari et al., 2010); 12 = Bátorliget fen, Bátorliget (Willis et al., 1995); 13 = Nyírjes fen, Csaroda (Sümegi & Törőcsik, 2010); 14 = Sarló-hát, Tiszadob (Magyari et al., 2010); 15 = Nádas Lake, Nagybárkány (Sümegi & Törőcsik, 2010); 16 = Nyírjes Lake, Sirok (Gardner, 1999)

In the northern part of the Trans-Tisza region, in the centre of the salt build-up region, species-rich halophilous vegetation developed both in dry and marshy areas (Borhidi, 2007). Levels of salt accumulation were detectable in the higher, drier, predominantly grassy levels of the earth pyramid layers of a Yamnaja culture burial mound and in the deepest areas (meadows) of the studied region (Figure III.4). Since the target area of sampling was a bombing range until August 1991, and Hungary was under Soviet military occupation (1956–1991), no correct map of the area could be made, which is why a digital elevation model of the drilling site was prepared at first (Figure III.5).

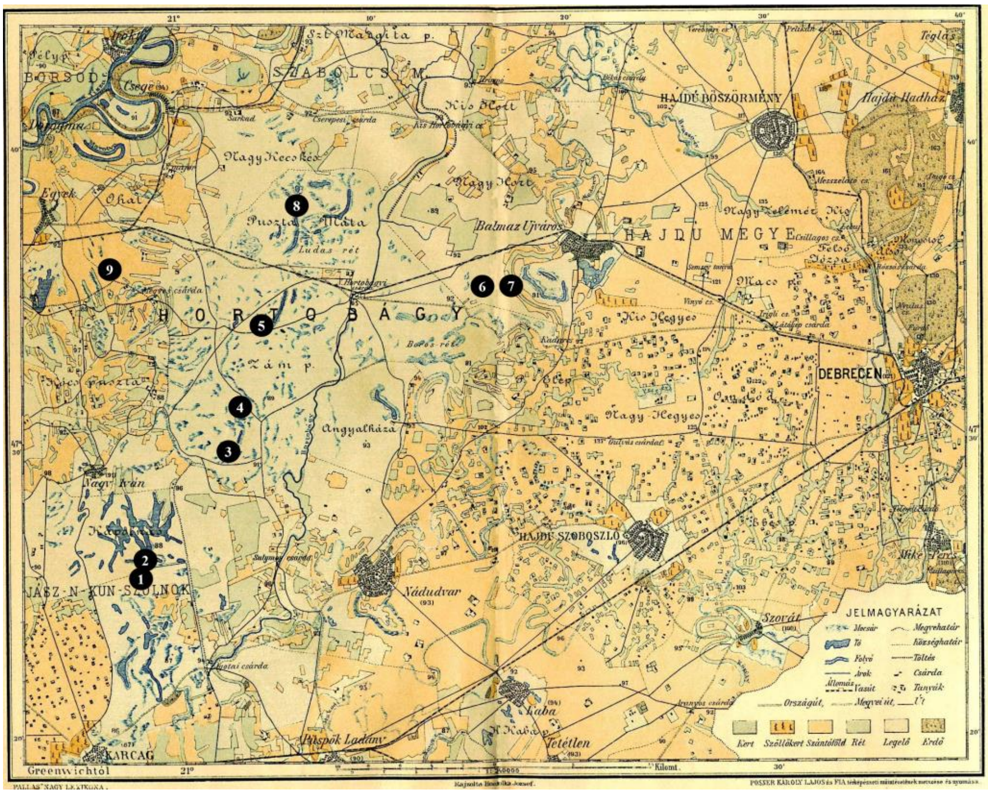

Figure III.4. Map of the wider Hortobágy region and surroundings (Ábrányi, 1895) prepared before the major river regulations and creation of fishponds with undisturbed core points.

1. Ecse mound at Karcag/Kunmadaras (Yamnaja culture burial hill); 2 Kunkápolnás marsh near Kunmadaras with the analyzed paleochannel (Róna Basin); 3. Halas Basin (paleochannel); 4. Faluvég mound (Yamnaja culture burial hill); 5. Kungyörgy Lake (paleochannel); 6. Szálka mound (Yamnaja culture burial hill); 7 = Fecske meadow (paleochannel); 8. = Pap-ere (paleochannel); 9. Csípő mound (Yamnaja culture burial hill). Legend items of land cover/use categories: Mocsár = Marsh; Tó = Lake; Folyó = River; Kert = Garden; Szőllőkert = Vineyard; Szántóföld: Arable land; Rét = Meadow; Legelő = Pasture; Erdő = Forest

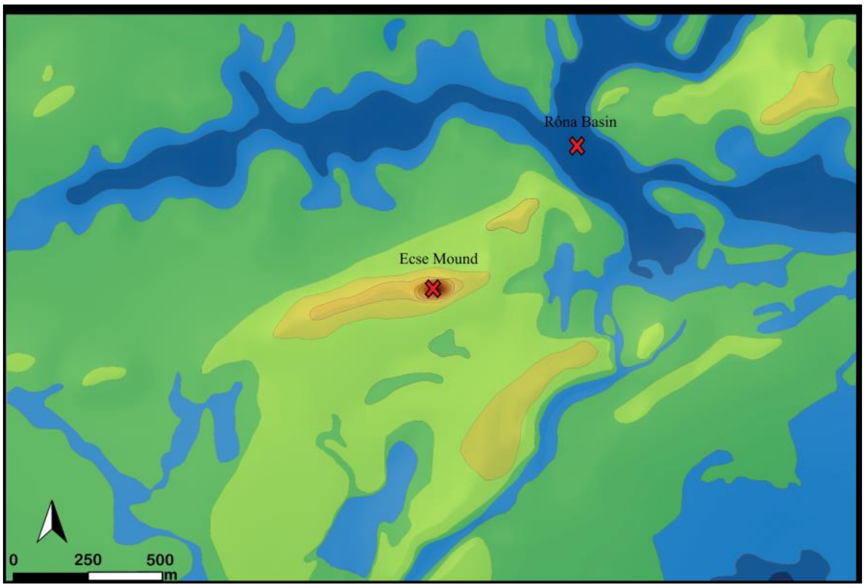

Figure III.5. Digital surface model of the southern part of the Kunkápolnás marsh system. x, undisturbed core points. Coordinates and altitudes above Baltic sea level—Róna Basin: 47.429540° N, 20.969391° E, 87.2 m; Ecse mound: 47.425279° N, 20.963044° E, 94.5 m.

The undisturbed core-drilling site was located at the edge of the Kunkápolnás marsh complex and in the middle of a backfilled embankment across one of the paleochannels of the swamp. The embankment was constructed in 1958, and the surrounding area was used as a bombing range and had human-disturbed surfaces, in particular, thousands of bomb craters. However, the embankment protected the underlying stratigraphic sequence, so we could use the most complete data set possible from the sedimentary assemblage accumulated up to the beginning of the Neolithic for our paleoecological study. We also used our drone images to map the morphological evolution of the area and to show the development of the vegetation. The drone images were taken at an average altitude of 500 m with a DJI Mavic 2 Pro drone and a Hasselblad L1D-20c camera. The sampling sites correspond to abandoned and infilled paleochannels fringing the open vegetation of alkaline grasslands (Figure III.6).

Figure III.6. Drone image of the southern part of the Kunkápolnás marsh system (bird's eye view from the south) (drone photo: Attila Szilágyi). ● undisturbed core point (Róna Basin).

Samples were taken in winter to avoid possible pollen contamination, and they were subjected to sedimentological, geochemical, palynological, malacological, and plant macrofossil and ^{14}C chronological analyses. The independent chronology established suggests that paleoenvironmental changes can be dated back to 50,000 cal BP years.

In the Hortobágy region, undisturbed sediment sequences were sampled from 9 different sites (Figure III.4), including the 10 m long core of the Kunmadaras–Kunkápolnás marsh (marked as no. 1 in Figure III.3 and no. 2 in Figure III.4) using a special double-walled core head with a diameter of 10 cm. The main lithostratigraphic characteristics of the sediment sequence were determined and analyzed. For the description of the cores, the internationally accepted system and symbols developed by Troels-Smith for unconsolidated sediments were used (Troels-Smith, 1955). For the description of the sediment sequence and the development of the figures, a protocol was followed (Vári, Gulyás, & Sümegi, 2023).

The organic matter (OM, LOI500), inorganic matter (IM, LOIres), and carbonate (CC, LOI900) contents of the samples were determined based on the loss on ignition method (Dean, 1974). The core was sampled at 2 cm sampling intervals, providing a total of 501 samples. The bulk samples were subjected to magnetic susceptibility testing (Oldfield, 1978). The magnetic susceptibility of the samples was measured at 2 kHz using a Bartington MS2 magnetic susceptibility meter with an MS2E high-resolution sensor (Dearing, 1994; Xu, 2012). Each sample was measured three times, and the average values of magnetic susceptibility were calculated and reported. Each sample was measured three times, and the average values of magnetic susceptibility were calculated and reported. Grain size data from pretreated sediment core samples were obtained at 2 cm (501 samples) intervals for 42 grain-size classes via laser diffraction using the OMEC Easysizer20 laser grain size analyzer (Njalsson, 2018).

The concentrations of selected major and trace elements were determined using flame and graphite furnace atomic absorption spectroscopy. Radiocarbon dates of the sequences were obtained using AMS (accelerator mass spectrometry) analysis. The radiocarbon ages of twenty-one samples were analyzed at the Nuclear Research Center of the Hungarian Academy of Sciences (Debrecen, Hungary) and the Direct Radiocarbon Laboratory (DirectAMS, Seattle, Washington, USA). Sample preparation and measurement protocols are described in detail by Hertelendi et al. (Hertelendi et al., 1989) and Molnár et al. (Molnár, Janovics, et al., 2013). Prior to graphitization, samples were pretreated with weak acid (2% HCl) to remove surface impurities and carbonate coatings. Raw dates were calibrated using the Intcal20 calibration curve (Reimer, 2020), using the atmospheric data of Stuiver et al. (Stuiver, 1998). The original dates (^{14}C) are indicated as uncal BP, while the calibrated dates are indicated as cal BC and cal BP. Age–depth modeling and the estimation of the sedimentation rate (accrate.depth) were conducted using RBacon 2.5.8 (RBacon) in RStudio (RStudio) Build 461 and the IntCal20 calibration curve (Blaauw, 2011).

The cores were also subsampled at 2 cm/4 cm intervals for pollen analysis. Samples of 1 cm3 were obtained using a volumetric sampler and processed for pollen analysis (Berglund, 1986). Some pollen samples were analyzed using the Zólyomi–Erdtman $ZnCl_2$ method, which is the most commonly used method in Hungary (Zólyomi, 1952), as this method provides better results than others for oxbow lake sediments (Magyari, 2002). A known amount of exotic pollen was added to each sample to determine the concentration of identified pollen grains (Stockmarr, 1971). To ensure a statistically manageable sample size, at least 300 grains per sample were counted (excluding exotics) (Maher, 1972). Charcoal abundance was determined using the point count method (Clark, 1982). Tablets with known *Lycopodium* spore content (from Lund University, Lund, Sweden) were added to each sample to calculate pollen concentrations and accumulation rates. Pollen types were identified and modified according to Moore et al. (Moore, 1991), Beug (Beug, 2004), Kozáková and Pokorny (Kozáková & Pokorný, 2007), supplemented by examinations of photographs by Reille (Reille, 1992, 1995, 1998) and reference material held in the Hungarian Geological Institute in Budapest. The analysis of local pollen zones and the statistical interpretations were carried out with the Psimpoll software package (version 4.26) created Benneth (Bennett, 2005). For macrobotanical studies, QLCMA analyses (Barber, 1994; Sugita, 1994) were used. For the quarter-malacological analyses, the methods, assessments, and recent distribution data of Ložek (Ložek, 1964), Sparks (Sparks, 1964), Alexandrowicz (Alexandrowicz, 2004; Alexandrowicz, 2014), Krolopp (Krolopp, 1965, 1973, 1983), and Welter-Schultes (Welter-Schultes, 2012) were applied, and the samples were pooled at 16 cm intervals to achieve a minimum of 100 per sample. The overall study procedure was based on the approach of Birks and Birks (Birks & Birks, 1980). The sedimentological, geochemical, pollen, macrobotanical, and quarter-malacological material, as well as the geochronological results, were used to reconstruct local and regional evolutionary events over the last 50,000 years.

It must also be acknowledged that watersheds in floodplains subject to recurrent flooding receive large amounts of so-called “alien” pollen from distant areas, which greatly distorts the final pollen spectrum (Fall, 1987; Hall, 1989). Consequently, these paleochannels are far from being ideal pollen traps. The extent of “pollen pollution” is highly dependent on the depth and extent of flooding and the vegetation of the flooded area, which can distort the reconstruction of local and regional vegetation. To control and limit the potential bias as much as possible, our work used the analysis of plant macrofossils that provide information on vegetation that has been destroyed and preserved in situ. In this way, elements of the previously in situ flora could be separated from potential regional and extra-regional elements. Paleovegetation can be reconstructed from pollen data using several approaches. For our purposes, the key goal was to assess the extent to which the surrounding landscape and region are occupied by forest–steppe or steppe, as opposed to a closed forest (Magyari et al., 2010). In our work, the so-called biomization method (Prentice, 1996) was used, complemented by an indicator taxa approach to infer the potential local presence of steppe (Magyari et al., 2010; Magyari, 2011).

According to the biomization approach (Prentice, 1996), steppe indicator pollen taxa are predominantly composed of herbaceous taxa typical of steppe grasslands. Although their occurrence was used as further evidence for the local presence of open stands, such conclusions should be drawn with caution. Many steppe indicator taxa (herbs) are insect or self-pollinated species and produce relatively small amounts of pollen (e.g., *Allium*, *Astragalus*, *Euphoria*, *Verbascum*) and, thus, are under-represented in the pollen spectra. Other steppe indicators are wind-pollinated and produce abundant pollen (e.g., *Artemisia*, *Gramineae*, *Chenopodiaceae*) and are, therefore, over-represented. Based on the work of Beug (Beug, 2004), Kozáková and Pokorný (Kozáková & Pokorný, 2007), and Magyari et al. (Magyari et al., 2010), the following steppe indicator pollen taxa were identified in the core sequence of the analyzed paleochannels: *Ajuga*, *Allium*, *Compositae* (including *Artemisia*, *Aster*-type species, and representatives of the subfamily *Cichorioideae*), *Caryophyllaceae* (including undetermined and *Dianthus*-type species), *Chenopodiaceae* (*Atriplex, Kochia*), *Euphorbia*, *Gramineae*, *Helianthemum, Inula*, *Matricaria*-type species (including *Achillea*, *Anthemis*, *Matricaria*), *Plantago lanceolata*, *Plantago major*/*P. media*, *Thalictrum, Astragalus, Trifolium pratense*-type species, *Trifolium repens*-type species, and *Verbascum*. The ultimate aim of our work was to provide a reliable reconstruction of the vegetation development of Hortobágy based on the study of local catchment basins (Sümegi, Bodor, & Törőcsik, 2005; Sümegi, Persaits, & Gulyás, 2012).

Recently, attempts have been made to extend the pollen results of oxbow lakes located in the distant floodplain of the Tisza (ca. 60 km) to the Hortobágy area (Magyari et al., 2010). These distance inferences are rather ambiguous, partly because of the taphonomic problems mentioned above and partly because the present floodplain of the Tisza is much younger (15–18,000 years) and has a morphological and geological evolution that is quite different from that of Hortobágy (Sümegi & Szilágyi, 2010).

3.3. Results

3.3.1. Geochronological results

According to the calibration of radiocarbon ages, the age of the bedrock sand dates back to 50,000 cal BP years (Figure III.7). The age of the top of the profile at 10 cm has also been slightly modified thanks to the new calibration from 403 ± 17 uncal BP years to 35,696 ± 297 uncal BP (850 cm). Thus, the Kunkápolnás 1000 cm section captures the paleoecological changes from approximately 400 years to 50,000 years in the 21 radiocarbon data (Table III.1). We focused mainly on the geochronological delineation of the LGM, MIS2, and MIS3 development in the eastern Carpathian Basin and did not specifically address the Late Glacial/Post-Glacial transition, which is the main issue of this paper. The 100 cm (10 m) long core sequence taken near Kunkápolnás (Figure III.7) provides us with information about the paleoenvironmental and paleovegetational changes in the study area during the past 50,000 years (Figures III.7 and III.8).

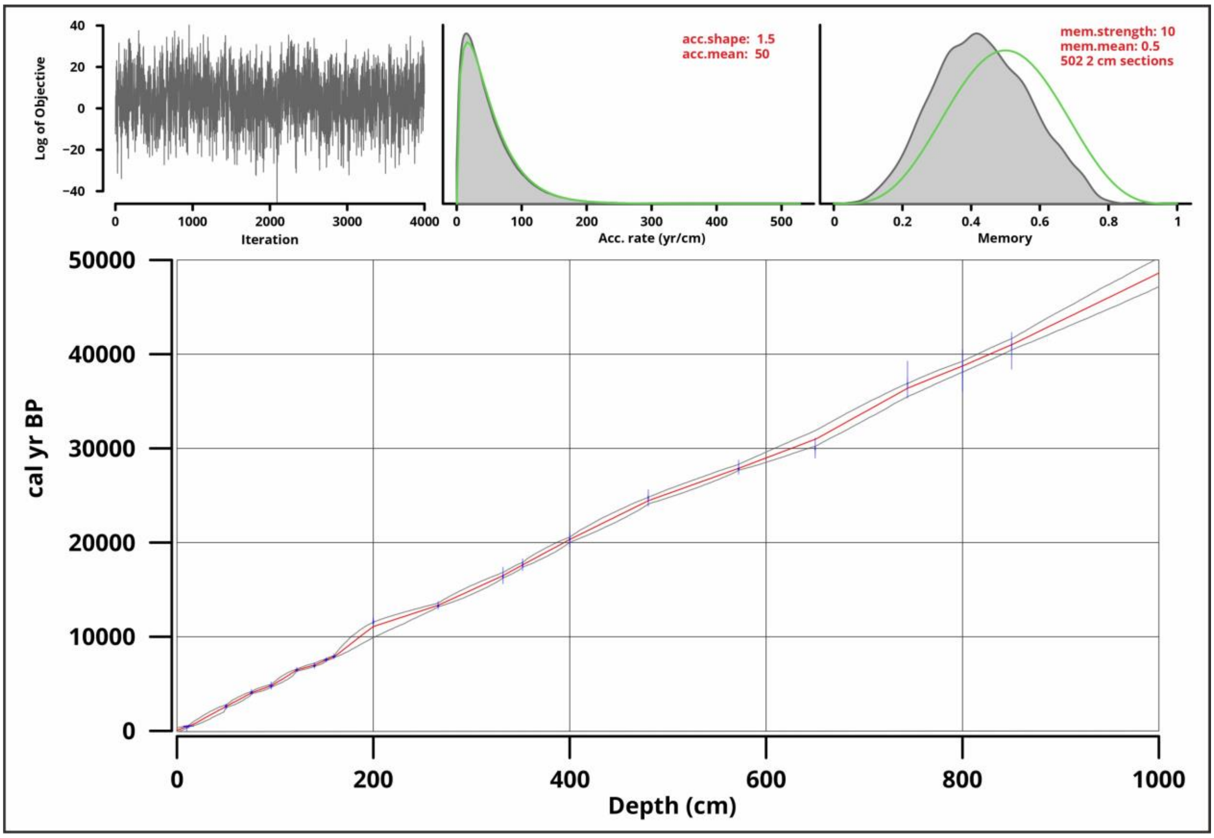

Figure III.7. Age–depth modeling and an estimation of the sedimentation rate (accrate.depth) were conducted using rbacon 2.5.8 (RBacon) in (RStudio) and the IntCal20 calibration curve (Blaauw, 2011; Reimer, 2020). Red line: linear interpolation of dated points; Vertical lines: dated samples

Table III.1. Twenty-one radiocarbon (AMS) data from undisturbed core sequence of the Kunkápolnás marsh in Hortobágy.

Cm	Type of Organic Material	Code	Uncal BP	+/−	Cal BP Interval	Cal BC/AD Interval
10	*Planorbis* shell	DeA–130891	403	17	339–506	1444–1611 AD
12	*Planorbis* shell	D–AMS21141	444	21	461–524	1426–1469 AD
50	*Planorbis* shell	D–AMS21152	2524	23	2496–2736	547–787 BC
76	*Planorbis* shell	DeA–130902	3732	20	3987–4151	2038–2202 BC
96	*Lymnaea* shell	D–AMS2113	4232	29	4649–4857	2700–2908 BC

122	*Unio* shell	DeA–130913	5696	22	6406–6552	4457–4603 BC
140	*Unio* shell	D–AMS21112	6065	26	6799–7146	4850–5197 BC
152	*Unio* shell	D–AMS21123	6698	30	7504–7655	5555–5701 BC
160	*Bithynia* shell	D–AMS21104	7067	29	7836–7965	5887–6016 BC
200	*Unio shell*	DeA–130914	10,055	33	11,357–11,803	9404–9854 BC
266	*Pisidium* shell	D–AMS21095	11,417	52	13,174–13,411	11,225–11,462 BC
332	*Pisidium* shell	D–AMS21086	13,598	70	16,197–16,654	14,208–14,705 BC
352	*Cochlicopa* shell	D–AMS21077	14,474	58	17,412–17,878	15,463–15,929 BC
400	*Succinella* shell	D–AMS21068	16,847	78	20,151–20,535	18,203–18,521 BC
480	*Trochulus hispidus*	DeA–130965	20,529	72	24,366–24,986	22,417–23,037 BC
572	*Succinella* shell	D–AMS21049	23,725	85	27,694–28,008	25,745–26,059 BC
650	*Pinus microharcoal*	DeA–131026	25,661	121	29,681–30,189	27,732–28,240 BC
744	*Helicopsis* shell	D–AMS210510	32,535	175	36,364–37,325	34,415–35,376 BC
800	*Succinella* shell	DeA–130977	33,433	232	37,455–39,161	35,506–37,212 BC
850	*Trochulus* shell	DeA–130988	35,696	297	40,158–41,323	38,209–39,374 BC

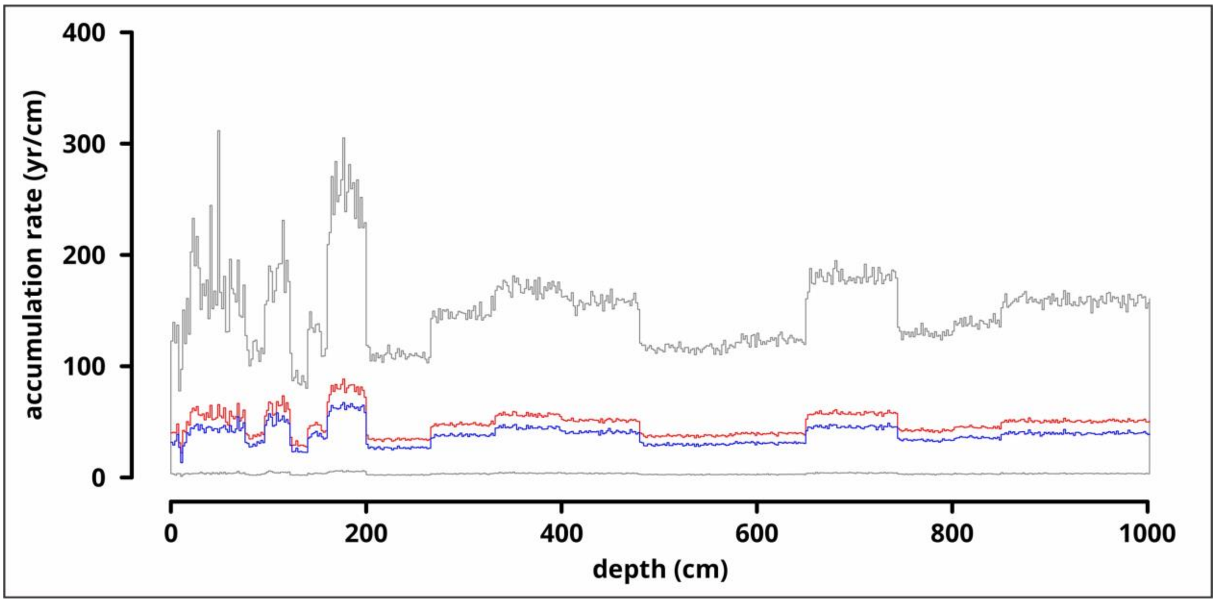

Figure III.8. Sedimentation rate (accrate.depth) made in RStudio (RStudio) with RBacon (RBacon) based on the results of age–depth modelling.
Red line: mean accumulation rates; Blue and grey lines: 95% confidence intervals.

The results obtained show that the paleochannel studied was characterized by a relatively steady and slow accumulation of clayey silt (As2Ag2), reflecting natural flood cycles over the last 50 years. Evidence of changes in sedimentation, associated with an increase in organic and clay content, is limited to the upper part of the past 5–6000 years. This suggests that relatively uniform sedimentological processes have prevailed over most of the evolution of the channel, which is advantageous from a paleoecological point of view, as the fluctuations and differences observed in the pollen and macrobotanical spectra reflect changes independent of changing geological processes (changing erosion base, selective pollen accumulation, and retention). Sedimentation rates showed relatively uniformly low values at the minimum, maximum, and mean (Figure III.8), but some faster rates were also identified. The acceleration of sedimentation rates during the glacial period is associated with the acceleration of loess accumulation phases observed in the Carpathian Basin (Figure III.8) (Sümegi et al., 2018). The increase in clay and organic matter content recorded in the upper part of the sequence may indicate anthropogenic disturbances in the basin environment, which may be attributed to the emergence of food-producing cultures (Willis, 1998), as this level appears to coincide with the appearance of Late Bronze Age–Early Bronze Age pit grave culture representatives in the study area (Szilágyi, Náfrádi, & Sümegi, 2019). Representatives of this culture are characterized by extensive animal husbandry and the construction of earth burial mounds (kurgans). One of these mounds is located 650 m southwest of the studied core of Kunkápolnás, and others associated with this culture have also been identified scattered within a radius of about 1 km from other investigated profiles in the Hortobágy area.

3.3.2. Sedimentological results

Between 50,000 and 25,000 years (1000–500 cm), the sand content indicates fluvial sedimentation (Figure III.9). The bedrock was dominated by the medium sand fraction (Figure III.9), the layer was slightly cross-bedded in the undisturbed core layer, and fluvial *Valvata piscinalis* shells were also found. It can be concluded that the analyzed bed of the Kunkápolnás marsh system (Róna Basin) was formed by the development of a riverbed. During the first 25,000 years, carbonated river sediment rich in sand and poor in finer-grained fractions accumulated in the gradually disconnected, 50,000-year-old riverbed (Figure III.9). The development of the river sediment is completely distinct from the sediments accumulated in the Tisza riverbed in terms of grain composition (Figures III.9 and III.10) and geochemical parameters (Figure III.11), which are characteristic of the Sajó and Hernád Rivers (Timár, Sümegi, & Horváth, 2005). From about 25/27 thousand years onward, the nature of sedimentation has fundamentally changed (Figures III.9–11), and sediment with a finer grain size composition has accumulated in the section. The changes in sediment composition (Figures III.9–11) indicate that the fluvial sedimentary phase has ended and that the cut-off meander phase dominated the bed formed for most of the years during MIS3. It is likely that sandy sediment accumulated in the basin, which developed in the cut-off riverbed only during major floods, and that it was the floodplain loess-like sediment that accumulated on the bank along the developed riverbed that was washed into the basin of the oxbow lake. However, it should be noted that at this time extensive soil formation took place in the region, and this has led to the formation of fossil saline soils (Sümegi, 1989, 1997, 2001; Szöőr, Sümegi, & Balázs, 1991).

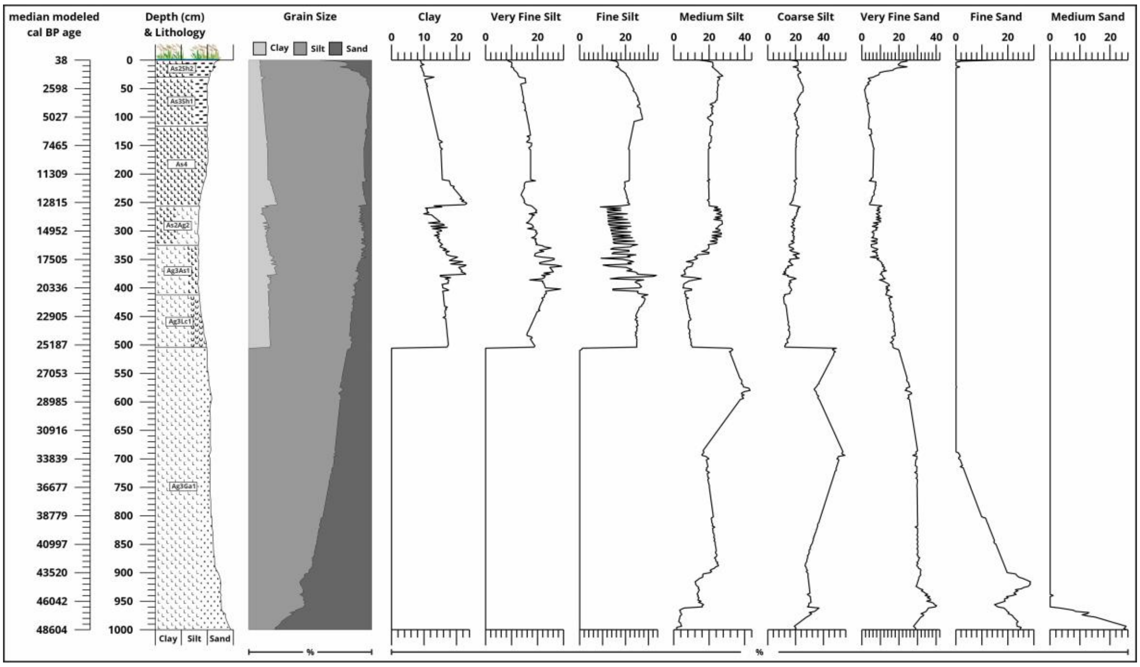

Figure III.9. Results of the grain size analysis.

Clay (<0.004 mm), silt (0.004–0.062 mm), and sand (0.062–0.5 mm) fractions in a percentage diagram and line diagrams of clay (<0.004 mm), very fine silt (0.004–0.008 mm), fine silt (0.008–0.016 mm), medium silt (0.016–0.031 mm), coarse silt (0.031–0.062 mm), very fine sand (0.062–0.125 mm), fine sand (0.125–0.25 mm), and medium sand (0.25–0.5 mm) fractions.

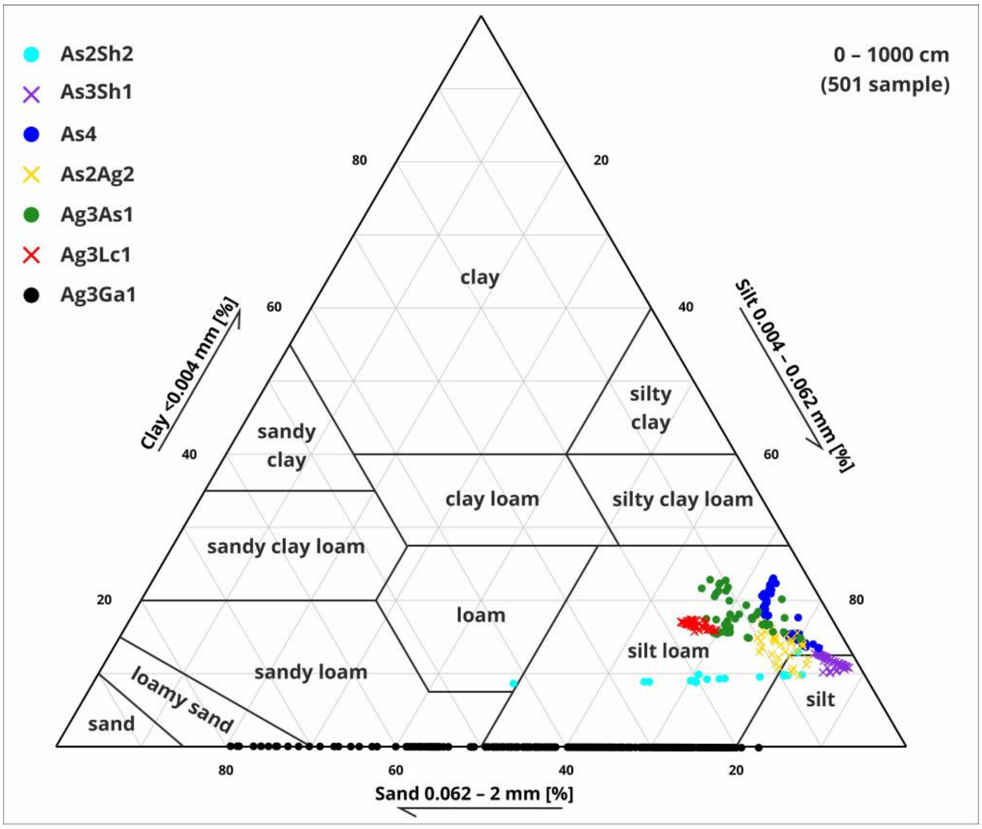

Figure III.10. Ternary diagram of clay, silt, and sand grain sizes with Troels-Smith (Troels-Smith, 1955) sediment types based on the grain size analysis.

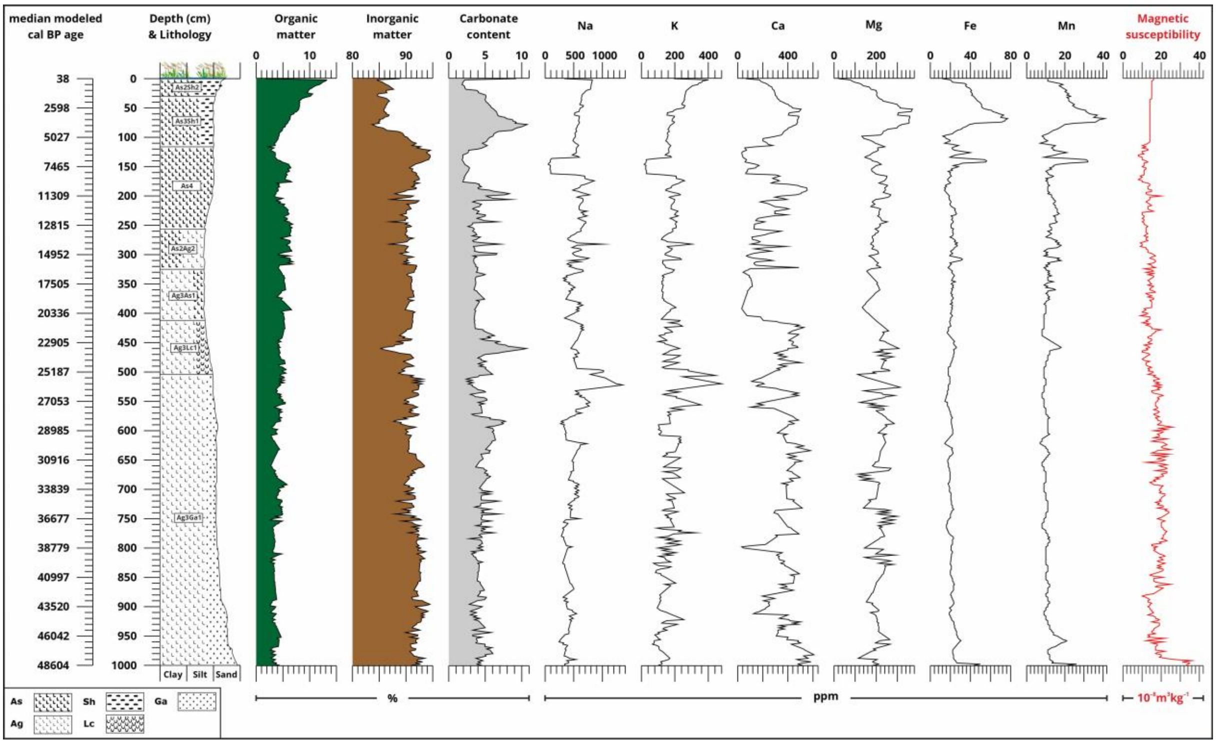

Figure III.11. Combined figure of (from left to right) the modeled median cal BP dates from the radiocarbon analysis; lithology profile based on grain size with Troels-Smith (Troels-Smith, 1955) sediment classification and depth (cm); results of the loss on ignition (Dean, 1974) with organic matter (OM), inorganic matter (IM), and carbonate content (CC); results of the geochemical (Dániel, 2004); and magnetic susceptibility analysis (Dearing, 1994).

Given continuous military activity, the area was excluded from the comprehensive geological mapping of the Hungarian Lowlands (Rónai, 1964, 1972, 1977, 1982, 1985), so our undisturbed core drilling analyses can only suggest that a saline soil level could have developed in the vicinity of the riverbed, which was transformed into a sediment basin. The material of the eolic sedimentation (Lehmkuhl et al., 2018; Lehmkuhl et al., 2021; Rónai, 1985; Sümegi, 1989, 1997) that developed in the region could have accumulated in the basin of the oxbow lake until 12,800/13,000 cal BP when the eolic sedimentation in the Carpathian Basin came to an end, meaning that, at the end of the Ice Age, polygenetic alluviation took place in the oxbow lake, which evolved over 27/25 thousand years ago. This heterogenetic sedimentation is reflected in the highly heterogeneous grain composition, from the clay to the fine sand fraction, and also in the rhythmic changes of the water-soluble element (Ca, Mg, Na, and K) content (Figures III.9–11). The rhythmic changes were completed in the Late Glacial period of the Ice Age, and we can expect steadily increasing clay, fine rock flour, and organic matter content during the Holocene.

The increase in organic matter and clay content became more pronounced from about 5000/5200 cal BP, when livestock-keeping communities colonized the area (Pit Grave culture = Yamnaja = Kurgan culture). In this period, given the human-induced soil erosion around the basin, a sharp increase in organic matter and clay content can be detected in the sediment column of the Róna Basin. Today, the riverbed is characterized by an alkaline, marshy environment.

3.3.3. Results of the pollen analysis

The entire pollen sequence, both at the end of the Ice Age and during the Holocene, is dominated by herbaceous taxa, above all, grasses (*Poaceae*), wormwood (*Artemisia*), and goosefoot species (*Chenopodiaceae*) (Figure III.12) but also by *Achillea* taxa. The cumulative proportion of arboreal species (Arbor Pollen) exceeded 60% only in two glacial levels (43–46,000 and 25–28,000 years). Both glacial forest levels were dominated by the subgenus *Pinus* (Figure III.12), as shown by anthracological analyses of charred trees recovered from fossil soils (Willis, 2000), and both glacial levels were associated with fossil soil formation (Szöőr, Sümegi, & Balázs, 1991) when the proportion of vegetation cover, especially coniferous trees, increased in the region.

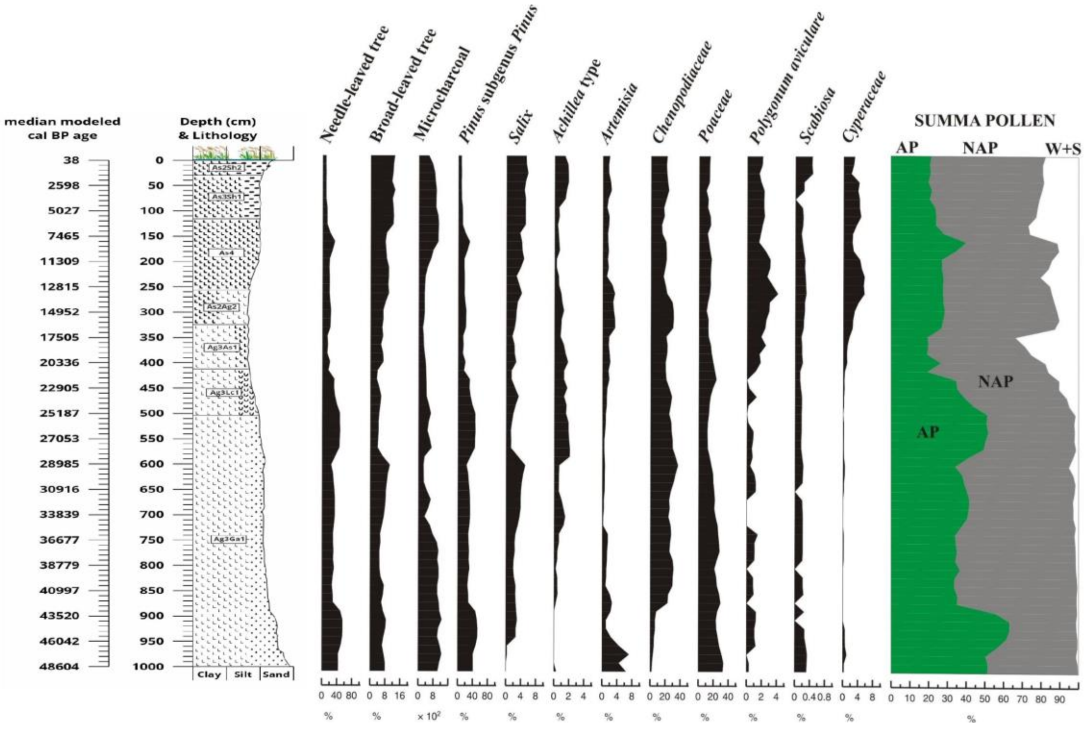

Figure III.12. Pollen diagram of Kunkápolnás for the undisturbed core sequence (selected taxa and summarized group).

A characteristic feature of the pollen section is that the alluvial–fluvial influence may have been present from 50,000 years until the end of the Ice Age (12,800 years). This suggests (Fall, 1987; Hall, 1989) that the pollen composition may have reflected a more regional relationship during the glacial period, irrespective of the diameter of the studied basin (Jacobson, 1981). However, the basin must have acted as a local pollen trap over the last 12,800 years. Yet, the Holocene pollen assemblage was dominated by herbaceous taxa, with an overall proportion of more than 40–45% in all samples. The share of broad-leaved tree pollen varied between 8 and 16% in total, and the most characteristic broad-leaved taxon in the section was the eurytopic willow (*Salix*), a softwood gallery forest element (Figure III.12).

Analysis of the pollen sequence and studies from the Eurasian forest–steppe–steppe environment (Prentice, 1985, 1992, 1988) suggest that steppe, or maximum boreal forest–steppe vegetation (Magyari et al., 2010) might have stabilized in the study area during the glacial period. Although the presence of marshy vegetation became more abundant (Figure III.12) in the Holocene, herbaceous species continued to dominate, and a predominantly temperate steppe cover developed and persisted to the present day in the study area. Fluctuations in the pollen composition indicate cooler and milder climatic phases in the sequence (Bond, 1992; Buiron, 2012; Genty, 2003; Grimm, 1993, 2006; Grootes, 1993; Svensson, 2008; Timmermann, 2010; Yiou, 1995). The cooling phases can be synchronized with the increased dominance of grasses (*Poaceae*) and, in general, non-arboreal pollen (Björck, 1998; Svensson, 2008; Walker, 1999), and in parallel with this trend, a decrease in arboreal pollen could be detected (Figure III.12). Glacial warmings are indicated by the increasing dominance of coniferous pollen. The Holocene period is reflected in a marked increase in broad-leaved pollen and charcoal abundance (Figure III.12). Given the changes in the pollen composition, the vegetation of the Hortobágy area has similarities with that of the Eurasian forest–steppe belt (Kremenetski, 2003).

As the basin is of fluvial origin, the pollen composition may have been influenced by fluvial inflow (Fall, 1987; Hall, 1989), and one has to consider the pollen input by the late glacial flooding of the Tisza river (Tímár, 2008) into the already marsh-dominated former riverbed (Magyari et al., 2010); our findings are based primarily on the AP/NAP pollen ratio. The relevant literature (Magyari et al., 2010; Tarasov et al., 2000; Tarasov et al., 1998) clearly shows that, during the warming periods, including the Holocene, when AP occurs at 50–60%, forest–steppe vegetation stabilized in the study area. Although the pollen composition can be described to be consistent with Eurasian forest–steppe, the current climate analysis of the Carpathian Basin (Szelepcsényi et al., 2018) suggests the development of a basin effect (rain shadowing) caused by the surrounding mountain range rather than by the influence of the Eurasian continental climate zone.

3.3.4. Macrobotanical results

Although Jakab has provided a detailed analysis of the pollen and macrobotanical data of the Kunkápolnás core sequence (Sümegi et al., 2013), it is reasonable to present his findings in this paper as well to complete the geochronological and sedimentological results.

From the core sequence, 2516 macrobotanical remains were recovered, the distribution of which is shown in Figure III.13. Minimal plant remains were found in the bed of the section, corresponding to riverine infilling between 50,000 and 17,500 years (1000–350 cm). The plant remains at this level were dominated by *Juncus* roots; indeterminate monocots; and other indeterminate plant fragments that could easily have leached from the river bank into the Late Glacial river system and accumulated with the leached sediment in the abandoned, infilling riverbed at the study site. The bed was characterized by low vegetation cover with highly fluctuating water levels. Among the macrofossils, roots of a sedge species (*Juncus* sp.) were found in the largest quantities.

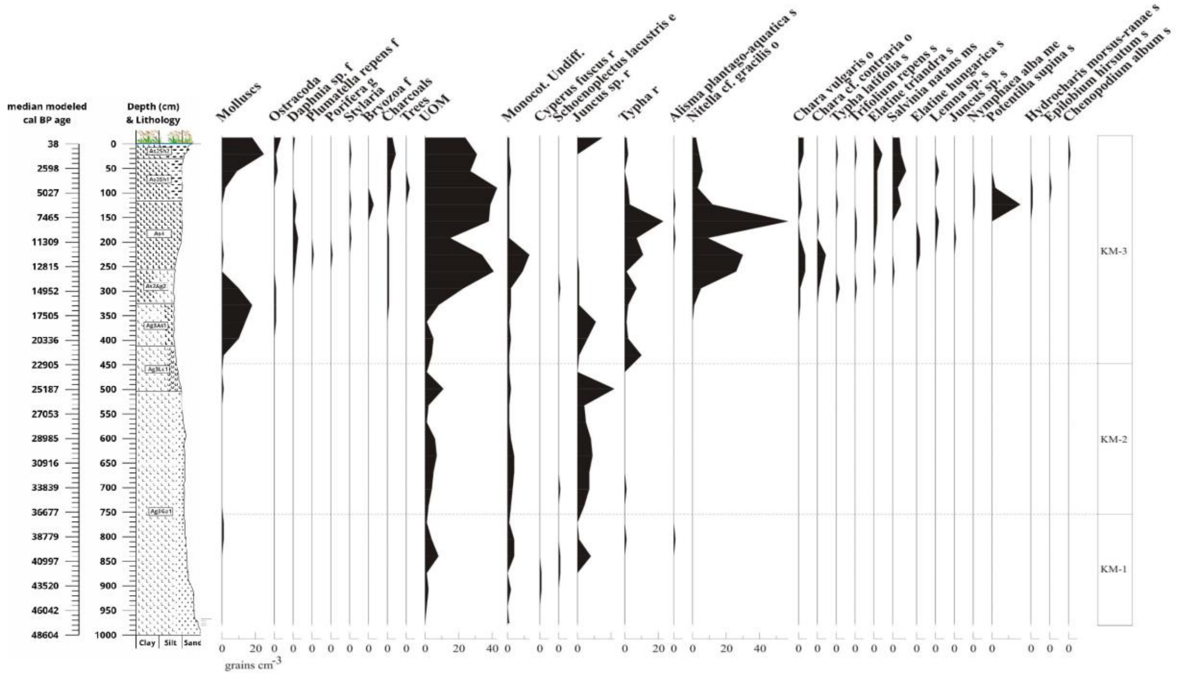

Figure III.13. Fauna and macrobotanical remains diagram of Kunkápolnás for the Róna Basin (Kunmadaras Town, Jász–Nagykun–Szolnok County) undisturbed core sequence (UOM = unidentified organic matter).

At 17,500 years, after the Last Glacial Maximum (LGM), in addition to the taxa that occupied the riverbed and formed the oxbow lake, oogonites (gyrogonites) of the *Chara* tax—above all, *Nitella* cf. *gracilis* and *Chara vulgaris*—appeared in significant numbers. As a result, we can reconstruct the formation of a mesotrophic oxbow lake (Pełechata, 2016), poor in phosphate and organic matter, from 17,500 years ago and persisting until the beginning of the Holocene (12,000–11,500 years ago). In Northern Europe, this *Chara* lake stage is generally typical of the beginning of the Holocene; however, in the case of the sedimentary deposits in the Carpathian Basin dating back to the end of the Ice Age, such as Kolon-tó near Izsák (Hungary) (Vári, Gulyás, & Sümegi, 2023), this stage had already developed in the final part of the Ice Age. In the Chara lake stage, around 15,000 years ago, terrestrial taxa, including those indicating a dry or periodically dry alkaline environment (*Trifolium repens* and *Elatine triandra* seeds), appeared (Figure III.13). The presence of elements indicating salinity suggests that alkalinization may have occurred as early as the end of the glacial period in the study area. Habitats typical of the alkaline environment may have developed along this mesotrophic oxbow lake—at the boundary between the loess grassland indicated by *Trifolium repens* seeds—and waterside mudflats, where groundwater fluctuations were (and still are) the most intense (Várallyay, 1989).

During the transition period between the end of the Ice Age and the beginning of the Holocene (between 12,800 and 11,300 cal BP), the studied floodplain was silted up, and seasonal cyclical groundwater level fluctuations may have been amplified, which appears to be demonstrated by the presence of *Elatine hungarica* seeds in the samples, indicating marked alkalinization, as this species can stay in an anabiotic stage for several years and spread during favorable periods because of shallow water cover. However, no taxa indicating deeper or permanent water cover were found in the samples. The water level could have been very low, a few centimeters at most, and the bed would have seasonally dried up. The constant presence of *Typha* species indicates a gradually warming climate. The vegetation of the marsh was poor, with the occurrence of the common water plantain (*Alisma plantago-aquatica*), a few sand cinquefoil (*Potentilla supina*), and water fern (*Salvinia natans*). Mollusk and ostracod shells were negligible. Of the mosses, *Amblystegium serpens* was found in very small numbers, often living on woody debris, but at this site, it is more likely to live on the decaying stems of some aquatic plant (e.g., *Schoenoplectus lacustris*).

Later in the Holocene (7500–5000 cal BP years), higher water levels are indicated by the appearance of the white waterlily (*Nymphaea alba*), common frogbit (*Hydrocharis morsus-ranae*), water fern (*Salvinia natans*), and duckweed species (*Lemna* sp.). Occasionally, the spiny naiad (*Najas marina*), typical of carbonate-rich waters, also appears, as well as the common bladderwort (*Utricularia vulgaris*) and water crowfoot species (*Batrachium* sp.). In open water, the presence of bryozoans and sponges, which are necessary for their colonization, is also indicative of denser vegetation. Cladocerans and ostracods also appeared in open water, with the most typical species being *Daphnia pulex*, *Cerodaphnia* sp., and *Simocephalus vetulus*. *Juncus* has been replaced by *Typha* in the riparian zone, while the common water plantain was found to be abundant in the marshy vegetation, along with the presence of mint species (*Mentha* sp.) and the fine-leaved water dropwort (*Oenanthe aquatica*). It can be assumed that the marsh may have been periodically filled with water and that typical Holocene aquatic riparian zonation developed without any productive human influence.

At 5000 cal BP years, the same indicator elements appeared, but in a different proportion than before. Mudflat communities spread, and the number of mollusk and ostracod shells increased, while the abundance of carophytes decreased. The amount of fly ash is the highest in this section, indicating more intensive land use. This change is fully associated with the appearance of Pit Grave culture communities, as indicated by the nearby Ecse mound (kurgan). In parallel with the emergence of pastoral communities of the Pit Grave culture, human communities that engaged in productive farming (livestock keeping) also appeared in the landscape of Hortobágy. Species indicative of seasonally drying mudflats are permanently present in the samples, such as the Hungarian waterwort (*Elatine hungarica*), the three-stamen waterwort (*E. triandra*), the sand cinquefoil (*Potentilla supina*), the dwarf clubrush (*Schoenoplectus supinus*), and the white clover (*Trifolium repens*). This community is very typical of regularly drying up or only periodically refilled beds. The occurrence of saltbush species (*Atriplex hastata/sagittata*) also indicates the development of silty, possibly alkaline, soils.

3.3.5. Malacological results

Samples were taken and processed at 8 cm but were evaluated and aggregated at 16 cm to reach a statistical minimum of 100 individuals per sample (Krolopp, 1983). More than 7800 specimens of 27 molluscan taxa were retrieved from the sequence. Up to the LGM level, i.e., up to 23,000 years, the malacological material (Figure III.15) is dominated by taxa preferring flowing water (rheophilous group), and then, in the transitional period of the Ice Age and the Holocene, by aquatic Mollusca that require more water cover but are less sensitive to water quality and belong to the catholic group according to Sparks (Sparks, 1964). Direct fluvial recharge probably occurred in the area for up to 23,000 years, after which, the proportion of elements indicating permanent water cover became dominant; i.e., fluvial recharge became more distant (Szöőr, Sümegi, & Balázs, 1991), but the area may have received significant additional water through rhythmic flooding after the development of the LGM level. At the same time, the slum group, which also tolerated intermittent water cover, also appeared in the sequence (Figure III.15), but only in the second half of the Holocene, during the last 5000 years, when it became dominant within the malacofauna, suggesting a tripartite subdivision of the aquatic fauna composition within the sequence. The bedrock of the sequence indicates riverine recharge between 50,000 and 23,000 years ago, after which, pond species with permanent water cover (*Bithynia tentaculata*, *Anisus vorticulus*, *Gyraulus albus*) dominated, but the members of the slum group also appeared, reflecting cyclical water-level fluctuations.

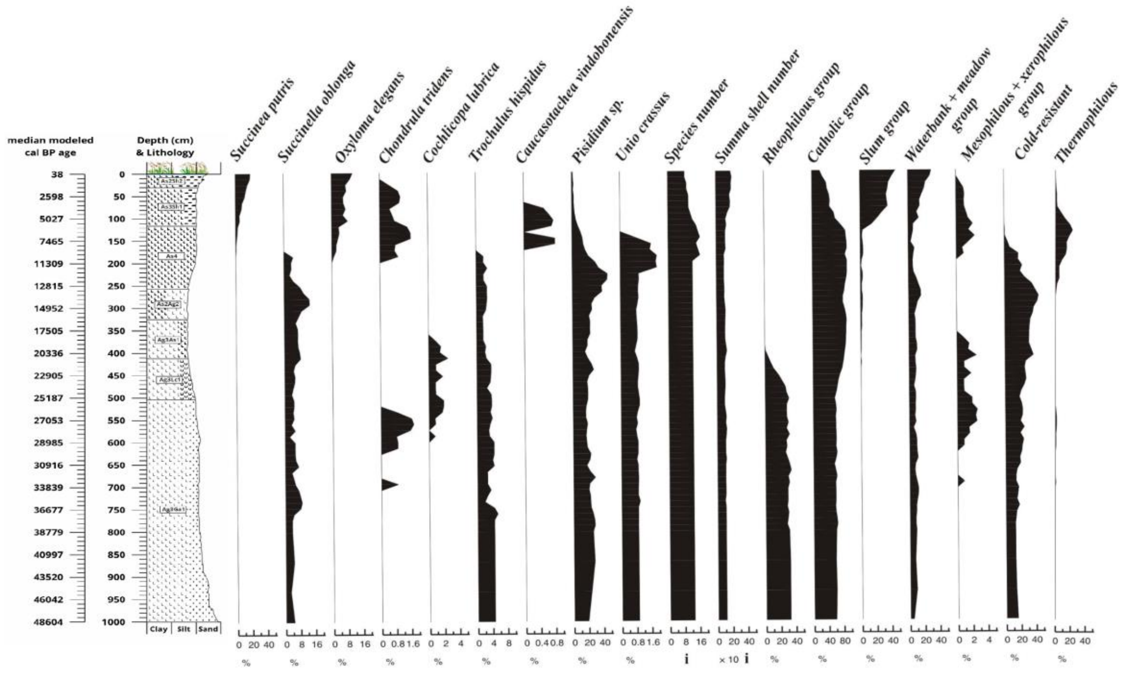

Figure III.14. Quarter-malacological diagram 1: terrestrial taxa and quartermalacological-based paleoecological groups in the Kunkápolnás undisturbed core sequence.

The water supply in the second half of the Holocene was cyclical, and the studied river basin may have periodically dried out during this period. Fauna elements living in a riparian environment were present throughout the sequence, but their proportion increased only in this last phase. The mesophilous and xerophilous taxa became dominant in the Holocene as well, but in the glacial period, between 29,000 and 24,000 years, such species (e.g., *Cochlicopa lubrica*, *Chondrula tridens*) also appeared in the sequence during the intensification of soil formation in the study area (Figure III.14). During the glacial period, the proportion of cold-resistant elements (*Lymnaea glabra*, *Valvata pulchella*, *Succinea oblonga*, and *Trochulus hispidus*) was highly significant. These taxa coexisted with thermophilous elements during the glacial/Holocene transition and at the beginning of the Holocene, before disappearing from the sequence in the Early Holocene.

Cepaea vindobonensis, a character species of the Pannonian forest–steppe (Bába, 1983), appeared at the beginning of the Holocene, indicating the spread of Pannonian forest–steppe vegetation. At this time, the number of species in the malacofauna increased, and beyond the appearance of 9–10 taxa at the end of the glacial period, species numbers exceeded 10 taxa per sample during the Pleistocene/Holocene transition and the Early Holocene. This increase in species may have been due to the survival of glacial species that did not become extinct, whereas dispersing elements had already appeared in the section during the Holocene (Figures III.14 and III.15). From the end of the Early Holocene (7500 cal BP) onward, species abundance declined sharply, and the terrestrial fauna became dominated by thermophilous, mesophilous–xerophilous elements in the steppe-like environment that evolved during the last 7500 years, which was certainly dry for part of the year. This mosaic environment may have stabilized after 5000 cal BP years in the second half of the Holocene when the number of individuals doubled to more than 200 individuals per sample.

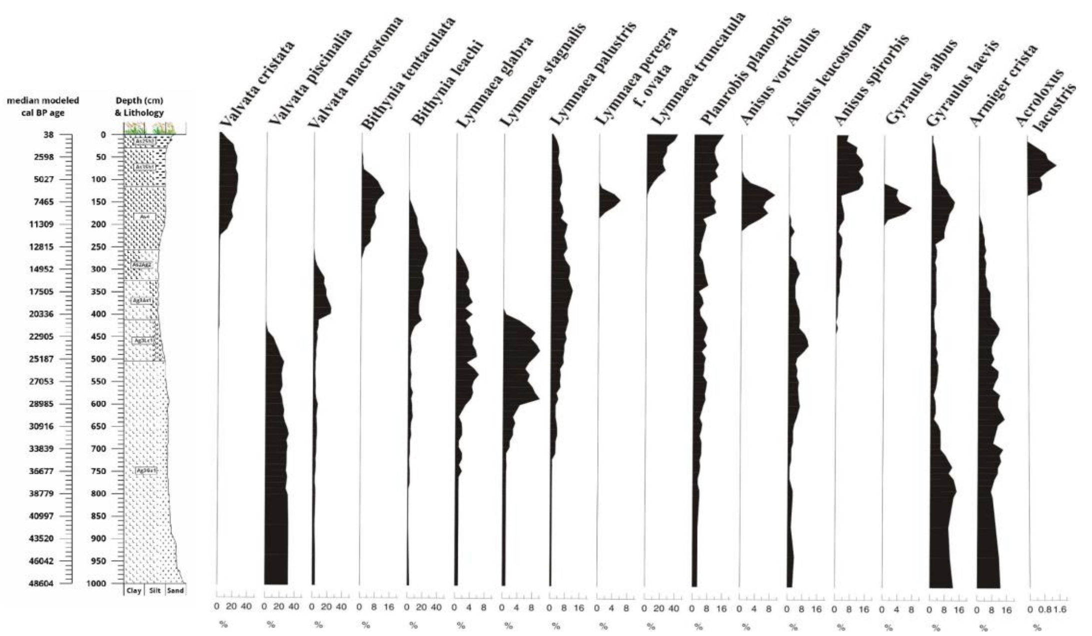

Figure III.15. Quartermalacological diagram 2: freshwater taxa in the undisturbed Kunkápolnás core sequence.

In the second half of the Holocene, the proportion of the group associated with a marshy environment also increased, along with the maximum of aquatic species indicating temporary water cover, and then, the vegetation of the Kunkápolnás marsh may have stabilized for the last 5000 years in the study area.

3.4. Discussion

A complete fluvial cycle has been revealed (Molnár, 1960, 1964, 1965, 1967, 1973; Timár, Sümegi, & Horváth, 2005) in the studied riverbed of the so-called Róna Basin at the edge of the Kunkápolnás marsh complex, which evolved from the carbonate fluvial sand sediment of the bedrock that formed about 50,000 years ago into a Holocene, organic-rich clayey rock silt (marsh) sedimentary layer. Trends in sedimentation parameters can be synchronized with the accumulation of major sediment layers, changes in the sediment-forming environment, and the climatic cycles of the past 50,000 years (Björck, 1998; Bond, 1992; Buiron, 2012; Genty, 2003; Grimm, 1993; Grootes, 1993; Walker, 1999).

Pollen analysis was carried out on the entire undisturbed core section, the results of which are completely different from those of the previously published pollen studies in Hungary (Gardner, 1999; Jakab, Sümegi, & Magyari, 2004; Magyari et al., 2010; Sümegi et al., 2011; Sümegi, Persaits, & Gulyás, 2012; Sümegi & Törőcsik, 2010; Willis, 2007; Willis et al., 1997; Willis et al., 1995). This became particularly obvious when based on the biomization approach (Prentice, 1985, 1996); the pollen composition of the undisturbed core drilling was compared with the pollen composition of the recent Eurasian biomes (Figure III.16) and with the arboreal pollen (AP) from pollen cores in the Carpathian Basin (Figure III.17). These results show that a boreal forest–steppe with a dominance of Pinus diploxylon-type pollen was established in the glacial period in the studied Kunkápolnás region. Previous pollen analyses have shown that Pinus-dominated taiga forest patches developed along former living river branches (Sümegi et al., 2011), and the pollen diagram (Figure III.16) shows that the pollen composition of Kunkápolnás is typical of the recent Eastern and Western Eurasian forest–steppe/steppe boundary. The pollen, macrobotanical, and malacological data suggest that the first patches of alkaline vegetation were established during the cold maximum of the glacial period (Figures III.12–15) in the study area.

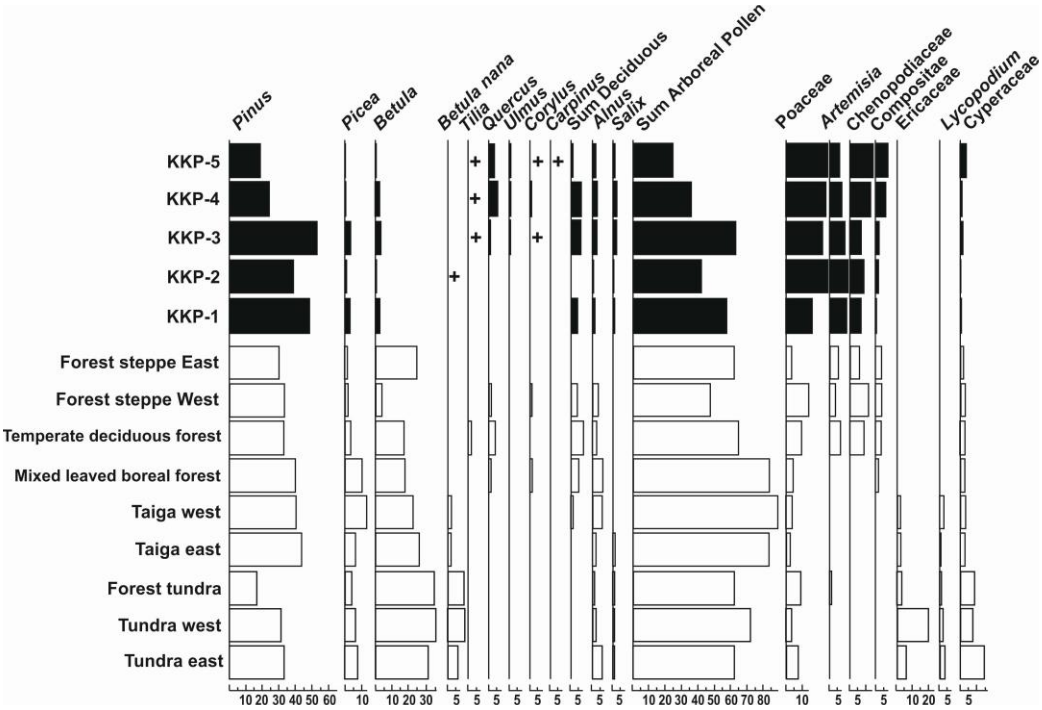

Figure III.16. Zone-average pollen frequencies of selected pollen types from Kunkápolnás marsh plotted alongside mean values of major pollen types in various vegetation zones of the former Soviet Union. Surface pollen spectra are redrawn from (Peterson, 1983).

KKP-1 = pollen spectra from Dansgaard–Oschger (Greenland Interstadial) events in the sequence of Kunkápolnás marsh; KKP-2 = pollen spectra from Heinrich (Greenland Stadial) events in the sequence of Kunkápolnás marsh; KKP-3 = pollen spectra from the Late Glacial Age in the sequence of Kunkápolnás marsh; KKP-4 = pollen spectra from early postglacial time (Early Holocene Age) in the sequence of Kunkápolnás marsh; KKP-5 = pollen spectra from late postglacial time (Late Holocene Age) in the sequence of Kunkápolnás marsh.

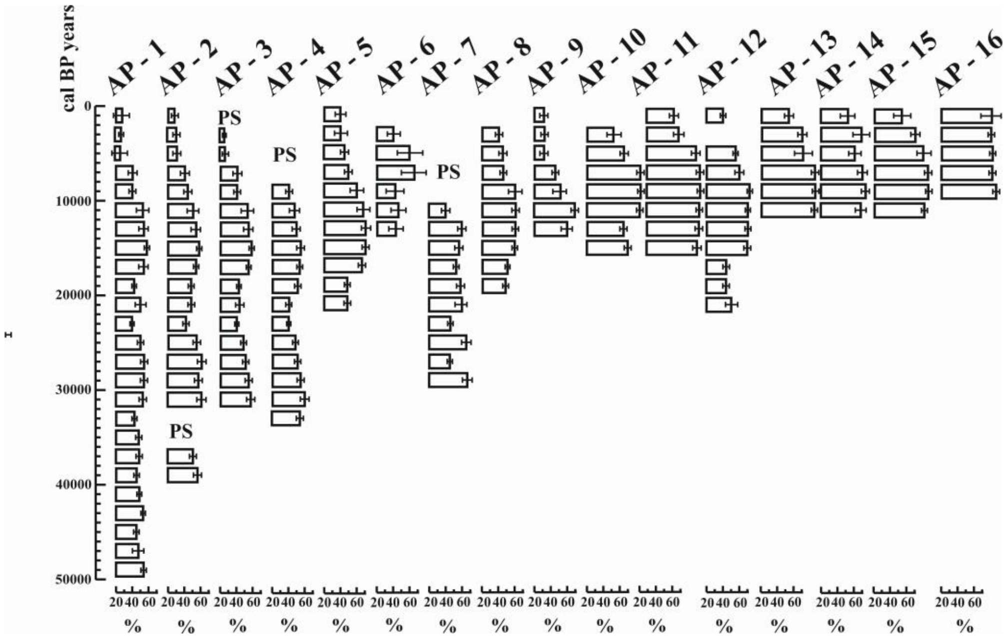

Figure III.17. Abundance of pollen of woody taxa in Holocene records from Hortobágy and the Carpathian Basin. The range of values, as well as an indication of the most frequent value, is plotted for each site for 2 millennial intervals from 50,000 to 0 cal BP years. AP = arboreal pollen.

1. Kunmadaras, Kunkápolnás marsh; 2. Hortobágy, Halas Basin; 3. Hortobágy, Pap-ere; 4. Balmazújváros, Fecske-rét; 5. Izsák, Lake Kolon (Sümegi et al., 2011); 6. Ecsegfalva, Lake Kiri (Willis,

2007); 7. Kardoskút, Lake Fehér (Sümegi et al., 1999); 8. Maroslele, Pana-hát (Sümegi, Persaits, & Gulyás, 2012); 9. Hajós (Jakab, Sümegi, & Magyari, 2004); 10. Kelemér, Kis-Mohos (Willis et al., 1997); 11. Nagy-Mohos, Kelemér (Magyari et al., 2010) 12. Bátorliget, fens (Willis et al., 1995); 13. Csaroda, Nyíres fen (Sümegi & Törőcsik, 2010); 14. Tiszadob, Sarló-hát (Magyari et al., 2010); 15. Nagybárkány, Nádas Lake (Sümegi & Törőcsik, 2010); 16. Sirok, Nyírjes Lake (Gardner, 1999).

However, general alkalinization and a drier steppe phase became widespread in the region with the gradual warming of the climate from the Late Glacial to about 12,000–13,000 years, together with the process that resulted in the dominance of the *Matricaria* pollen type *Chenopodiaceae* and *Artemisia* pollen (Figure III.12). This was also the time when plant remains (*Elatine* sp.) typical of alkaline vegetation and drier loess steppes appeared (Sümegi et al., 2013). Then, at the beginning of Holocene warming, from about 11,000 years onward, a change in the dominance of pollen and the appearance of vegetation remains typical of drier loess–steppe environments (*Trifolium repens*, *Atriplex*) resulted in the expansion of dry steppe and alkaline marsh patches. Based on the analysis of the radiocarbon-dated pollen and macrobotanical and malacological material, a mosaic habitat complex of alkaline marshes and steppes, without any human influence, was established in the studied region at the end of the Ice Age, during the turn of the Late Glacial and the Early Holocene. It appears that in contrast to the mountain rims and hill regions of the Carpathian Basin (Willis et al., 1997), no forest phase was established in the area at the beginning of the Early Holocene, but a mosaic vegetation structure of a forest–steppe developed, where trees occurred only at the margins of the former watercourses, while their cut and transformed beds gradually filled up with sediments. These data are in good agreement with the previously reported paleoecological data on the mosaic environmental structure of the Carpathian Basin (Sümegi, 2005). However, it seems that local environmental factors (micromorphology, alkaline soil, morphology, and groundwater) were extremely strong in the Kunkápolnás region, amplifying the essentially climate-driven alkalinization process (Figure III.18), and therefore, the alkaline patches in the Pannonian forest–steppe region were formed on a regional scale (Szelepcsényi et al., 2018; Szelepcsényi, Breuer, & Sümegi, 2014a, 2014b) under the influence of locally evolved edaphic factors.

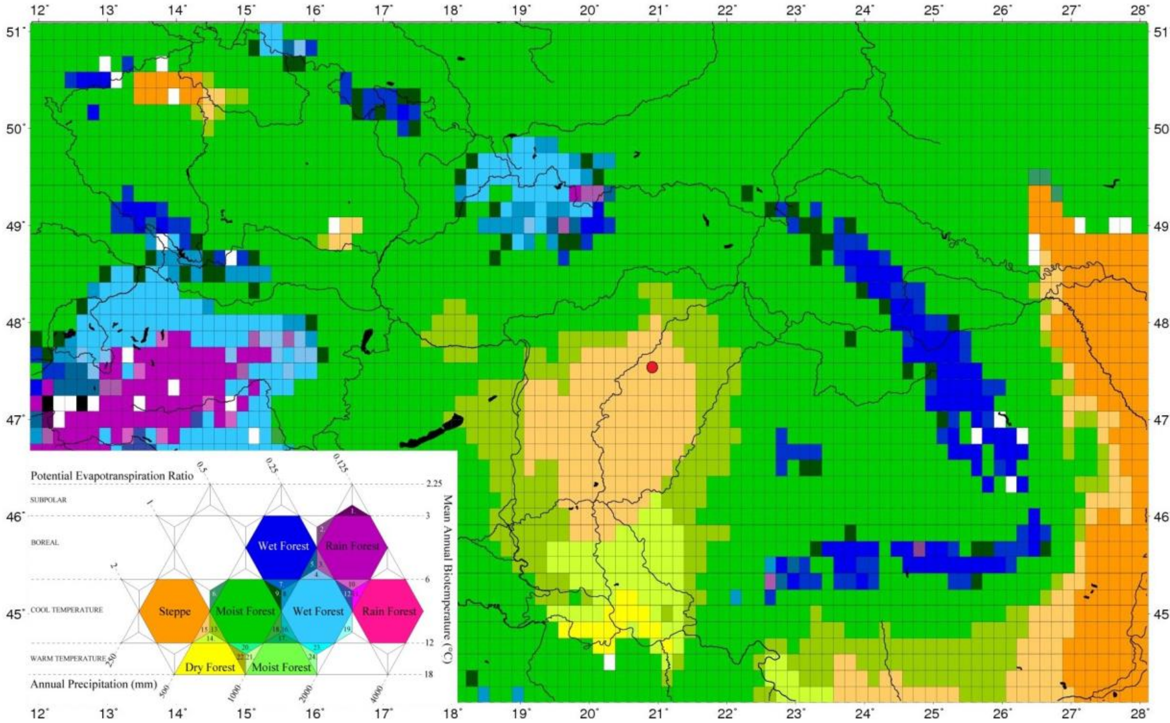

Figure III.18. The Holdrige type classification of the vegetation of the Carpathian Basin (Szelepcsényi et al., 2009a, 2009b; Szelepcsényi et al., 2018; Szelepcsényi, Breuer, & Sümegi, 2014b).

The first pastoralist cultures (Pit Grave culture = Yamnaja = Kurgan culture), which appeared around 3300 BC, only reinforced ongoing natural processes (Szilágyi, Náfrádi, & Sümegi, 2019) but did not fundamentally transform the vegetation of the Kunkápolnás region. Similarly, there were no significant changes in the landscape character of the region over the following millennia, when the land management by domestic animals gradually increased and eventually completely took over habitat management, i.e., the grazing role of large ungulates, such as the aurochs and the European bison, which became extinct during the Holocene (Németh et al., 2017).

Significant negative changes have been brought about to the natural areas of the wider Hortobágy region by the river management and agricultural intensification interventions of the last two centuries, including the drainage of marshes, the irrigation of pastures, and the creation of fishponds and rice fields. Hortobágy National Park, Hungary's largest protected area, was established in 1973 in the central part of the region, which has been relatively little affected by these interventions, and the natural alkaline grassland–wetland complexes continue to dominate the landscape to this day (Figure III.2). The foundation of Hortobágy National Park 50 years ago put a halt to these negative processes. Since then, the site management organization, the Hortobágy National Park Directorate, initiated and implemented several habitat restoration projects aiming to preserve and restore the degraded natural vegetation mosaics. As a result of these consequent conservation efforts, water supply systems for altogether 5000 hectares of marshes have been established, and more than 1000 km of disused channels, dykes, and ditches were eliminated in the already 80,000 ha area of the National Park. These already-implemented, landscape-scale conservation measures, together with the recently planned restoration of the water regime of the central part of the Hortobágy area, will hopefully enable the conservation of this unique habitat complex's mosaic structure, along with the diverse fauna it hosts, for future generations.

In light of the recent scientific results providing evidence on the primary, natural origin of the alkaline grassland–wetland complexes of the site, as well as based on the limited occurrence of alkaline and sodic areas in Eurasia (Boros & Kolpakova, 2018), the relevant Hungarian authorities might consider the nomination of the Hortobágy National Park—the Puszta property for the World Heritage List under the following natural criteria as well.

Criterion (vii): The flat and open landscape of Hortobágy National Park is an area of exceptional natural beauty, representing the highest scenic quality, with pleasing and dramatic patterns and combinations of landscape features, which provides it a distinctive character, including aesthetic qualities and topographic and visual unity.

Criterion (viii): The site is an outstanding example that represents the natural landscape and vegetation development of the Late Quaternary stage of Earth's history, including significant ongoing geological processes in the development of landforms and significant geomorphic features.

Criterion (x): Hortobágy National Park contains the most significant natural habitats for the in situ conservation of biological diversity in the temperate steppe zone, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

Chapter 4: Revision of the age of construction phases of a mound dated to the late Copper - early Bronze Age in Eastern Hungary relying on ^{14}C-based chronologies

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Radiocarbon, Vol 60, Nr 5, 2018, p 1403–1412
DOI:10.1017/RDC.2018.107

Abstract

Ecse Mound is a burial mound in the Hortobágy region of eastern Hungary. Built by prehistoric nomadic peoples from the east, it now stands on the border between two modern settlements. The construction of the mound was assumed to be related to representatives of the Pit Grave Culture populating the area between the Late Copper and Bronze Ages. This theory considered similarities in shape, orientation, and stratigraphy of this mound with other absolute-dated ones in the Hortobágy region alone. The mound comprises two construction layers as indicated by magnetic susceptibility and on-site stratigraphic observations. According to detailed sedimentological, geochemical analyses of samples taken from the bedrock, artificial stratigraphic horizons, and the overlying topsoil, there is a marked similarity between the soil forming the body of the mound in both artificial horizons and the underlying bedrock soil. In contrast the pedological, geological character of the modern topsoil is utterly different. According to our dating results, the uppermost stratigraphic horizon is coeval with the absolute-dated mounds in the region, assigning it to the period of the Pit Grave Culture. However, the lower anthropological horizon is older and dates to between the Early and Late Copper Ages.

4.1. Introduction

Burial and dwelling mounds were the very first features subjected to incipient geoarchaeological studies (Forchhammer, Steenstrup, & Worsaae, 1851; Jefferson, 1783; Vanuxem, 1843). Mounds are among the first studied objects of Hungarian archaeology too (Rómer, 1868a, 1868b, 1868c, 1878). Since the early period of archaeological excavations determination of the date of origin has been the most important aspect of mound research, as not only the type but also the time of construction displayed large-scale variance. The Hungarian term "kunhalom"[2] (Gárdonyi, 1893, 1914; Gyárfás, 1870; Győrffy, 1921; Horvát, 1825; Jerney, 1851) is a catch-all category into which all types of mounds have been thrown without consideration to their function or date of origin (Barczi et al., 2009; Dani & Horváth, 2012; Makkay, 1964; Pető & Barczi, 2011; Tóth & Tóth, 2003; Tóth, 2006). This issue can only be tackled if the initial phase of each research includes stratigraphical and chronological analyses, so the very function and age of the mound are revealed (Sümegi, Bede, & Szilágyi, 2015a; Sümegi et al., 2015b). After setting up a stratigraphy using sedimentological, geochemical, and geophysical methods, a chronology is set up using absolute dates. A precise chronology can only be achieved by radiocarbon analyses (Dani & Horváth, 2012; Ecsedy, 1979; Gazdapusztai, 1968; Gulyás, Sümegi, & Molnár, 2010; Molnár et al., 2004; Molnár & Svingor, 2011; Sümegi & Hertelendi, 1998). Additional information can be obtained with the OSL analyses (Liritzis et al., 2013) of wattle-and-daub fragments or pottery remains conserved in the layers. It is important to note though that pottery and wattle-and-daub fragments piled up with the soil can originate from the very same culture that created the mound itself, but also from earlier cultures. Thus, OSL analysis of the pottery and wattle-and-daub fragments may result in the incorrect conclusion that some layers are older than their actual age (Gazdapusztai, 1968).

In addition, uncertainty of OSL measurements is too high compared to ^{14}C analysis rendering them unsuitable for the construction of some hundred or a couple of thousand year-resolution chronologies for archeological periods of the younger Holocene. These skewed results can be rectified by mass radiocarbon or AMS dating on organic materials (Barczi et al., 2012; Dani & Horváth, 2012; Molnár et al., 2004; Molnár, Rinyu, et al., 2013) derived from the grave

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[2] Meaning „Cumanian mound".

(wooden structure, bulrush shroud covering the corpse) or on the humus content of the piled-up soil.

In this paper results of a comprehensive stratigraphic work complemented by absolute chronology based on ^{14}C AMS analyses on samples from the Ecse Mound (Sümegi, 2012) are discussed along with age-depth models built via Bayesian analysis using models that seem to be best suited for capturing the deposition rates characterizing mound formation.

4.2. Location and characteristics of the site

The Ecse Mound is in NE Hungary in the Hortobágy 12km north-northeast to the town of Karcag (N47°25′31.11″, E20°57′47.71″) at a height of 93.5m ASL. The mound is 5.5m high with a length of 75.5m and width of 67.5m (Figure IV.1). The mound occupies a Pleistocene lag-surface wedging into the Holocene alluvia of the Hortobágy. It rises on the eastern end of a slightly elevated, elongated loess ridge that is clearly separable from its surroundings based on its vegetation and geomorphology. Traces of a ditch that was created when the earth was piled up on the mound are barely perceivable (Sümegi, 2012).

Ecse Mound is mentioned (Benedek & Zádorné Zsoldos, 1998; Gyárfás, 1883) first in a charter describing village borders from 1521 (in the form “Echehalma”). In the Early Modern Era it was the border point between the villages of Asszonyszállás and Kápolnás. Today it lies on the administrative border between Karcag and Kunmadaras; the borderline breaks in an angle on the top of the mound.

Manuscript maps from the 18th–19th centuries and later printed maps consistently represent the whole area of the mound as pasture (Bede et al., 2016). In the beginning of the 20th century, however, its southern half was ploughed due to the increased demand for arable land, and in 1943, this is the picture presented. Socialist large-scale agriculture and the consequent largescale landscape transformations did not spare the Ecse Mound, either: in the 1950s rice parcels were established on its southern side, traces of which are still visible. In the 1960s the area served again as pasture and has been used the same way until today (Bede et al., 2016). In the wider vicinity of the mound farmsteads, dirt roads, ditches, embankments, grasslands and lower lying swamps can be found. The mound rises above its marshy, alkaline environment, thus most of its surface is covered by a loess grassland association (*Salvio nemorosae-Festucetum rupicolae*) and its derivatives. Arboreal vegetation is only sparsely present in the area. The mounds are characteristic refugia for the survival of such habitat types, having a significant conservation value, even the plant association itself (Horváth et al., 2013; Illyés & Bölöni, 2007; Joó, 2003).

4.3. Materials and methods

4.3.1. Field Survey, Sampling

The first step of our work included the collection of historical and high-resolution regional maps of the area to create a digital elevation model of the surrounding landscape (Figure IV.1). This was followed by a field survey during which mapping data points have been recorded on the mound itself to provide an up-to-date DEM of the mound for further geomorphological studies. This was complemented by probe coring to reveal the spatial variability of the stratigraphy before actual sampling via undisturbed cores.

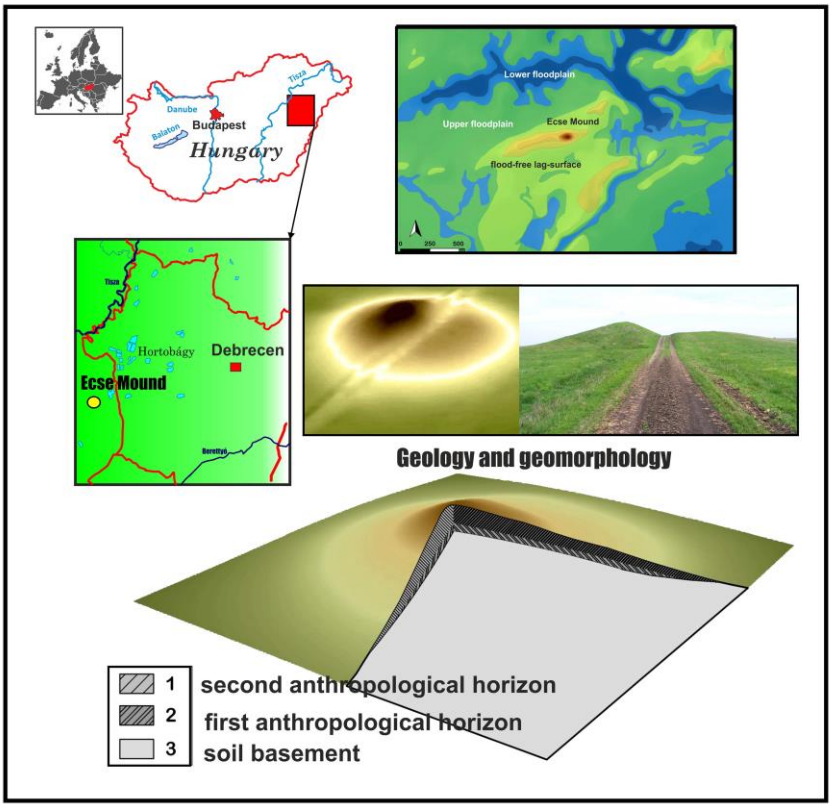

Figure IV.1. Location, geomorphology and observed stratigraphy of the Ecse Mound in the Hortobágy, NE Hungary.

Sediment types were determined and described on the field using the Troels-Smith system (Troels-Smith, 1955), internationally accredited for paleoecological works. Both wet and dry colors were determined (Munsell, 2000).

4.3.2. Magnetic Susceptibility

Measuring magnetic susceptibility (MS) has proved to be one of the best methods to yield reliable stratigraphic data in case of studies of mounds (Bede et al., 2014; Bede et al., 2015; Sümegi, 2012, 2013; Sümegi, Bede, & Szilágyi, 2015a). For this study samples were taken at 2–4-cm intervals. Prior to the start of the measurement, all samples were crushed in a glass mortar after weighing. Then samples were cased in plastic boxes and dried in air in an oven at 40°C for 24 hr. Afterwards, magnetic susceptibilities were measured at a frequency of 2 kHz using an MS2 Bartington magnetic susceptibility meter with a MS2E high resolution sensor (Dearing, 1994). All the samples were measured three times and the average values of magnetic susceptibility were computed and reported.

4.3.3. Grain-Size Distribution and Loss on Ignition

The grain size composition of sedimentological samples was carried out using the laser-sedigraph method. First the samples were pre-treated with 1 M HCl and H_2O_2 to remove $CaCO_3$ and organic content respectively. A more detailed description of the pre-treatment process is given by Konert and Vandenberghe (Konert & Vandenberghe, 1997). All the samples were measured for 42 intervals between 0.0001 and 0.5mm using an Easy Laser Particle Sizer 2.0 and Fritsch sieves in Szeged (Hungary). For LOI examination sub-samples were taken at every 2–4-cm intervals and the loss on ignition method was applied, commonly used for the analysis of the organic and carbonate content on calcareous sediments (Dean, 1974).

4.3.4. Radiocarbon dating

Six shell samples were submitted for radiocarbon dating taken from major stratigraphic units as depicted in Table IV.1 and Figure IV.1. AMS ^{14}C dating measurements were done in the internationally referenced AMS laboratory of Seattle, WA, USA (Table IV.1). The dead carbon effect was negligible in case of our chosen taxa because certain herbivorous gastropods are known to yield reliable ages for dating deposits of the past 40 ka with minimal measurement error on the scale of perhaps a couple of decades (Pigati et al., 2013; Pigati et al., 2004; Pigati, Rech, & Nekola, 2010; Újvári et al., 2014). This uncertainty is preserved even after calibration yielding us dates on the sub-centennial scale. Considering the presently available multicentennial resolution of prehistoric archeochronology this level of uncertainty suited our needs.

Preparation of the samples and the actual steps of the measurement followed the methods of (Hertelendi et al., 1989; Hertelendi, Sümegi, & Szöőr, 1992; Molnár, Janovics, et al., 2013). Shells were ultrasonically washed and dried at room temperature. Surficial contaminations and carbonate coatings were removed by pre-treatment with weak acid etching (2% HCl) before graphitization. Conventional radiocarbon ages were converted to calendar ages using the software OxCal 4.2 (Bronk Ramsey, 2009) and the most recent IntCal13 calibration curve (Reimer et al., 2014). Calibrated ages are reported as age ranges at the 2-sigma confidence level (95.4%). A U_Sequence age-depth model was constructed for the upper part of the sequence representing the actual mound via Bayesian modelling using OxCal (Bronk Ramsey, 2009). As these layers were artificially built up we may presume a relatively uniform deposition rate related to the events of mound formation. In our models we used a U_Sequence model assuming strictly uniform deposition for the anthropogenic stratigraphic horizons.

Table IV.1. Conventional (year BP) ^{14}C ages for Ecse Mound.

	Conventonal ^{14}C ages		Fraction of modern	
Material	(BP yr)	1σ	pMC	1 σ error
Chondrula tridens	531	29	93.60	0.34
Chondrula tridens	2926	25	69.47	0.11
Unios crassus	4281	27	58.69	0.20
Chondrula tridens	5475	30	50.58	0.19
Chondrula tridens	5804	24	48.55	0.17
Anisus spirorbis	10,266	37	28.00	0.13

4.4. Results

4.4.1. Lithology and Stratigraphy

The substrate sediment is comprised of fine sand and coarse-grained silt with substantial carbonate, low clay and organic content between 10 and 8m. The sediment also contained tiny iron-manganese precipitation particles in the form of granules and coating. The overlying stratigraphic unit (8–7.8m) is composed of very fine to fine sands with medium sand intercalations. This unit is overlain by yellowish brown calcareous clayey silt (7.8–5.8 m.) Between 5.8 and 4.15m a meadow chernozem soil was encountered with well-developed A and B horizons. This is seen in a sudden increase in Corg values as well (Figure IV.S1). This soil gave the base of the artificial mound. Start of the first man-made horizon was noted between the depths of 4.15 and 4.10m also seen in elevated Fe content and magnetic susceptibility values (Figure IV.S1). This horizon is overlain by another soil layer marking a different disturbance phase starting around 2.9–2.8m. Start of this second soil layer is recorded in a drop of magnetic susceptibility and soluble Fe values and a peak in Corg (Figure IV.S1).

The soil built up in the first two anthropological horizons is of polygonal structure with hydromorphic qualities that is very similar to the A and B layers of the underlying meadow chernozem soil. The organic content is significantly higher in this horizon (Figure IV.S1), also showing an abrupt change of the soluble elements and insignificant level of carbonate content.

However, the elemental and carbon concentrations must have changed considerably during the soil development process, and later due to ground water table fluctuations and precipitation percolating into the soil. Another disturbance layer was noted just below the modern topsoil (1.5m) containing pottery as well as wattle and daub fragments. The last 1.5m is the modern chernozem type topsoil. The sedimentological and geochemical properties of the topsoil overlying the artificial horizons is completely different from the artificially built (Figure IV.S1). This is in line with earlier pedological and sedimentological observations made on other kurgans of the Hortobágy and Nagykunság (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013) that chernozem soil has developed on top of the artificial pile of kurgans. This type of top soil and related loess grassland association (*Salvio nemorosae-Festucetum rupicolae*) form the topmost layer of the kurgan.

4.4.2. Chronology

The AMS-based chronology assessment of the Ecse Mound was investigated from the bedrock to the first few artificially built-up horizons. According to the dates obtained, the bedrock of the base soil of the mound is dated to the Early Holocene (10,207–9877 cal BC). The upper part of the base soil of polyhedral structure was placed into the Late Neolithic as seen from radiocarbon dates received for a local steppe dwelling mollusc (4723–4558 cal BC) (Figure IV. 2; Table IV.3: Phase 1). The next age corresponds to the first date at the boundary of the lower anthropological horizon (Figure IV.2; Tables IV.1–2). According to the modelled ages this boundary could be placed between 4446–4263 cal BC; i.e. Early Copper Age (Vaday, 2004). Shell fragments of the aquatic bivalve *Unio crassus* found in the top boundary of the first artificially piled layer of terrestrial sediment suggest external, most probably human influence. ^{14}C studies on freshwater shells from Neolithic mounds in SE Hungary indicated no significant dead carbon effect on obtained ages at the centennial scale (Gulyás, Sümegi, & Molnár, 2010). Modelled ages for this level representing the uppermost part of the first anthropological layer yielded ages 2922–2878 cal. BC (Figure IV.2; Table IV.2). As these two ages are bracketing the first anthropological horizon we may presume that the first anthropological horizon must have been built up during the Early Copper Age. The 2nd anthropological horizon clearly postdates the level marking the start of this horizon (Figure IV.2; Table IV.2). This must have been built up during the latest phase of the Late Copper Age. Thus, based on our dates the mound must have been constructed by a local community of the Pit grave (Yamna) Culture (Ecsedy, 1979; Gazdapusztai, 1968; Horváth et al., 2013; Vaday, 2004) inhabiting the area between the late Copper Age–Bronze Age period.

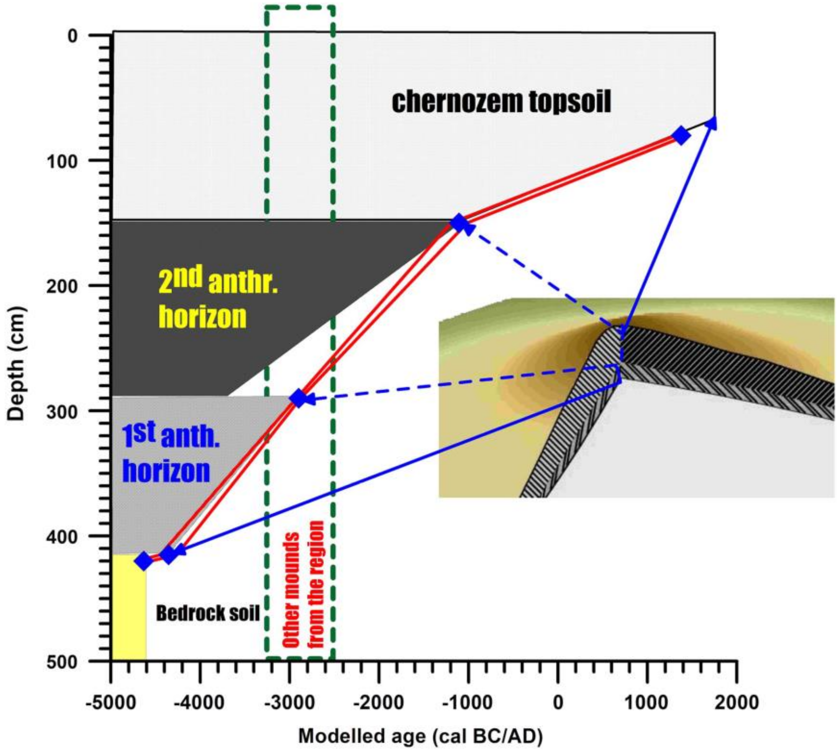

Figure IV.2. Constructed age-depth model for the mound.

Table IV.2. Modelled ^{14}C ages (cal BC/AD) for the individual stratigraphic horizons at the 2σ (95.4%) confidence level.

U_Sequence	Depth	Modeled ages (cal BC/AD) from (2σ)	to (2σ)	Agreement (%)	Congruence (%)
Start		–10,207	–9877		95
			Phase 1		
D-AMS 6514	580	–10,207	–9877	89.1	95
D-AMS 6515	420	–4713	–4552	89.3	96
			Phase 2		
D-AMS 6517	415	–4446	–4263	100.7	97.3
D-AMS 6516	290	–2922	–2878	99.1	98.8
			Phase 3		
D-AMS 6518	150	–1195	–1017	94.5	97.9
D-AMS 6519	80	1316	1439	91.9	98.7
End		1316	1439		98.7

Table IV.3. Conventional (year BP) and calibrated (cal BC/AD) ^{14}C ages from different kurgans around Ecse Mound in the Great Hungarian Plain (Gazdapusztai 1966–1967; Ecsed 1973, 1979; Dani and Nepper 2006; Horváth et al. 2008, 2013; Dani and Horváth 2012).

		Conventional ^{14}C ages		Calibrated ages at the 2σ (95.4%) level (cal BC/AD yr)	
Sites	Cultural allifiation	yr BP	1σ	From	To
Tiszavasvári-Gyepáros	Pit Grave III. phase	4355	35	3087	2899
Tiszavasvári-Deákhalom	Pre Pit Grave II. phase	4350	40	3089	2894
Tiszavasvári-Deákhalom	Pre Pit Grave II. phase	4430	30	3326	2926
Hajdúnánás-Tedej-Lyukashalom	Pre Pit Grave II./III. phase	4270	40	3012	2705
Hajdúnánás-Tedej-Lyukashalom	Pit Grave III./IV. phase	4210	35	2901	2677
Hajdúszoboszló-Árkushalom	Early Pit Grave III. phase	4385	35	3095	2910
Balmazújváros-Hortobágy- Árkus-Kettőshalom	Early Pit Grave III. phase	4320	35	3020	2888
Hortobágy-Ohat-Dunahalom	Early Pit Grave III. phase	4030	35	2832	2470

4.5. Discussion

Mounds were constructed in the Hortobágy and its wider region as early as 3300 BC (first appearance of the peoples of the Pit-Grave Culture or Pre-Pit Grave Culture) until as late as the15th century, which is a 4900–5000-yr timespan.

There have been assumptions (Bede et al., 2014; Bede et al., 2015) before the current chronological study that the Ecse Mound had been built by communities of the Pit-grave (Yamna) culture (Gimbutas, 1980; Merpert, 1974; Rassamakin, 1994) considering the similarities in shape, orientation and stratigraphy of this earth-pyramid, and comparative geomorphological research of other mounds in the Hortobágy region (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013). According to our investigations the first phase of mound construction could be placed to the Early Copper Age, while the second part dates to the Late Copper Age, i.e. the time of first infiltration of the Yamna (Pit Grave or Ochre Grave) Culture. It is interesting to note that ^{14}C ages from surrounding mounds covering a period of the Pre-Pit, Early Pit, and Classical Pit Cultures, clearly overlap with our ages obtained for the base of the second anthropogenic unit of Ecse Mound (Table IV.3; Figure IV.2).

4.6. Conclusion

This paper can be considered as a pilot research to a much larger scale scientific program with the objective of studying kurgans by the means of undisturbed core sampling. By publishing these preliminary data, we also wanted to draw attention to the need of concentrated and focused research efforts, and using standardized methodology in kurgan research, so the results from different researches done by different research groups are consistent and comparable. As of today, comparative studies are virtually impossible not only due to the different drilling and sampling techniques, but also for the lack of standardized methodology in fine stratigraphy and common understanding of geology, paleoecology and geoarchaeology.

Supplementary Figure

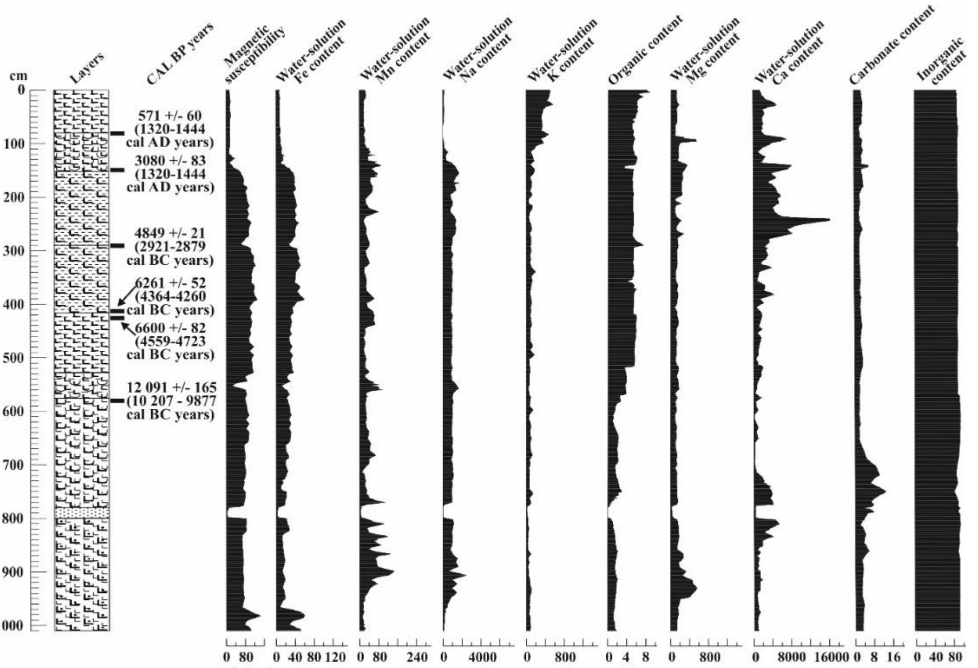

Figure IV.S1. Radiocarbon-dated sedimentological, magnetic susceptibility data, water-soluble Fe, Mn, Na, K, Mg, Ca, organic and carbonate content from the undisturbed core sequence of Ecse Mound.

Chapter 5: A preliminary chronological study to understand the construction phases of a Late Copper–Early Bronze Age kurgan (kunhalom)

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Central European Geology, Vol 62, Nr 1, 2019, p 27-55

DOI: 10.1556/24.61.2018.11

Abstract

The aim of this study is to identify the milestones of landscape evolution around the Ecse Mound (Karcag-Kunmadaras, Hortobágy National Park, Hungary) in the Holocene period by sedimentological and malacological analysis of strata underneath and within the body of the kurgan concerned, including that of the same characteristics of the artificially piled layers. An undisturbed core drilling was carried out and the sedimentological properties of both the mound and of the substrate base rock were revealed, analysis of which has been supported by three radiocarbon (AMS) measurements. The base rock formation during the last phase of the Ice Age, Middle and Upper Pleniglacial, and Late Glacial phases was followed by soil development in the Holocene, while the mound was constructed in two phases at the end of the Copper Age by the communities of the Pit Grave (Yamna or Ochre Grave) Culture. By publishing these preliminary data, it is also intended to draw attention to the need of focused research efforts by standardized methodology in kurgan research, in order to make the results of different studies consistent and comparable.

5.1. Introduction

The Eurasian steppe and forest steppe zones are estimated to have once extended from Mongolia to the Danube delta (Bohn, Zazanashvili, & Nakhutsrishvili, 2007) over an 8–13 billion km2 area before human agricultural and industrial activities have begun (Wesche & Treiber, 2012). Various studies, primarily botanical in scope, have proved that the Pannonic forest steppe of the Great Hungarian Plain in the Carpathian Basin is part of this zone (Borhidi, 1956, 2003; Molnár et al., 2012; Zólyomi, 1957, 1987; Zólyomi & Fekete, 1994) that was cut off by the uplift of the Carpathian Mountains, as a result of which it has developed as a detached habitat island (Molnár & Kun, 2000). This once vast natural ecosystem has mostly been ruined or transformed (Szirmai, Czóbel, & Nagy, 2005) by the network of settlements, roads, and railroads, increasing agricultural activity, particularly the highly motorized and chemically enhanced intensive crop farming and animal husbandry. The most dramatic changes have taken place in the Ukraine, where only 5%–10% of the indigenous steppe and forest steppe vegetation has subsisted within this vegetation zone ((Sudnik-Wójcikowska & Moysiyenko, 2013). A very similar human encroachment and its effects have taken their toll in Kazakhstan, where 90% of the former steppe has been turned into arable land, since the announcement of the Virgin Lands Campaign movement in the 1950s (Rachkovskaya & Bragina, 2012).

The same anthropogenic processes have influenced the transformation of the Pannonic forest steppes developed in the Great Hungarian Plains for the past 100–150 years (Deák et al., 2015; Molnár et al., 2014). Therefore, Hungarian nature conservancy and particularly the national park directorates situated in the Great Plains play a significant role, also from an international perspective (Dengler et al., 2014), in the conservation of primary forest steppe and steppe areas, as well as in the extension and reconnection of habitat fragments based on the existing network of protected areas (Balázs, 2006). This nature conservation task is particularly difficult in the case of loess steppes, since they predominate in chernozem soils, while these highly fertile areas have long been cultivated as croplands (Kelemen et al., 2010; Török et al., 2011). This is the main reason for the existence of the few remaining examples of Pannonic forest steppe and loess steppe habitats in the Great Plains, mostly sustained in ditch slopes, balks, as well as on burial and watch mounds (Balázs & Kustár, 2012; Bede et al., 2014; Bede et al., 2015; Csathó, 2009; Csathó et al., 2015; Deák et al., 2015; Penksza et al., 2011; Tóth, 1998; Zólyomi, 1969).

These mounds have a one ha surface area on average (Deák et al., 2016; Deák et al., 2015), and despite their small size play a pivotal role in the conservation of the steppe and forest steppe biota, because their botanical and zoological assets can be particularly diverse. This property can be attributed to the very structure of these mounds, i.e., their pyramidal shape with rather steep slopes. These steep, conic slopes were difficult or impossible to plough, and depending on their exposure, very diverse microhabitats and diverse microclimatic conditions have developed on them (Sudnik-Wójcikowska et al., 2011; Vona & Penksza, 2004).

Burial mounds are the most important objects of nature conservation efforts aiming at the restoration of the original vegetation and soil conditions, since they were built on the natural ground surface, and the earth around the burial site was used as building material (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007). Thus, contemporary soil types can be studied in the building strata of the mounds (Bede et al., 2014). Beyond the pedological research, by the careful study of plant remains, primarily pollen and phytoliths (Persaits et al., 2008; Persaits & Sümegi, 2011, 2015; Persaits, Sümegi, & Törőcsik, 2014; Sümegi, 2001, 2002), it is possible to reconstruct the vegetation of the area within the period of the construction. This research can yield very precise data on the soil conditions and vegetation before and during the construction of the mounds in the heart of the Carpathian Basin. As the soil beneath these earth-pyramids has not developed any longer (Demkin et al., 2014; Kashirskaya et al., 2010; Khomutova et al., 2007; Lomov et al., 2017), the study of the natural original soil can reveal the soil conditions before the mounds were constructed.

The geoarcheological study of these burial and dwelling mounds is very important, since these were the very first archeological sites to be included in geo-archeological research studies (Forchhammer, Steenstrup, & Worsaae, 1851; Jefferson, 1783; Vanuxem, 1843). Mounds are among the earliest objects of interest of archeology in Hungary, and *Flóris Rómer* (one of the founding fathers of Hungarian archeology) was the first to study them scientifically in the vicinity of Vaskút (Rómer, 1868a, 1868b, 1868c) 1868b, 1868c). The first full-scale scientific register of these man-made landforms was also compiled by Flóris Rómer (Rómer, 1878), but he carried out in-depth studies of kurgans in Bihar and on a set of kurgans in Trans-Danubia (in the region of Szalacska, Tihany, and Tátika) dating back to the Bronze and Early Iron Age (Pásztor, 2004). These archeological undertakings then lead to further scientific studies in Hungary (Kőhegyi & Vörös, 1999, 2000, 2002; Kulcsár, 1989; Párducz, 1959; Vörös, 2002).

The date of origin of the mounds has been a most important question since the early period of archeological excavations. Not only did the mounds vary, but also the time of their construction ranged within a wide period of time. The Hungarian term "kunhalom" (meaning "Cumanian mound") (Gárdonyi, 1893, 1914; Gyárfás, 1870; Győrffy, 1921; Horvát, 1825; Jerney, 1851) is highly problematic, since this is the umbrella term for all types of mounds without consideration of their function or date of origin (Barczi et al., 2009; Dani & Horváth, 2012; Pető & Barczi, 2011; Tóth & Tóth, 2003; Tóth, 2006). This term persisted despite archeologists' warnings of the problems and misunderstandings it has caused, both in chronology and functional classification, since this term denotes Late Neolithic and Middle Bronze Age tells, Late Copper and Early Bronze Age kurgans, as well as Iron Age burial mounds, and burial mounds of Scythian, Sarmatian, Hungarian, and Cumanian origin. As *Makkay* (Makkay, 1964) has pointed out, regardless of their function whether tells, burial mounds, watch and border mounds, cultic mounds, they are all labelled as "kunhalom."

There have been assumptions (Bede et al., 2014; Bede et al., 2015), before this study, that the Ecse mound had been built by communities of the Pit Grave (Yamna) Culture (Gimbutas, 1980; Merpert, 1974; Rassamakin, 1994), considering the similarities in shape, orientation, and stratigraphy of this earth-pyramid, and the comparative geomorphological research of other mounds in the Hortobágy region (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013). Findings and data from this artificially piled layer correlate with the radiocarbon data from 80 to 100 samples from the East European Plains, as the infiltration of the Pit Grave (Yamna) Culture to the Carpathian Basin from there took place in several waves; they define the third wave, or the beginning of the so-called classic phase, i.e., Horizon A (Morgunova & Khokhlova, 2006, 2013).

Without accelerator mass spectrometry (AMS) or radiocarbon data, it is impossible to identify the culture of origin, since mounds were built in the Great Hungarian Plain throughout millennia, including in the area studied, by various cultures and peoples, like Scythians, Sarmatians, early Hungarians, and later Cumans (Tóth & Tóth, 2003; Tóth, 2006). Mounds were built in the Hortobágy and its broader region as early as 3300 BC (first appearance of the peoples of the Pit Grave Culture) until as late as the 15th century, which is a 4,900- to 5,000-year timespan.

Archeological research papers rarely report on the fact of which nature conservationists are well aware of, i.e., that early archeological excavations and research methodologies took a toll on the mounds, leading to either their full or partial disintegration in most cases. Several of the archeological sites were left without reconstruction (their central part dug up, transacted and the soil deposited beside the mound). What all these excavations share in common is that the soil was not filled back. The reconstruction of these mounds would require a systematic program requiring substantial financial resources (Bede & Czukor, 2015). This also encouraged the authors to follow a different methodology of large diameter core drilling as a sample and information source in the chronology and environmental history studies.

This issue can only be tackled if the initial phase of each study includes stratigraphical and chronological analyses, so that the very function and age of the mound are revealed (Sümegi et al. 2015a). Following up on Borsy's observations (Borsy, 1968), the first such examinations were carried out on the section of the "Őrhalom" at Sárrétudvari (Sümegi, 1992), and on the "Szálka-halom," Hortobágy, by drilling and sampling (Sümegi, 1988). These pilot studies have led to the elaboration of a methodology of mound research (Sümegi, 2001, 2002, 2003).

Microstratigraphic sampling, sedimentological, geo-chemical, petrographic, and malacological analyses were the primary source of information guiding the methodology development. Samples were taken from the archeological excavation transects (by the archeologist *Ibolya Nepper Módy*) of the "Őrhalom", Sárrétudvari, as the excavation trenches and illegal earth extraction made mapping and core drilling precise and easy. In addition, samples for radiocarbon analyses were collected from this same site to determine the age of specific strata (Sümegi, 1992, 2004a).

The development of the methodology continued, and further Neolithic and Bronze Age tells (Sümegi, 2009, 2013; Sümegi et al., 1998; Sümegi et al., 2002; Sümegi et al., 2013), and kurgans of the Hortobágy were involved (Sümegi & Szilágyi, 2011; Szilágyi et al., 2013). The kurgans of the Hortobágy included the "Ecse-halom" (Sümegi, 2012), which would be discussed in the following sections of this paper.

5.2. Methodology

It might be justified to ask why the methodology of undisturbed core drilling was chosen instead of archeological excavation, particularly in the case of this kurgan damaged in the 20th century (Bede et al., 2016; Bede et al., 2014; Bede et al., 2015). Firstly, there are financial reasons, since the cost of drilling and the analysis of the drilling sample were only a fraction of that of an archeological excavation. Since several human activities, among them archeological excavations, have had serious negative nature conservation consequences for the kurgans throughout the Great Hungarian Plain, all of them are *ex lege* protected by the Hungarian national legislation. In addition, on the top of all that, Ecse Mound is located within the first national park of Hungary. The first major kurgan research took place in the southern part of the Great Hungarian Plain, at Kétegyháza, between 1966 and 1968, when *Gyula Gazdapusztai* excavated 17 graves from 11 kurgans (Ecsedy, 1979). Findings from the Bodrogkeresztúr and Boleraz cultures were unearthed from the Holocene paleosoil beneath the kurgans and the soil layers of the kurgans (Ecsedy, 1973); the body of the kurgans contained graves from later ages (by Scythians and Sarmatians). Some of the graves were then plundered during the Great Migration Period (Ecsedy, 1979).

Similar to the geo-archeological analysis at archeological sites (Figure V.1), the first phase of studying mounds is to carry out geomorphologic research (Figures V.2 and V.3) on the site (geo-archeological protocol; (Bede et al., 2014; Sümegi, 1994-1999, 2002, 2003). As a second phase, by geologic drilling, the different layers and their development boundaries can be mapped, followed by undisturbed core sampling (Figure V.4), or in the case of destroyed or disintegrated mounds, by establishing the geologic section by drilling the slopes. This geologic profile or drilling section aims to first identify the sediment types based on the international unconsolidated standards (Troels-Smith, 1955) and on the sediment colour chart (Munsell, 2000). In this way, based on the results of the mapping, coring, and excavation samplings, the sequence of strata can be mapped and delineated.

This protocol is pivotal in any mound research, since the development of a mound might have had different stages, also representing different functions; e.g., a burial mound could have been used as a lookout post, or a structure (church or other cultic/ religious building, etc.) may have been built on top. Thus, delineating the particular layers, and the macroscopic and stratigraphic analyses thereof, are of particular importance. Measuring magnetic susceptibility (MS) has proved to be one of the best methods to yield stratigraphic data (Bede et al., 2014; Bede et al., 2015; Sümegi, 2012; Sümegi, Bede, & Szilágyi, 2015a).

Environmental magnetic analyses were carried out on bulk samples (An et al., 1991; Rousseau & Kukla, 1994; Sun & Liu, 2000; Zhu, Q. Liu, & Jackson, 2004). Samples were taken at 2–4 cm intervals. Prior to the start of the measurement, all samples were crushed in a glass mortar after weighing. Then, the samples were encased in plastic boxes and dried in air in an oven at 40 °C for 24 h. Afterward, magnetic susceptibilities were measured at a frequency of 2 kHz using an MS2 Bartington MS meter with a MS2E high resolution sensor (Dearing, 1994). All of the samples were measured thrice and the average values of MS were computed and reported.

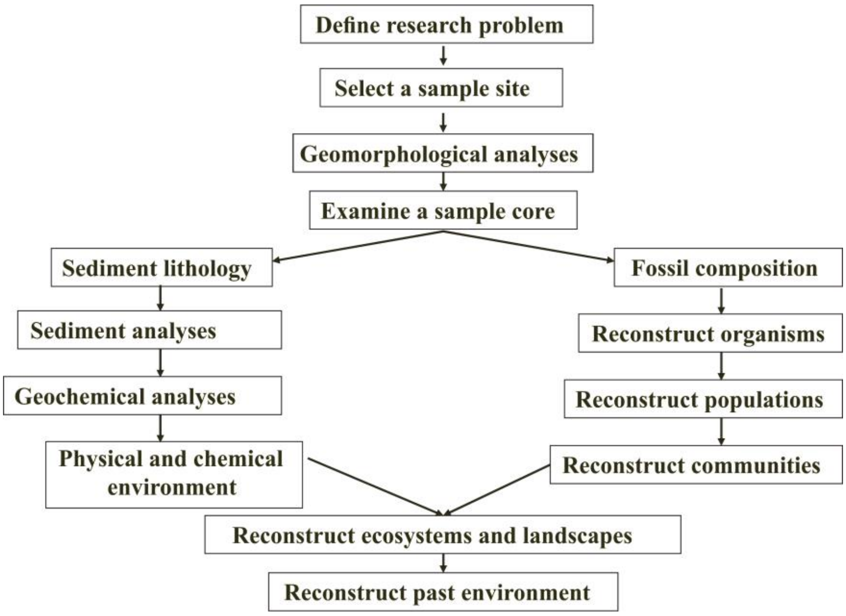


Figure V.1. Stages in a Quaternary paleoecological study; redrawn after (Birks & Birks, 1980).

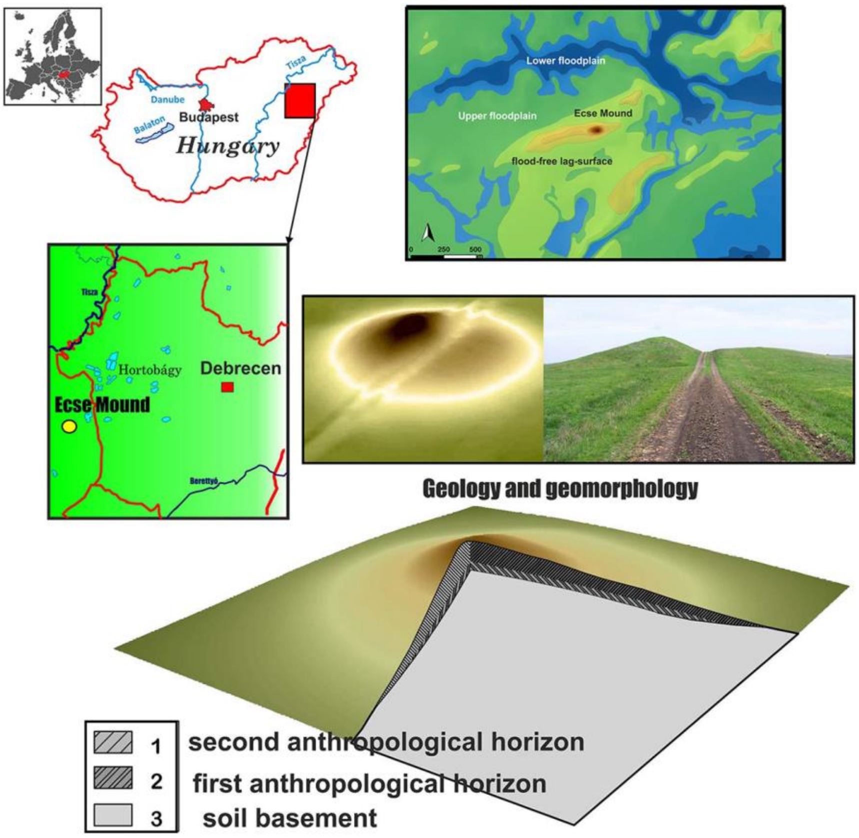


Figure V.2. Location, geomorphology, and observed stratigraphy of the Ecse Mound in the Hortobágy, NE Hungary.

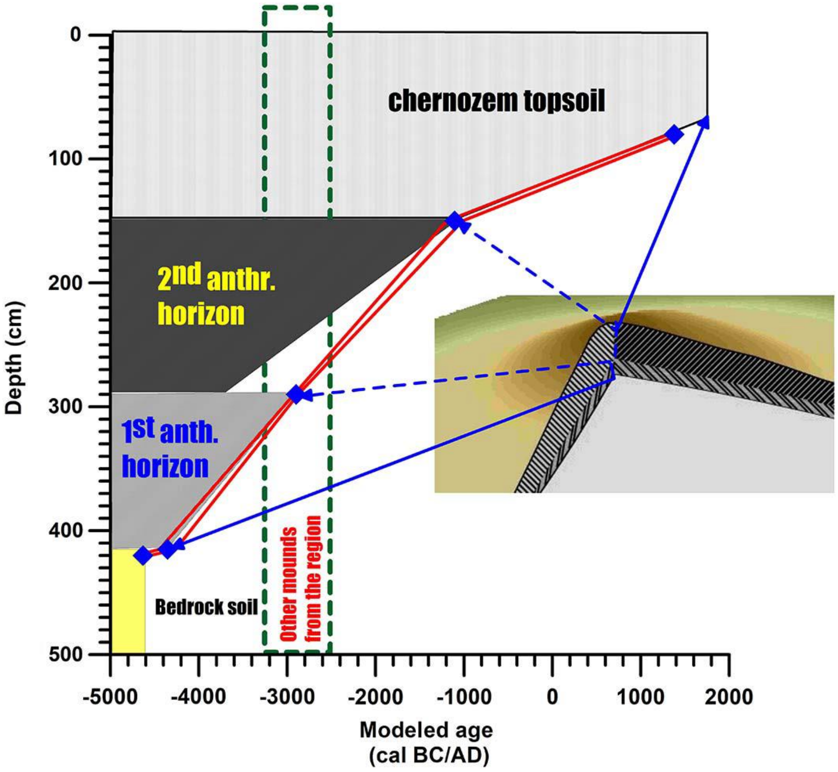


Figure V.3. 3D detailed section of the reconstructed Ecse Mound.

1: the second construction layer of the mound; 2: the first construction layer of the mound; 3: the surface of the paleosol under the mound (Bede et al., 2015)

In addition to MS, macroscopic and mechanical strata analyses, as well as variance in organic content, carbonate and mineral particle composition and their changes are also considered in the identification of strata. These soil properties, just like MS, have to be measured at 2–4 cm intervals (Sümegi, Bede, & Szilágyi, 2015a). Denser, i.e., 1 cm or less intervals have not proved to yield more precise information because of the postgenetic changes, most importantly those caused by bioturbation.

The grain size composition of sedimentological samples was carried out using the laser-sedigraph method. First, the samples were pretreated with 1 M HCl and H_2O_2 to remove carbonate and organic content, respectively (for a more detailed description of the pretreatment process, see (Konert & Vandenberghe, 1997). All of the samples were measured for 42 intervals between 0.0001 and 0.5 mm using an Easy Laser Particle Sizer 2.0 and Fritsch sieves in Szeged (Hungary). For loss of ignition (LOI) examination, subsamples were taken at every 2–4 cm interval and the LOI method was applied, commonly used for the analysis of the organic and carbonate content on calcareous sediments (Dean, 1974).

A new, so-called sequential extraction method (Dániel, 2004) with a long established history in the analysis of the geochemical composition of lacustrine sediments was adopted in this study. From the complete procedure, the step of water extraction for unseparated samples was sufficient to suit our analytical needs, as was shown by previous work (Dániel, 2004; Sümegi et al., 2013b); the most important paleohydrological and paleoecological data originate from water extraction samples.

Figure V.4. Undisturbed core process on the surface of the Ecse Mound at Karcag in the pollen-free winter time of 2012.

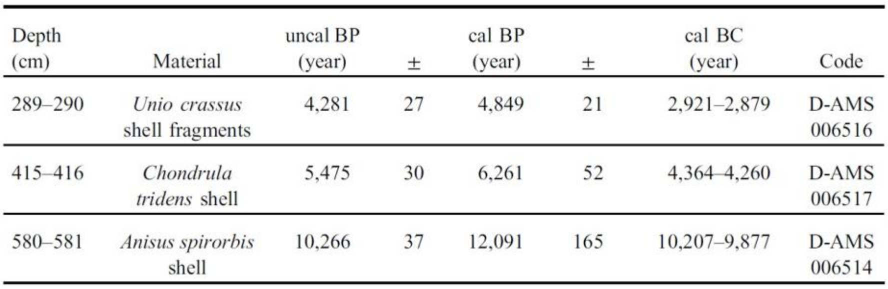
Therefore, the geochemical results from water extraction samples will be shown as follows: the results from the geochemical analyses are plotted against depth. Distilled water was purified using a Millipore fife 5 Plus Water Purification System for water extraction samples. An amount of 100 ml distilled and purified water was added to 1.0 g sample and was shaken for 1 h, and then the water extract elements of Na, K, Ca, Mg, and Fe were analyzed using a Perkin-Elmer AAS spectrometer (Dániel, 2004).

The macroscopic, physical, and chemical analyses made the mapping of the sequence of the sediment layers and layer boundaries possible. More precise chronology can only be achieved by radiocarbon and AMS analyses (Barczi et al., 2012; Dani & Horváth, 2012; Ecsedy, 1979; Gazdapusztai, 1968; Molnár et al., 2004; Molnár, Rinyu, et al., 2013; Molnár & Svingor, 2011). Additional information can be obtained with the optically stimulated luminescence (OSL) analyses (Liritzis et al., 2013) of wattle-and-daub fragments or pottery remains conserved in the layers. On the other hand, it is important to note that pottery and wattle-and-daub fragments had been piled up with the soil, and can originate from the very same culture that created the mound itself, but also from earlier cultures. The OSL analysis of the pottery and wattle-and-daub fragments may result in the false conclusion that some layers are older than their actual age (Gazdapusztai, 1968).

The radiocarbon analysis of the shells of terrestrial or fresh water snails and bivalves mixed in with the earth of the mounds also yield sufficient dating information (Gulyás, Sümegi, & Molnár, 2010); therefore, this method was selected in the case of the Ecse-halom (Ecse Mound), Karcag. AMS dating measurements were carried out in the internationally referenced AMS laboratory of Seattle, WA, USA. Three snail shells from the core sequence of the Ecse Mound at Karcag were prepared for radiocarbon dating and the radiocarbon data have been shown in this preliminary paper. Certain herbivorous gastropods are known to yield reliable ages for dating deposits of the past 40 kys with no or minimal error on the scale of perhaps a couple of hundreds of years. It is still acceptable on the scale of a multiple mollusc shell-based study (Pigati et al., 2013; Pigati et al., 2004; Pigati, Rech, & Nekola, 2010; Sümegi & Hertelendi, 1998; Újvári et al., 2014). The preparation of the samples and the actual steps of the measurement followed the methods of Hertelendi et al. (Hertelendi et al., 1989; Hertelendi, Sümegi, & Szöőr, 1992) and Molnár et al. (Molnár, Rinyu, et al., 2013). Shells were ultrasonically washed and dried at room temperature. Surficial contaminations and carbonate coatings were removed by pretreatment with weak acid etching (2% HCl) before graphitization. Conventional radiocarbon ages were converted to calendar ages using the Calib 7.0 software (Table V.1) and the most recent Intcal13 calibration curve (Reimer et al., 2014).

Further analyses are in progress beyond the three radiocarbon (AMS) measurements described in this paper, i.e., a further six samples and measurements are under preparation, and samples are being cleaned. In addition, the full drilling sample of the Ecse Mound is being analyzed for pollen, phytolith, and malacological records. Once the research is complete, an overarching article is to be published, also including previous results of the petrographical, botanical, and geomorphological studies (Bede et al., 2016; Bede et al., 2014; Bede et al., 2015). The current article is to share the important geo-archeological findings made recently with peer researchers of geo-archeology, since it is strongly believed that the current results can contribute to the methodology of dating the mounds. These results can also add to previous research articles providing them with another dimension.

Table V.1. Uncal BP data and calibrated chronological data from the core sequence of the Ecse Mound at Karcag.



Depth (cm)	Material	uncal BP (year)	±	cal BP (year)	±	cal BC (year)	Code
289–290	*Unio crassus* shell fragments	4,281	27	4,849	21	2,921–2,879	D-AMS 006516
415–416	*Chondrula tridens* shell	5,475	30	6,261	52	4,364–4,260	D-AMS 006517
580–581	*Anisus spirorbis* shell	10,266	37	12,091	165	10,207–9,877	D-AMS 006514

5.3. Study Area

The Ecse Mound (in Hungarian Ecse-halom) is located in the Great Hungarian Plain, in Jász-Nagykun-Szolnok County, in the area of the historical Nagykunság (Greater Cumania), in the Hortobágy region, within the Hortobágy National Park, 12 km north–northeast of the town of Karcag (Figure V.2). It is a border point between the administrative areas of the settlements of Karcag and Kunmadaras, found in the heart of the special forest steppe region, based on the modified Holdridge bioclimatic system (Szelepcsényi et al., 2018; Szelepcsényi, Breuer, & Sümegi, 2014a) and map (Figure V.5). The central coordinates of the Ecse Mound are N47°25’31.11”, E20°57’47.71”; absolute height: 93.5 m asl; relative height: 5.5 m; length: 75.5 m, width: 67.5 m (Figure V.2).

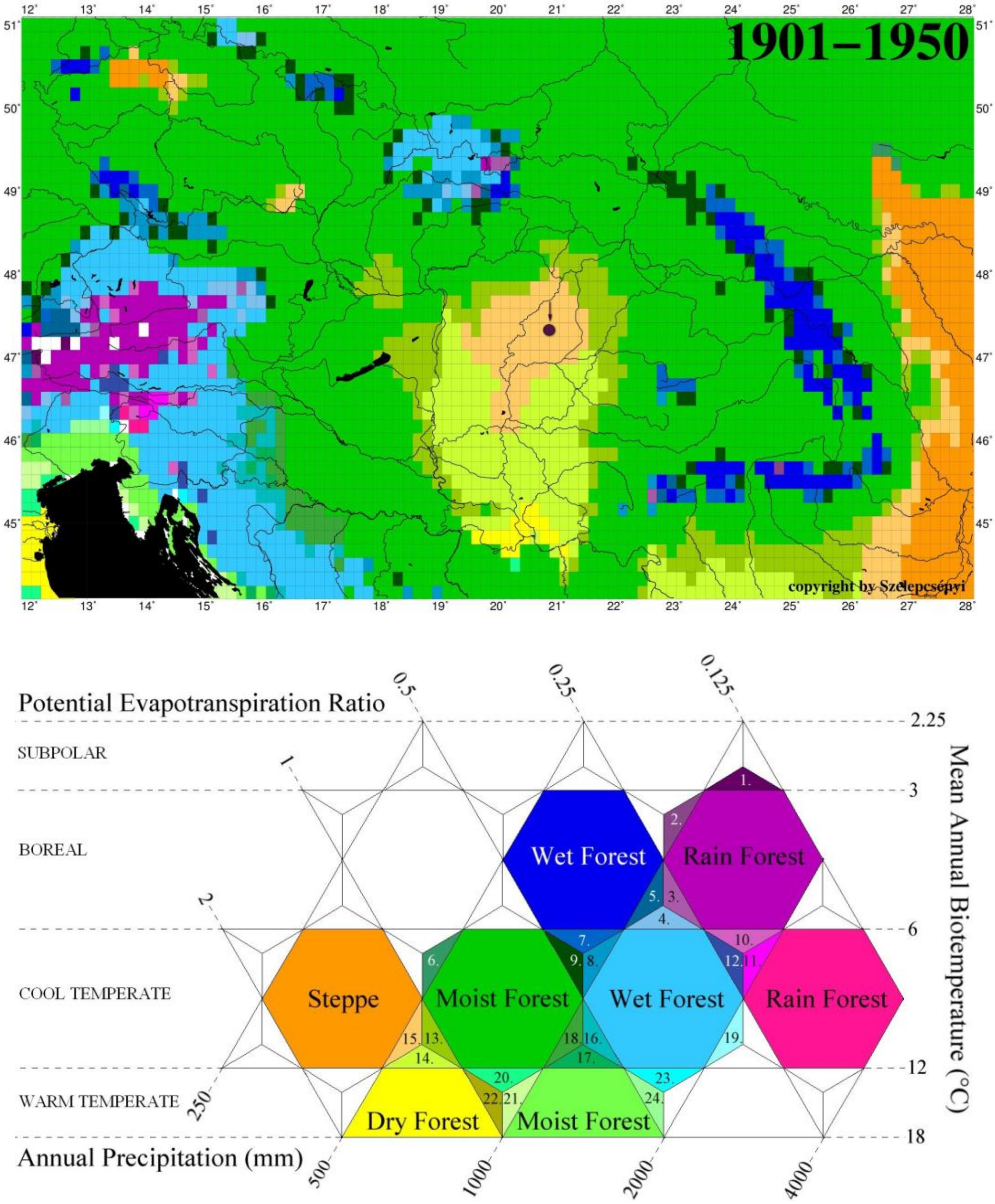


Figure V.5. Position of Ecse Mound on a spatial distribution of the Carpathian Region’s core and transitional life zones for the beginning of 20th century, based on the Holdridge-modified life zone system (Szelepcsényi et al., 2018; Szelepcsényi, Breuer, & Sümegi, 2014a, 2014b).

The Ecse Mound (Figure V.2) itself is located on an elevated point in the landscape, on a remnant surface covered by Pleistocene infusion loess; it shows connections with the loess landscape of the Nagykunság area, and it is basically its north-eastern protrusion that wedges into the Holocene alluvium of the Hortobágy. The mound rises on the eastern end of a slightly elevated, elongated loess ridge that is clearly separable from its surroundings on the basis of its vegetation and geomorphology. The traces of a ditch that was created when the earth was piled up on the mound are barely perceivable around the mound (Sümegi, 2012); this filled up, geomorphologically hardly detectable ditch is more visible along the northwestern and northern edges.

The roughly circular mound, slightly elongated along its west–east axis, has been considerably deformed in the course of the past centuries (Figure V.2). The most apparent change is the deep cut through the center of the mound in an east–west direction, which has served as a road of local significance since medieval times (Figure V.2); due to continuous abrasion and erosion cuts (Figure V.3), it now has cut many meters deep into the body of the mound (Bukovszki & Tóth, 2008; Kovács, 2013). A border line of medieval origin (Figure V.2), which is still visible just to the north of the road in the form of a border ditch, was established along it (Figure V.2). This dirt road (practically a road cut deep in the soil) running across the Ecse Mound was shaped by hundreds of years of use and consequent erosion. It was already used in the Middle Ages, since a road of local interest ran this way, connecting the village of Kunkápolnás and the town of Nádudvar (Elek, 2008). Later on (after the destructions of the Late Ottoman Period), it lost its significance, although the locals still use it to this day. The continuation of the road to the east is the Ecse barrage, which enables the crossing of the deeper parts of the Kunkápolnás marsh system (Bede et al., 2016; Bede et al., 2014; Bede et al., 2015).

The Ecse mound is first mentioned (Benedek & Zádorné Zsoldos, 1998; Gyárfás, 1883) in a charter describing village borders (Figure V.6) from 1521 (in the form “Echehalma”). In the Early Modern Era, it was the border point between the destroyed medieval villages of Asszonyszállás and Kápolnás. Today, it lies on the administrative border between Karcag and Kunmadaras; the borderline breaks in an angle on the top of the mound.

Manuscript maps from the 18th to 19th centuries and later printed maps consistently represent the entire area of the mound as pasture (Bede et al., 2016). In the beginning of the 20th century, however, its southern half was ploughed due to the increased demand for arable land, and already in 1943, this agricultural usage is presented. In the wider vicinity of the mound, farmsteads, dirt roads, ditches, embankments, grasslands, and lower lying swamps can be found.

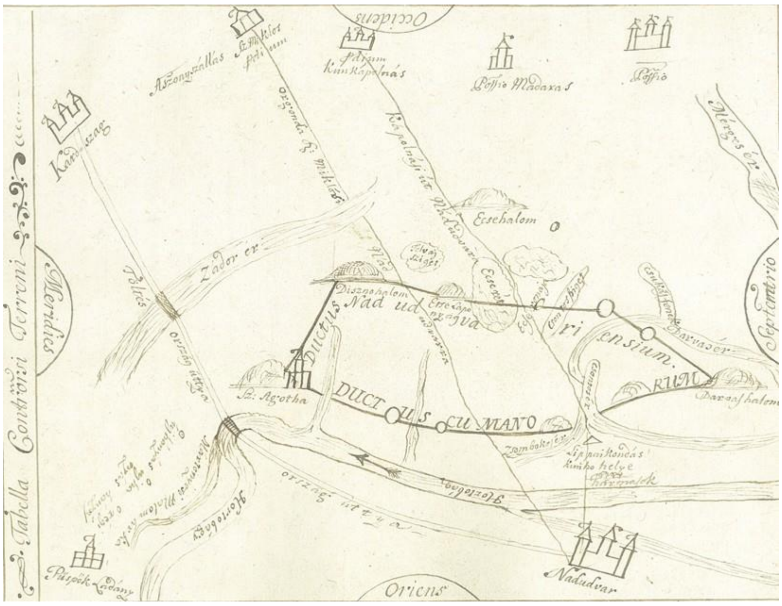


Figure V.6. Draft map of the 1521 land survey, prepared in 1759 (Kováts, 1784-1787).

The occurrence of about 90 species has been detected on the kurgan to date. Characteristic species are *Aegilops cylindrica, Agropyron cristatum, Androsace elongata, Bassia sedoides, Carthamus lanatus, Linaria biebersteinii, Muscari comosum, Ranunculus pedatus, Salvia nemorosa*, and *Verbascum phoeniceum* (Bede et al., 2016). Although the Ecse mound is not among the most valuable mounds in terms of plant species composition, regionally it certainly represents significant natural value, especially thanks to the presence of species characteristic of loess grasslands (Bede et al., 2016; Bede et al., 2014; Bede et al., 2015). The kurgan rises above its marshy, alkaline environment; thus, most of its surface is covered by a loess grassland association (*Salvio nemorosae–Festucetum rupicolae*) and its derivatives (Figure V.7). The mounds are characteristic refuges for the survival of such habitat types, having a significant conservation value, even the plant association itself (Horváth et al., 2011; Illyés & Bölöni, 2007; Joó, 2003). In the northern half of the Ecse Mound, loess grassland in fairly good condition can be found. Crested wheatgrass, characteristic for the dry vegetation of loess bluffs, forms only a few smaller patches beside the top and on the northern side. In the southern half of the mound, vegetation is secondary, uncharacteristic dry grass, a fallow zone unploughed for decades (Bede et al., 2016). But even this area already contains a few loess grassland species. The steep, south-looking side immediately to the south of the top is covered by a community of dry ruderal species, and this is separated by a fairly sharp border from the other vegetation zones. On the road cutting through the mound in an east–west direction, the tracks are flanked by trampled weed associations. Arboreal vegetation is only sparsely present in the area. In summary, it can be stated that the vegetation of the Ecse Mound is in a fairly good condition, partly due to its maintenance by regular, but not excessive, grazing, and mowing.

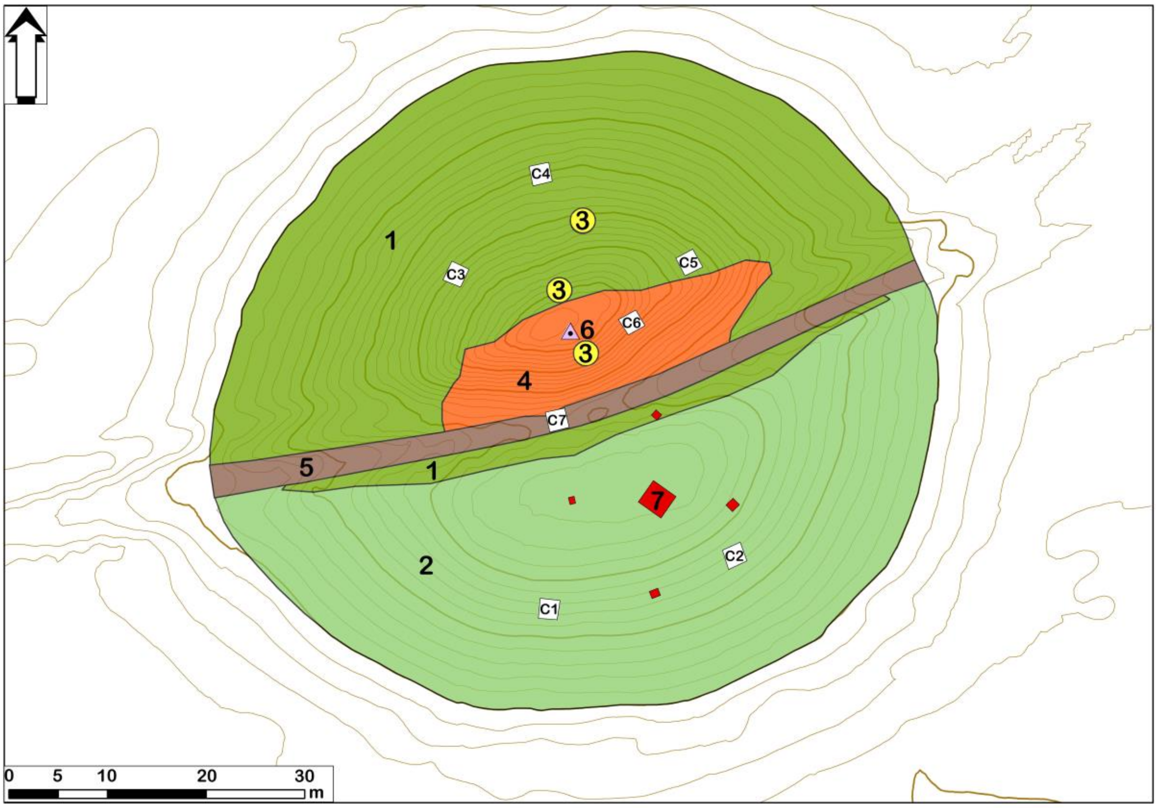


Figure V.7. Vegetation map of Ecse Mound (Bede & Czukor, 2015; Bede et al., 2016; Bede et al., 2014; Bede et al., 2015).

1: loess grassland; 2: characterless dry grassland with loessy elements; 3: crested wheatgrass stands; 4: extremely dry, ruderal plant association of weeds; 5: used dirt road with weed colonies; 6: triangulation point; 7: surface concrete parts of the military observation tower base; C1, C2, C3, C4, C5, C6, and C7: coenological sampling plots

The coring was conducted at the highest elevation, next to the geodetic triangulation point land surveying triangle, in the crested wheatgrass population, in January 2012, on a cold winter day, under frozen soil and pollen-free conditions, in order to reduce disturbance caused by the drilling.

5.4. Results

The AMS-based chronology assessment of the Ecse Mound investigated the bedrock and the first few artificially piled layers (Table V.1). The radiocarbon analysis has shown that the accumulation of the bedrock was still an ongoing process at the end of the Ice Age, as the baserock of soil development, the top layer of the series of fluvial strata (Figure V.8) developed (Table V.1) at the end of the Ice Age within the Pleistocene–Holocene transitional layer (Ralska-Jasiewiczowa et al., 2003; Rasmussen et al., 2006; Walker et al., 2009).

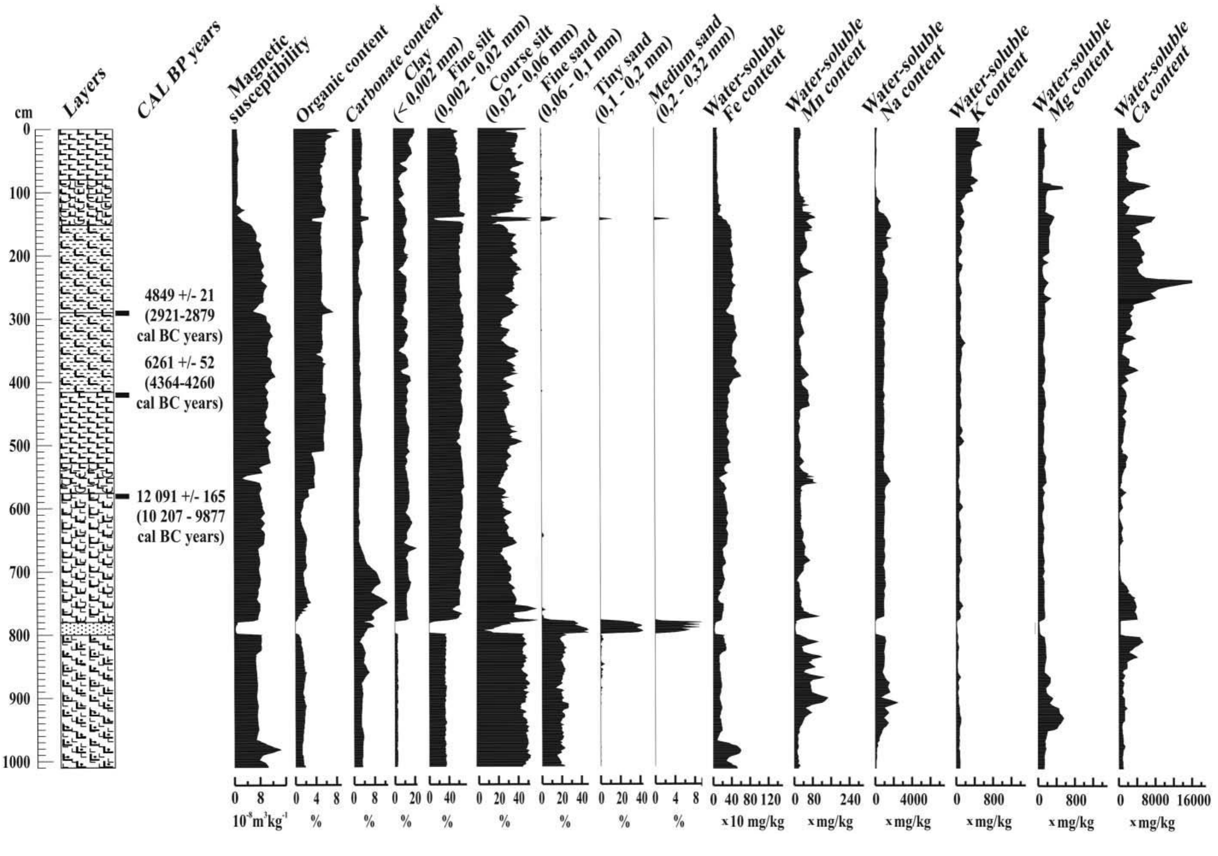


Figure V.8. Radiocarbon-dated sedimentological, magnetic susceptibility data, water-soluble Fe, Mn, Na, K, Mg, Ca, organic and carbonate content from the undisturbed core sequence of Ecse Mound in the Hortobágy.

Based on the radiocarbon-dated soil development chronology data of the Carpathian Basin (Sümegi, 2004b; Sümegi & Molnár, 2007; Sümegi & Náfrádi, 2015; Sümegi, Rudner, & Törőcsik, 2012; Willis et al., 1997), soil development is assumed to have started at the beginning of the Holocene on the silt and carbon-rich fluvial sediment (Figure V.8) that had accumulated up until the end of the Ice Age. Holocene climatic and vegetation conditions, and consequent soil development, are estimated to have started within the period of cc. 11,500–10,500 cal BP = 9,500–8,500 cal BC in the plain region (Willis et al., 1997; Willis et al., 1998). This period falls in line with the Mesolithic Age, as the radiocarbon measurements of soil layers in the Rejtek and Petényi caves, with findings from the Mesolithic Age, have proved (Sümegi & Náfrádi, 2015; Sümegi, Rudner, & Törőcsik, 2012). The environment of the Ecse Mound during the Ice Age was a floodplain that partially dried out at the end of the Mesolithic Age, resulting in a hydromorphic soil development on the slightly elevated so-called Ecse Plateau, where the Ecse Mound is situated (Figure V.2). As a result, a polyhedral soil structure with substantial organic material content had developed, which is very similar to the development of chernozem soils (Fuchs, 2012; Michéli et al., 2005; Minasny, Mcbratney, & Hartemink, 2009; Stefanovits, 1963, 1972; Szabolcs, 1966). Since soil development took place right on the baserock, and no rearrangement of layers in a sediment pool occurred, or no natural (or even artificial) cover layer developed, the beginning and end of soil development cannot be dated precisely (Sümegi, 1998, 2001, 2002, 2003, 2004b; Sümegi & Náfrádi, 2015; Sümegi, Rudner, & Törőcsik, 2012; Willis et al., 1997; Willis et al., 1998).

The AMS data (Table V.1) retrieved from C. tridens terrestrial snail shell remain unearthed from the intact soil layer undoubtedly indicate that soil development was still in an active phase 6,261 ± 52 cal BP (4,364–4,260 BC), i.e., at the beginning of the Copper Age (Raczky, 1988, 1995; Szilágyi, 2008; Vaday, 2004). The transition of the late Neolithic and Copper Ages was a time-transgressive process (Gyucha et al., 2006; Gyucha, Parkinson, & Yerkes, 2004; Parkinson, 2006), which means that there is no definite division line in chronology, but rather a time interval of changes. Taking this into consideration, the substrate soil beneath the Ecse Mound could very likely have already developed in the Copper Age, as the calibrated BC dating indicates.

The shell fragments of the aquatic bivalve *U. crassus* found in the first artificially piled layer of terrestrial sediment suggest external, most probably human influence. The AMS analysis data of these fragments (Table IV.1) 4,849 ± 21 cal BP (2,921–2,879 BC) unambiguously indicate that the first layer of the mound was piled up at the end of the Copper Age (Vaday, 2004). Thus, it can be stated that the mound was constructed by a local community of the Pit Grave (Yamna) Culture (Ecsedy, 1979; Gazdapusztai, 1968; Horváth et al., 2013), and that its people predominated within the research area at the late Copper Age–Bronze Age period.

Based on the radiocarbon measurements in the geologic section, sedimentological, geochemical, and MS properties can be described as follows.

The substrate sediment comprising fine sand and coarse-grained silt with substantial carbonate, soluble magnesium, and calcium, and low clay and organic content, between 8 and 10 m, was deposited at the end of the Ice Age (no radiocarbon dating so far). Based on the geologic data from the study area (Franyó, 1966; Rónai, 1985; Sümegi, Molnár, & Szilágyi, 2000), this sediment complex was likely to have been deposited by the Sajó-Hernád river system, supposedly during the Marine Isotope Stage (MIS) 3 period. The sediment also contained iron–manganese nodules. This is likely the cause of the increased level of soluble iron and manganese in the sediment, and the increased MS level (Figure V.8) experienced.

The top layer of the fluvial sediment complex (between 7.8 and 8.0 m) consists of very fine and carbonated fine sand mixed with a substantial level of medium-grained sand. This structure and sediment content indicates that this layer was also deposited by the Sajó-Hernád river system that was still present in the Hortobágy during the MIS3 period (Franyó, 1966).

On top of this accumulated fluvial sediment, another type of yellow–brown, loess-like alluvial sediment was deposited at the end of the Ice Age between 7.8 and 5.8 m. It is rich in silt, carbonate, and clay. This depositional process was likely to have taken place between 24.5k and 12k years cal BP, thus fully covering the MIS2 period. This sediment layer and its development are comparable to the alluvial sediment layers of the Ice Age that developed on river banks in the Hortobágy, previously called infusion loess layer (Nyilas & Sümegi, 1991; Sümegi, 2005; Sümegi et al., 2015b).

This silt-rich alluvial sediment that had accumulated until the end of the Ice Age can be considered the base rock of soil development in the Holocene, from the Early Holocene to the Early Copper Age (9,500–4,200 cal BC). This type of soil is of polygonal structure with hydromorphic qualities that is very similar to A and B layers of the meadow chernozem soil that was found between 4.15 and 5.8 m buried in the kurgan. The organic content is significantly higher in this horizon (Figure V.8), also showing a change in soluble elements and insignificant level of carbonate content.

The first sign of perturbation of this (first artificially piled) soil layer could be traced between 4.15 and 4.10 m, that is the Late Copper Age. The follow-up research will be targeted at the radiocarbon measurement of this very horizon. On the other hand, this layer is between the Early Copper Age and the second perturbation (artificially piled) layer, i.e., 2.90 and 2.80 m. Based on radiocarbon analysis, the age of the second artificially piled layer is estimated at 4,849 ± 21 cal BP (2,921–2,879 cal BC), so the first artificial pile of 4.15–4.10 m was very likely built in an earlier horizon, but still in the Late (very end of the) Copper Age (Vaday, 2004). Yet another perturbation was traced at 1.50 m, as the coring yielded substantial amounts of pottery and wattle-anddaub fragments from this layer. This finding was insufficient for proper archeological dating, and thus for the chronology of the perturbation layer, but most probably they are from a Scythian or Sarmatian community.

There followed a significant change of the sedimentological and geochemical properties of the kurgan soil, as the development of the top 150 cm of soil is completely different from the artificially laid ones. The geochemical properties and the development features indicate that after the construction of the kurgan in the Late Copper Age, a new layer of top chernozem soil (with A and B layers) developed on top of the dry earth pile of the kurgan. This is in line with earlier pedological and sedimentological observations made on other kurgans of the Hortobágy and Nagykunság (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013), namely that chernozem soil has developed on top of the artificial pile of kurgans. This type of top soil and related loess grassland association (*Salvio nemorosae–Festucetum rupicolae*) form the topmost layer of the kurgan.

5.5. Discussion

The study was carried out on the Ecse Mound, situated on the border of the settlements of Karcag and Kunmadaras. An undisturbed core drilling was carried out, and the sedimentological properties of both the mound and of the substrate baserock were revealed. The sediment series of the substrate comprised fluvial sand and silt layers, while a loess-like alluvial layer topped the series of fluvial sediments between the MIS3 and MIS1 levels. A polyhedral, hydromorphic (chernozem-like) soil layer developed from the beginning of the Holocene until the Copper Age, and a kurgan with at least two artificially piled layers was constructed by the community of the Pit Grave (Yamna) Culture at the end of the Copper Age. As the AMS study indicated, the second artificially piled layer was completed at the end of the Copper Age, more precisely in the period of 4,849 ± 21 cal BP (2,921–2,879 cal BC). The AMS analysis has proved that the date of origin of the Ecse Mound is the Late Copper Age, i.e., the first infiltration of the Yamna (Pit Grave or Ochre Grave) Culture. As comparative chronology for the Copper Age and archeostratigraphic analyses have indicated, this classic Yamna A Horizon of the Late Copper Age is parallel with, and comparable to, the classic Baden Culture elsewhere in Hungary (Horváth, Svingor, & Molnár, 2006).

While the first artificially piled layer requires further radiocarbon measurements, the stratigraphic properties indicate that it was also constructed at the end of the Copper Age. Traces of perturbation were identified from more recent layers dating back to the Stone Age or the Antiquity, and the undisturbed core samples have proved that the topsoil of chernozem developed in-situ after the construction of the kurgan, as a similar process has taken place on other kurgans in the Hortobágy and Nagykunság (Barczi, Sümegi, & Joó, 2003, 2004; Barczi et al., 2006; Joó, Barczi, & Sümegi, 2007; Sümegi, 1992; Sümegi & Szilágyi, 2011; Szilágyi et al., 2013).

This research can be considered as the first phase of a long-term program on the scientific research of kurgans. Thus, the methodology of sampling and analysis was fundamentally based on the results and conclusions gained in Quaternary paleoecological and archeogeologic studies in Hungary and abroad (Sümegi, 2001, 2002, 2003). It is worth noting that fine stratigraphic sampling was already used in the 1950s in Quaternary paleoecological and archeogeologic studies internationally, as well as in Hungary (Hokr, 1951; Jánossy, 1962, 1979; Jánossy & Kordos, 1976; Kordos, 1983; Kretzoi, 1953, 1957; Kriván, 1955; Krolopp, 1961; Stieber, 1956; Sümegi, 2001, 2002, 2003; Vértes et al., 1956).

These results clearly show that the methodology reintroduced by the representatives of the so-called landscape ecology (Barczi, 2004; Barczi et al., 2011; Barczi et al., 2012; Barczi & Joó, 2003, 2009; Pető & Barczi, 2011; Tóth, Joó, & Barczi, 2015; Tóth, Pethe, & Hatházi, 2014) is a regressive approach, since sediment samples are taken only from the visually distinct macroscopic soil layers. As most scientists (Cushing & Wright, 1967; Horácek & Ložek, 1988; Jánossy, 1979) studying Quaternary objects, including archeological ones, have concluded that sampling from only macroscopic layers will yield skewed results. This statement is even more valid in the case of such an archeological object as an earthen pyramid (kurgan, burial mound) having been piled up of soil. However, the level of elements and carbon must have changed considerably during the soil development process, and later due to ground water table fluctuations and precipitation percolating into the soil.

It must be considered that postgenetic influences, like carbonate movements, or secondary soil formation, can easily cover the real characteristics of the original soil content. By the individual sampling of soil layers, one will gain only a pool of data, but hardly with any trend. Thus, the analysis and interpretation of these data are highly problematic, as nothing more can be scientifically concluded other than that the layers are different, which is already obvious from the macroscopic examination. This method does not allow statistical analysis, and does not inform the results of research on the genetics and precise stratification of layers. To avoid all these mistakes, all sections and core samples were analyzed in 2–4 cm sections with fine stratigraphic methods.

5.6. Conclusions

The mound that was the object of the study is situated in the Hortobágy in a diversified geomorphological environment predominated by hydromorphic chernozem soil types, and a mosaic of marshland, alkaline, and loess steppe vegetation. The study began by taking large-diameter core samples on a cold winter day, under pollen-free conditions. The 10-m core sample gave a panoramic view of all strata of the mound and the substrate. The radiocarbon measurements and dating have revealed the history of the environment. The baserock formation during the Ice Age was followed by soil development in the Holocene, while the mound was constructed at the end of the Copper Age by the communities of the Pit Grave (Yamna or Ochre Grave) Culture. At least two layers of piled up soil have been identified. While dating of the construction layers needs to be further refined by the AMS analysis (under preparation) of organic remains preserved in the particular layers, it is already certain that both of the construction layers were piled up at the end of the Copper Age.

This study can be considered as a pilot research one, aiming for a much larger-scale scientific program, with the objective of studying kurgans by the means of undisturbed core sampling. The ongoing AMS analyses are amended with phytolith, pollen, malacological, and micromorphological investigations. The results are to be summarized in a publication on the environment and construction of kurgans. Since the results of this preliminary research are in line with earlier kurgan studies, publishing these results is already worthwhile. By publishing these preliminary data, we also wanted to draw attention to the need of concentrated and focused research efforts, and of using standardized methodology in kurgan research, so that the results from different studies performed by different research groups are consistent and comparable. At present, comparative studies are virtually impossible, not only due to the different drilling and sampling techniques, but also because of the lack of standardized methodology in fine stratigraphy and a common understanding of geology, paleoecology, and geoarcheology.

Chapter 6: Discussion

6.1. Summary of the results

Results of my studies confirm the scientific view - which has been in the minority for a long time - that the Hortobágy solonetz soils were developed as a result of natural geological processes and have been present in the central and southern part of the Hortobágy National Park for tens of thousands of years. Conditions favourable to alkalinization have developed as early as the last glacial cycle dated to MIS3 as part of an intense brief interstadial warming, the Dansgaard-Oeschger cycle (Figure VI.1). In addition, the undisturbed core taken from the Ecse mound revealed the presence of buried chernozem and alkaline soils in the Early Holocene, and descriptions of naturalist travelers also confirm the large scale presence of solonetz soils in the Hortobágy before the extensive hydroregulation measures started in the mid-19th century (Lőkös, 2001; Townson, 1797).

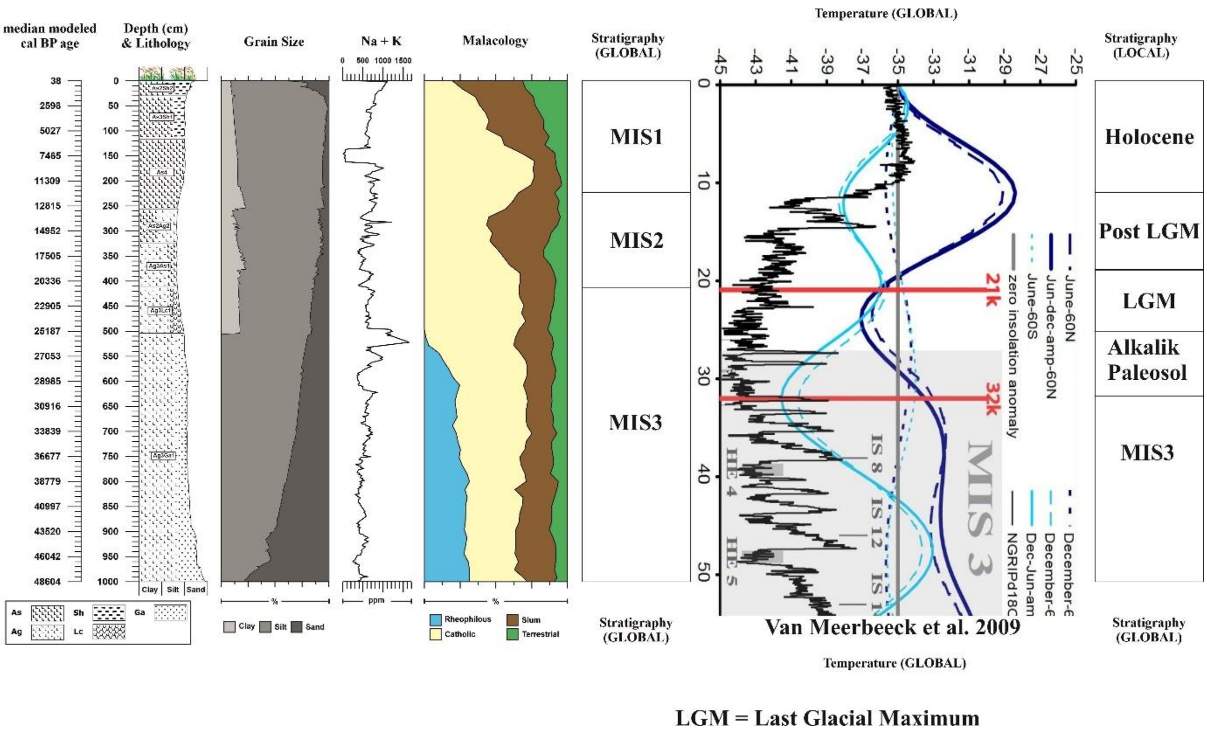


Figure VI.1 Combined presentation of the sedimentological, important geochemical and malacological results indicating the global and local stratigraphy and global temperature changes during the last 50,000 years according to Van Meerbeeck, Renssen & Roche (2009)

A complete fluvial cycle has been revealed in the studied riverbed of the so-called Róna Basin at the southern part of the Kunkápolnás marsh complex that evolved from the carbonate fluvial sand sediment of the bedrock, formed about 50,000 years ago, into a Holocene, organic-rich clayey rock silt (marsh) sedimentary layer. During the first half of this period, carbonated river sediment rich in sand and poor in finer-grained fractions accumulated in the gradually disconnected, 50,000-year-old riverbed. The development of the river sediment is completely distinct from the sediments accumulated in the Tisza riverbed in terms of grain composition and geochemical parameters, which are characteristic of the Sajó and Hernád Rivers (Timár, Sümegi & Horváth, 2005). From about 25/27 thousand years onward, the nature of sedimentation changed fundamentally, and finer-grained sediment accumulated in the section, indicating that the fluvial sedimentary phase had ended and the cut-off meander phase dominated in the bed formed during the MIS3 period (Figure VI.1). This means that the Hortobágy, as a separate landscape unit may have been formed at this time on the former floodplain of the Sajó and Hernád rivers, as a result of the Tisza occupying its present valley 15,000-18,000 years ago, separating the Hortobágy on its left bank from the alkaline areas of the Borsodi Mezőség on the right. The floods of the Tisza River were received by the marsh systems of several hundred square kilometres in the northern part of the Hortobágy, on the left bank of the river, from which the current hydrographical axis of the landscape, the Hortobágy River, originated, which in the south flowed into the marshes of the Nagy-Sárrét fed by River Berettyó. The alkaline areas of the Hortobágy may have been flooded by the Hortobágy River during the high water levels of the two major rivers, the Tisza and the Berettyó (Sümegi & Szilágyi, 2010).

Results of the pollen analysis are completely different from those of the previously published pollen studies in Hungary, in particular when comparing them with the pollen composition of the recent Eurasian biomes and with the arboreal pollen (AP) from pollen cores in the Carpathian Basin. The pollen diagram shows that the pollen composition of the Kunkápolnás area is similar to those of the recent Eastern and Western Eurasian forest-steppe/steppe boundary. In addition, results of the pollen, macrobotanical and malacological data suggest that the first patches of alkaline vegetation were established during the cold maximum of the glacial period in the study area. General alkalinization and drier steppe phase became widespread in the region with the gradual warming of the climate from the Late Glacial from about 12,000-13,000 years, together with the process that resulted in the dominance of *Matricaria, Chenopodiaceae* and *Artemisia* pollen. Then, at the beginning of the Holocene warming, from about 11,000 years onwards, a change in the dominance of pollen and the appearance of vegetation remains typical of drier loess-steppe environments (*Trifolium repens, Atriplex*) indicate the expansion of dry steppe and alkaline marsh patches. Based on the analysis of the radiocarbon-dated pollen, macrobotanical and malacological material, a mosaic habitat complex of alkaline marshes and steppes was established in the studied region at the end of the Ice Age, during the turn of the late glacial and the early Holocene. It appears that in contrast to the mountain rims and hill regions of the Carpathian Basin, no forest phase was established in the area at the beginning of the Early Holocene, but a mosaic vegetation structure of a forest-steppe developed, where trees occurred only at the margins of the former watercourses, while their cut and transformed beds gradually filled up with sediments of a local origin. These data are in good agreement with the previously reported paleoecological data on the mosaic environmental structure of the Carpathian Basin. However, it seems that local environmental factors (micro-morphology, alkaline soils, morphology and cyclic groundwater movements) were extremely strong in the Kunkápolnás region, amplifying the essentially climate-driven alkalinization process, and therefore the alkaline patches in the Pannonian forest-steppe region were formed on a regional scale in the Hortobágy landscape.

The first and - until the early 20th century - the last culture, which left a visible trace on the Hortobágy landscape was the pastoralist Pit Grave, Yamnaja or Kurgan Culture, appeared around 3300 BC in the Hortobágy area. According to the results of the analysis of the 10-meter long undisturbed core sample taken from the Ecse Mound, the base-rock formation during the Ice Age was followed by soil development in the Holocene, while the mound was constructed at the end of the Copper Age by the communities of the Pit Grave Culture. At least two layers of piled up soil have been identified both piled up at the end of the Copper Age. Communities of this culture did not seem to fundamentally transform the vegetation of the Hortobágy landscape, as they used the grassland-wetland mosaics for grazing their domestic animals. Similarly, there were no significant changes in the landscape character of the region over the subsequent millennia, when the land management by domestic animals gradually increased and eventually took over completely the habitat management, i.e. grazing role of large ungulate species, such as the wild horse, the Asiatic Wild Ass (Onager), the Auroch and the European Bison, all became extinct during the second half Holocene, due to hunting.

6.2. Outlook

It seems that it has been human interventions over the last two centuries that have brought landscape-scale negative changes on a landscape scale to the natural areas of the Hortobágy region, including river management and agricultural intensification activities, drainage of marshes, irrigation of pastures and creation of fishponds and rice fields. The Hortobágy National Park, Hungary's largest protected area, was established in 1973 in the central part of the region, which has been relatively little affected by these interventions, and where the natural alkaline grassland-wetland complexes continue to dominate the landscape to this day.

The foundation of the Hortobágy National Park 50 years ago successfully put a halt to the above negative processes. Since then the site management organization, the Hortobágy National Park Directorate initiated and implemented several habitat restoration projects aiming at the preservation and restoration of the degraded natural vegetation mosaics. As a result of these consequent conservation efforts water supply systems for altogether 5000 hectares of marshes have been established and more than 1000 kilometres of disused channels, dykes and ditches were eliminated in the already 80,000 ha large area of the National Park. These already implemented landscape-scale conservation measures together with the recently planned restoration of the water regime of the central part of the Hortobágy area will hopefully enable the long term conservation of this unique habitat complex mosaic structure, along with the diverse flora and fauna it hosts for future generations.

The recently legally established zoning system of the Hortobágy National Park provides a good basis for its long-term management, which can serve as a best practice for conservation measures in similar areas across Eurasia. In addition, the nature based solutions applied in the management of the Hortobágy National Park can be a good example to mitigate the negative impacts of climate change, as the environmentally sustainable use of such resilient landscapes serves not only protection of steppes of the Eurasian temperate zone, but also the long-term well-being of people and land users living and farming in and round such areas.

In light of the recent scientific results providing evidence on the primary, natural origin of the alkaline grassland–wetland complexes of the site, as well as based on the limited occurrence of alkaline and sodic areas in Eurasia (Boros & Kolpakova, 2018), the relevant Hungarian authorities might consider the nomination of the Hortobágy National Park—the Puszta property for the World Heritage List under the following natural criteria as well.

- Criterion (vii): The flat and open landscape of Hortobágy National Park is an area of exceptional natural beauty, representing the highest scenic quality, with pleasing and dramatic patterns and combinations of landscape features, which provides it a distinctive character, including aesthetic qualities and topographic and visual unity.
- Criterion (viii): The site is an outstanding example that represents the natural landscape and vegetation development of the Late Quaternary stage of Earth's history, including significant ongoing geological processes in the development of landforms and significant geomorphic features.
- Criterion (x): Hortobágy National Park contains the most significant natural habitats for the in situ conservation of biological diversity in the temperate steppe zone, including those containing threatened species of outstanding universal value from the point of view of science or conservation.

The future conservation management of the Hortobágy National Park is based on the recently legislated zoning system, including not only a proper zonation within the park, but the designation of a more than 90,000 ha large buffer zone around it. This important legal step should be followed by the elaboration of a World Heritage management plan in order to achieve the full management system required by the Operational Guidelines of the World Heritage Convention.

6.3. New scientific results

My research has provided the following new scientific results and answers to the questions raised under points 1-5 in section 1.4:

1. My research demonstrates that the Hortobágy solonetz soils have developed as a result of natural geological processes and have been present in the central and southern part of the Hortobágy National Park for tens of thousands of years. Conditions favourable to alkalinization had already developed during the last glacial cycle, dated to MIS3, as part of an intense brief interstadial (Dansgaard-Oeschger cycle event) between 25-30,000 years BP.
2. I have revealed the major hydrological changes of the Hortobágy over the last 50,000 years, which lead to a regime characterizing the landscape until the middle of the 19th century. A fluvial sedimentary phase had characterized the studied riverbed until 25-27,000 years BP, followed by a cut-off meander one to 15-18,000 years, when River Tisza had occupied its current valley, separating the Hortobágy on its left side from the alkaline areas of the Borsodi Mezőség on the right, and the region was no longer the floodplain of the Sajó-Hernád river-system.
3. By the collective analysis and interpretation of the pollen, macrobotanical, and malacological data I have been able to demonstrate that the first patches of alkaline vegetation were established during the cold maximum of the glacial period in the study area. General alkalinization and a drier steppe phase became widespread in the region with the gradual warming of the climate from the Late Glacial to about 12,000–13,000 years. It appears that no forest phase was established in the area at the beginning of the Early Holocene, but a mosaic vegetation structure of a forest–steppe developed, where trees occurred only at the margins of the former watercourses.
4. Through the joint interpretation of the results of my paleoecological studies and the available archaeological information I have shown that it is unlikely that there were significant human-induced changes in the character of the Hortobágy landscape in the second half of the Holocene, which was most probably only suitable for animal keeping in the last 5-6000 years. The Yamnaja culture was represented by large livestock keeping human communities, therefore it is unlikely that they changed the character of the Hortobágy landscape beyond the construction of the kurgans. Their massive appearance in the period of 3100/3000-2600/2500 BC in the Great Hungarian Plain, including the Hortobágy landscape indicate the beginning of the period, during which the land management by domestic animals gradually increased and eventually completely took over habitat management, i.e., the grazing role of large ungulates, such as the wild horse, aurochs and the European bison.
5. Hortobágy National Park, Hungary's largest protected area, was established in 1973 in the central part of the Hortobágy landscape, which was little affected by the human interventions of the past 150 years, therefore the natural alkaline grassland–wetland complexes continue to dominate the landscape to this day. The two critical issues of the management of the steppe ecosystem are the establishment of a proper grazing and hydrological, i.e. water supply system. The recently legislated zoning system, including not only a management-oriented zonation within the park, but also the designation of a more than 90,000 ha large buffer zone around it, provides a sound basis for the conservation management of the Hortobágy National Park in the future. Of all the management tasks, the reconstruction of the hydrological system at landscape level appears to be the most important, the importance of which is underlined by the challenges posed by climate change.

Acknowledgements

First of all, I would like to express my sincere gratitude to my supervisor, *Prof. Dr. Sümegi Pál*, for his valuable and continuous help, thoughtful guidance, understanding, knowledge and patience during the almost three decades of our work together.

I owe a special thanks to *Dr. Aradi Csaba*, retired director of the Hortobágy National Park Directorate, who introduced me and let me discover the Hortobágy landscape and taught me to ask Nature appropriate questions to understand the past and ongoing natural processes.

I would like to thank the staff of the *Department of Geology and Palaeontology*, in particular my consultant, *Dr. Gulyás Sándor* for their support in many different ways.

Last but not least, I would like to take this opportunity to thank my wife, *Zsuzsanna*, her gentle but firm support in helping me through the most difficult times of my work.

References

Ábrányi, K., Bokor, J., Timon, Á., Radó, A., Gaál, J., Wargha, S. (1895). *A Pallas Nagy Lexikona*. Pallas Irodalmi és Nyomdai Részvénytársaság - Révai Testvérek.

AGROTOPO. *MTA TAKI Agrotopográfiai adatbázis*. Retrieved 23 January 2024 from www.mta-taki.hu/osztalyok/gis-labor/agrotopo

Alexandrowicz, W. P. (2004). Molluscan assemblages of Late Glacial and Holocene calcareous tufa in Southern Poland. *Folia Quaternaria, 75*, 3-309.

Alexandrowicz, W. P. (2014). Malacological sequence of Weichselian (MIS 5-2) loess series from a profile in Grodzisko Dolne (southern Poland) and its palaeogeographic significance. *Quaternary International, 319*, 109-118.

An, Z., Kukla, G. J., Porter, S. C., & Xiao, J. (1991). Magnetic susceptibility evidence of monsoon variation on the Loess Plateau of central China during the last 130,000 years. *Quaternary Research, 36*, 29-36.

Arany, S. (1934). A hortobágyi szikes talajok. In E. Sajó, Trummer, A. (Ed.), *A magyar szikesek* (pp. 98-108). Patria Nyomda.

Arany, S. (1956). *A szikes talaj és javítása. (Melioration of alkali soils)*. Mezőgazdasági Kiadó.

Bába, K. (1983). History of the investigation of the terrestrial snails of the Great Hungarian Plain and its present situation - II. *Tiscia, 18*, 83-95.

Balázs, R. (2006). Experiences of mound survey in the Kiskunság National Park. In A. Kiss, Mezősi, G., Sümeghy, J. (Ed.), *Táj, környezet és társadalom [Landscape, Environment, Society]* (pp. 69-77). SZTE Éghajlattani és Tájföldrajzi Tanszék.

Balázs, R., & Kustár, R. (2012). *Halmok az évszázadok sodrában. Halmok–hegyek–várak a Duna–Tisza közén [Mounds Over the Centuries. Mounds–Mountains–Castles]*. Kiskunsági Nemzeti Park Alapítvány.

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

Barczi, A. (2004). The importance of pedological investigations in Holocene palaeoecological reconstructions. *Antaeus, 27*, 129-134.

Barczi, A., Bucsi, T., Centeri, C., Joó, K., Kenéz, Á., Pető, Á., & Saláta, D. (2011). *Földtan és talajtan [Geology and pedology]*. University Course book, Szent István Egyetem.

Barczi, A., Horváth, T., Pető, Á., & Dani, J. (2012). Hajdúnánás–Tedej–Lyukas-halom: egy alföldi kurgán régészeti értékelése és természettudományos vizsgálata [Hajdúnánás–Tedej–Lyukas-halom: archaeological assessment and scientific examination of a typical kurgan from the Great Hungarian Plain]. In A. Kreiter, Á. Pető, & B. Tugya (Eds.), *Környezet–Ember–Kultúra: Az Alkalmazott Természettudományok és a Régészet Párbeszéde [Environment–Human–Culture: Dialogue Between Applied Sciences and Archaeology]* (pp. 25-45). Magyar Nemzeti Múzeum Nemzeti Örökségvédelmi Központ.

Barczi, A., & Joó, K. (2003). A hortobágyi Csípő-halom morfol´ogiai és talajtani elemzése [Pedological studies on Csípő-halom (mound) in Hortobágy (Hungary)]. *Földrajzi Értesítő, 52*, 37-45.

Barczi, A., & Joó, K. (2009). The role of Kurgans in the palaeopedological and palaeoecological reconstruction of the Hungarian Great Plain. *Zeitschrift für Geomorphologie*, *53*, 131-137.

Barczi, A., Sümegi, P., & Joó, K. (2003). Adatok a Hortobágy paleoökológiai rekonstrukciójához a Csípő-halom talajtani és malakológiai vizsgálata alapján [Data for the palaeoecological reconstruction of the Hortobágy based on pedological and malacological studies made on the Csípő mound]. *Földtani Közlöny, 133/3*, 421-432.

Barczi, A., Sümegi, P., & Joó, K. (2004). Adatok a Hortobágy paleoökológiai rekonstrukciójához a Csípő-halom talajtani és malakológiai vizsgálata alapján [Data for the palaeoecological reconstruction of Hortobágy on the basis of the pedological and malacological analysis of Csípő-halom]. In A. Tóth (Ed.), *A kunhalmokról más szemmel [Mounds in an Other Perspective]* (pp. 13-25). Alföldkutatásért Alapítvány.

Barczi, A., Tóth, Cs., Tóth, A., & Pető, Á. (2009). A Bán-halom komplex tájökológiai és paleotalajtani felmérése [Survey of the biotical and abiotical landscape factors of the Bán-halom kurgan and its surrounding territory]. *Tájökológiai Lapok, 7*, 191-208.

Barczi, A., Tóth, T. M., Csanádi, A., Sümegi, P., & Czinkota, I. (2006). Reconstruction of the paleo-environment and soil evolution of the Csípő-halom kurgan, Hungary. *Quaternary International*, *156-157*, 49-59.

Barker, G. (2006). *The Agricultural Revolution in Prehistory: Why Did Foragers Become Farmers?* Oxford University Press.

Bede, Á., & Czukor, P. (2015). A Körös-Maros Nemzeti Park Kígyósi-puszta törzsterületén található halmok állapotfelmérése, tájtörténeti leírása és helyreállítási javaslata. Kutatási jelentés [Review, landscape history of and restoration proposal for the mounds in the Kígyósi-puszta reference area of the Körös-Maros National Park. Research report]. In K.-M. N. P. Directorate (Ed.), (pp. 170). Szarvas: Research Library.

Bede, Á., Csathó, A. I., Czukor, P., & P., S. (2016). Actual botanical survey of an interdisciplinary research at the Ecse-halom kurgan in Hortobágy, Hungary. In Z. Barina, K. Buczkó, L. Lőkös, B. Papp, D. Pifkó, & E. Szurdoki (Eds.), *Book of Abstracts. 11th International Conference "Advances in research on the flora and vegetation of the Carpatho-Pannonian region"* (pp. 127-129). Magyar Természettudományi Múzeum.

Bede, Á., Csathó, A. I., Czukor, P., Páll, D. G., Szilágyi, G., & Sümegi, P. (2014). A hortobágyi Ecse-halom geomorfológiai, tájtörténeti, botanikai, szedimentol´ogiai és mikromorfol´ogiai vizsgálatának előzetes eredményei [Preliminary results of the geomorphological, landscape historical, botanical, sedimentological and micromorphological analyses of the Ecse-mound in Hortobágy]. In P. Sümegi (Ed.), *Környezetföldtani és környezettörténeti kutatások a dunai Alföldön [Environment Geological and Environment Historical Research in the Great Hungarian Plain Along the Danube River]* (pp. 29-41). GeoLitera.

Bede, Á., Salisbury, R. B., Csathó, A. I., Czukor, P., Páll, D. G., Szilágyi, G., & Sümegi, P. (2015). Report of the complex geoarcheological survey at the Ecse-halom kurgan in Hortobágy, Hungary. *Central European Geology*, *58*, 268-289.

Benedek, G., & Zádorné Zsoldos, M. (1998). Jász-Nagykun- Szolnok megyei oklevelek. 1075–1526. *Jász-Nagykun-Szolnok Megyei Levéltár közleményei*, *3*, 1-320.

Bennett, K. D. (2005, 12 February 2008). *Psimpoll*. Retrieved 22 August 2010 from http://www.kv.geo.uu.se/psimpoll.html

Berardelli, P. (2008). *Human-Driven Planet: Time to Make It Official?* Science. http://www.sciencemag.org/news/2008/01/human-driven-planet-time-make-it-official

Béres, A., Bodó, I., & Jakucs, P. (1976). *Hortobágy - A nomád Pusztától a Nemzeti Parkig* (G. Kovács & F. Salamon, Eds.). Natura.

Berglund, B. E., Ralska-Jasiewiczowa, M. (1986). Pollen analysis and pollen diagrams. In B. E. Berglund (Ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology*. J. Wiley and Sons Ltd.

Bernátsky, J. (1905). A magyar Alföld szíklakó növényzetéről. *Annales Musei Nationalis Hungarici*, *3*, 121-174.

Beug, H. J. (2004). *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete*. Pfeil.

Birks, H. J. B., & Birks, H. H. (1980). *Quaternary paleoecology*. Edward Arnold.

Björck, S., Walker, M.J.C., Cwynar, L.C., Johnsen, S., Knudsen, K.L., Lowe, J.J., Wohlfarth, B. and INTIMATE Members. (1998). An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: A proposal by the INTIMATE group. *Journal of Quaternary Science*, *13*, 282-292.

Blaauw, M., Christen, J.A. (2011). Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis, 6(3),* 457-474.

Bohn, U., Zazanashvili, N., & Nakhutsrishvili, G. (2007). The map of the natural vegetation of Europe and its application in the Caucasus Ecoregion. *Bulletin of the Georgian National Academy of Sciences*, *175*, 112-121.

Bond, G. C., Heinrich, H., Broecker, W., Labeyrie, L., McManus, J., Andrews, J., Huon, S., Jantschik, R., Clasen, S., Simet, C., Tedesco, K., Klas, M., Bonani, G., Ivy, S. (1992). Evidence for massive discharges of icebergs into the North Atlantic ocean during the last glacial. *Nature*, *360*, 245-249.

Borbás, V. (1886). *A magyar homokpuszták növényvilága, meg a homokkötés*. Private edition.

Borhidi, A. (1956). Die Steppen und Wiesen im Sandgebiet der Kleinen Ungarischen Tiefebene. *Acta Botanica Academicae Scientiarium Hungaricae*, *2*, 241-274.

Borhidi, A. (2003). *Magyarország növénytársulásai*. Akadémiai Kiadó.

Borhidi, A. (2007). *Magyarország növénytársulásai*. Akadémiai Kiadó.

Boros, E., & Bíró, C. (1999). A Duna-Tisza-közi szikes tavak ökológiai állapot változásai a XVIII-XX. századokban (Ecological changes in natron lakes of the Danube-Tisza Interfluve between the 18th and 20th centuries). *Acta Biologica Debrecina Oecologica Hungarica*, *9*, 81-105.

Boros, E., & Kolpakova, M. (2018). A review of the defining chemical properties of soda lakes and pans: An assessment on a large geographic scale of Eurasian inland saline surface waters. *PloS ONE*, *13(8)*, e0202205. https://doi.org/10.1371/journal.pone.0202205

Borsy, Z. (1968). Geomorfológiai megfigyelések a Nagykunságban [Geomorphological observations in the Nagykunság region]. *Földrajzi Közlemények*, *2*, 129-151.

Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. *Radiocarbon*, *51*, 337-360.

Buiron, D., Stenni, B., Chappellaz, J., Landais, A., Baumgartner, M., Bonazza, M., Capronc, E., Frezzotti, M., Kageyama, M., Lemieux-Dudon, B., Masson-Delmotte, B., Parrenin, F., Schilt, A., Selmo, E., Severi, M., Swingedouwc, D., Udisti, R. (2012). Regional imprints of millennial variability during the MIS 3 period around Antarctica. *Quaternary Science Reviews, 48*, 99-112.

Bukovszki, J., & Tóth, Cs. (2008). Changes in the state of Cumanian mounds lying in the vicinity of Karcag from the end of the 18th century till today. *Acta Geographica ac Geologica et Meteorologica Debrecina, 3*, 145-153.

Clark, R. L. (1982). Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores, 24*, 523-535.

Crutzen, P. J., & Stoermer, E. F. (2000). The 'Anthropocene'. *Global Change Newsletter, 41*, 17-18.

Cushing, E. J., & Wright, H. E. (1967). *Quaternary palaeoecology*. Yale University Press.

Csathó, A. I. (2009). A mezsgyék természetvédelmi jelentősége és védelmük időszerűsége [Significance and timeliness for nature conservation of the verges]. *Természetvédelmi Közlemények, 15*, 171-181.

Csathó, A. I., Bede, Á., Sudnik-Wójcikowska, B., Moysiyenko, I., Dembicz, I., & Sallai-Kapocsi, J. (2015). A szagtalan rezeda (Reseda inodora Rchb.) előfordulása a Tiszántúlon [Reseda inodora Rchb. in the Tiszántúl region (East Hungary)]. *Kitaibelia, 20*, 48-54.

Dani, J. (2020). A KURGÁNOK ÉS AZ ÉPÍTŐIK - Az Alföld a bronzkor hajnalán. *Magyar Régészet, 2*, 1-19.

Dani, J., & Horváth, T. (2012). *Őskori kurgánok a magyar Alföldön. A Gödörsíros (Jamnaja) entitás magyarországi kutatása az elmúlt 30 év során. Áttekintés és revízió. [Prehistoric Kurgans in the Great Hungarian Plain. The Research of the Gödörsíros (Jamnaja) Entity in Hungary Over the Past 30 Years. An Overview and Revision]*. Archaeolingua Alapítvány.

Dániel, P. (2004). Methods of the five-step extraction-digestion method. In P. Sümegi, Gulyás, S. (Ed.), *The geohistory of Bátorliget Marshland*. Archaeolingua Press.

Dapsy, L. (1869). Tiszaszabályozás befolyása a magyar talajra. *Természettudományi Közlöny, 1*, 97-108.

Deák, B., Tóthmérész, B., Valkó, O., Sudnik-Wójcikowska, B., Moysiyenko, I. I., Bragina, T. M., Dembicz, I., & Török, P. (2016). Cultural monuments and nature conservation: A review of the role of kurgans in the conservation and restoration of steppe vegetation. *Biodiversity and Conservation, 25*, 2473–2490.

Deák, B., Török, P., Tóthmérész, B., & Valkó, O. (2015). Mondró-halom kurgan (Hencida, East Hungary), a refugium of loess grassland vegetation. *Kitaibelia, 20*, 143-149.

Deák, J. (1974). Izotóptechnikai módszerek alkalmazása a Tiszántúlon, a talaj-, a mélységi- és a felszíni víz kapcsolatának vizsgálatára. *Beszámoló a VITUKI 1972. évi munkájáról, 3*, 317-334.

Deák, J. (1975). *Use of environmental isotopes to investigate the connection between surface and subsurface waters in the Nagykunság region, Hungary* Isotope Techniques in Groundwater Hydrology, Vienna, Austria.

Dean, W. E. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition; comparison with other methods. *Journal of the Sedimentary Research, 44*, 242-248.

Dearing, J. (1994). *Environmental Magnetic Susceptibility: Using the Bartington MS2 System*. Chi Publishing.

Demkin, V. A., Klepikov, V. M., Udaltsov, S. N., Demkina, T. S., Eltsov, M. V., & Khomutova, T. E. (2014). New aspects of natural science studies of archaeological burial monuments (kurgans) in the southern Russian steppes. *Journal of Archaeological Science, 42*, 241-249.

Dengler, J., Janišová, M., Török, P., & Wellstein, C. (2014). Biodiversity of Palaearctic grasslands: A synthesis. *Agriculture, Ecosystems & Environment, 182*, 1-14.

Dövényi, Z. (2010). *Magyarország kistájainak katasztere*. MTA Földrajzkutató Intézet.

Dudley, N. (2008). *Guidelines for Applying Protected Area Management Categories WITH Stolton, S., P. Shadie and N. Dudley (2013). IUCN WCPA Best Practice Guidance on Recognising Protected Areas and Assigning Management Categories and Governance Types, Best Practice Protected Area Guidelines Series No. 21, Gland, Switzerland: IUCN. xxpp.* IUCN.

Ecsedy, I. (1973). Újabb adatok a Tiszántúl rézkori történetéhez [New data on the history of the Copper Age in the region beyond the Tisza]. *A Békés Megyei Múzeumok Közleményei, 2*, 3-40.

Ecsedy, I. (1979). *The People of the Pit-Grave Kurgans in Eastern Hungary*. Fontes Archaeologici Hungaricae, Akadémiai Kiadó.

Elek, G. (2008). *Várostörténet ötvenkét tételben. Karcag város története 1506–1950 között [City History in Fifty-Two Theses. History of Karcag City Between 1506 and 1950]*. Karcagi Nyomda Kft.

Endrédy, E. (1941). A szikes talajok képződésnek kérdéséről. *Öntözésügyi Közlemények, 3*, 207-217.

Fall, P. (1987). Pollen taphonomy in a canyon stream. *Quaternary Research, 28(3)*, 393-406.

Faragó, N., Gáll, E., Gulyás, B., Marcsik, A., Molnár, E., Bárány, A., & Szenthe, G. (2022). Dietary and cultural differences between neighbouring communities: A case study on the early medieval Carpathian Basin (Avar and post-Avar period, 7th–9th/10th centuries AD). *Journal of Archaeological Science Reports, 42(3)*, 103361.

Forchhammer, G., Steenstrup, J., & Worsaae, J. (1851). *Untersegölser i geologisk-antiguarisk Retning. Saerskilt optrykt af Oversigten over Videnkabernes Selskabs Forhandlinger i Aarene 1848 og (1851)*. Bianco Luno's Bogtrykkeri.

Fórizs, I. (2003). Isotopes as natural tracers in the water cycle: Examples from the Carpathian Basin. *Studia Universitatis Babeş-Bolyai, 48*(Physica Special Issue), 69-77.

Fórizs, I., Tóth, T., & Kuti, L. (2006). A szikesedés izotóp-hidrogeokémiai vizsgálata a hortobágyi Nyírő-laposon. In G. Szendrei (Ed.), *Magyarország környezetgeokémiai állapota* (pp. 83-90). MTA Földtudományok Osztálya.

Franyó, F. (1966). A Sajó-Hernád hordalékkúpja a negyedkori földtani események tükrében (Der Schwämmfächer der Flüsse Sajó und Hernád im Spiegel der geologischen. Ereignisse des Quartärs) [Alluvial cone of the Sajó and Hernád Rivers in the view of the geological event of the Quaternary Period]. *Földrajzi Értesítő, 15*, 153-178.

Fuchs, M. (2012). *Nagy duzzadó agyagtartalmú talajok osztályozásának diagnosztikai szemléletű korszerűsítése [Diagnostic modernization of soil classification containing high swelling clays]* Szent István Egyetem]. Gödöllő.

Galgóczy, K. (1876-1877). *Pest, Pilis és Solt törvényesen egyesült vármegye monográfiája* (Vol. I-III). Országos Monográfia Társaság.

Gardner, A. R. (1999). *The impact of Neolithic agriculture on the environments of south-east Europe* University of Cambridge]. Cambridge.

Gárdonyi, N. G. (1893). A régi kunok temetkezése [Burial of ancien kuns]. *Archaeologiai Értesítő, 13,* 105-117.

Gárdonyi, N. G. (1914). A magyarországi halmok kérdéséhez [To the question of Hungarian mounds]. *Archaeologiai Értesítő, 13,* 105-117.

Gazdapusztai, G. (1968). Chronologische Fragen in der Alfölder Gruppe der Kurgan-Kultur. *Móra Ferenc Múzeum Évkönyve, 2,* 91-100.

Genty, D., Blamart, D., Ouahdi, R., Gilmour, M., Baker, A., Jouzel, J., Van Exter, S. (2003). Precise dating of Dansgaard-Oeschger climate oscillations in Western Europe from stalagmite data. *Nature, 421,* 833-837.

Gerasimenko, N., Yurchenko, T., & Zaytsev, Y. (2013). Paleoecology of the Scythian population in the foothills of the Crimean mountains based on pollen study of the ak-kaya settlement. In A. Gilbert & V. Yanko-Hombach (Eds.), *From the Caspian to Mediterranean: Environmental Change and Human Response during the Quaternary* (pp. 63-65). IGCP - Ilia State University – Avalon Institute of Applied Sciences.

Gerling, C., Bánffy, E., Dani, J., Köhler, K., Kulcsár, G., Pike, A. W., Szeverényi, V., & Heyd, V. (2012). Immigration and transhumance in the Early Bronze Age Carpathian Basin: the occupants of a kurgan. *Antiquity, 86(334),* 1097-1111.

Gimbutas, M. (1980). The kurgan wave 2 into Europe and the following transformation of culture. *Journal of Indo-European Studies, 8,* 273-317.

Grimm, E. C., Jacobson, G.L., Watts, W.A., Hansen, B.C.S., Maasch, K.A. (1993). A 50,000-Year Record of Climate Oscillations from Florida and Its Temporal Correlation with the Heinrich Events. *Science, 261,* 198-200.

Grimm, E. C., Watts, W.A., Jacobson, G.L., Hansen, B.C.S., Almquist, H.R., Dieffenbacher-Krall, A.C. (2006). Evidence for warm wet Heinrich events in Florida. *Quaternary Science Reviews, 25,* 2197–2211.

Grootes, P. M., Stuiver, M., White, J.W.C., Johnsen, S.J., Jouzel, J. (1993). Comparison of oxygen isotope records from the GISP2 and GRIP Greenland ice cores. *Nature, 366,* 552-554.

Gulyás, S., Sümegi, P., & Molnár, M. (2010). New radiocarbon dates from the Late Neolithic tell settlement of Hódmezővásárhely-Gorzsa, SE Hungary. *Radiocarbon, 52(3),* 1458-1464.

Gyárfás, I. (1870). Valami a kunhalmokról [Something about mounds]. *Archaeologiai Értesítő, 3,* 33-42.

Gyárfás, I. (1883). *A jász-kúnok története III. Szerző tulajdona (Magánkiadás)*. Rákos István nyomda.

Győrffy, I. (1921). Kúnhalmok és telephelyek a karczagi határban [Kurgans and sites within the borders of Karcag]. *Föld és ember, 1,* 59-62.

Gyucha, A., Bácsmegi, G., Fogas, O., & Parkinson, W. A. (2006). House construction and settlement patterns on an Early Copper Age site in the Great Hungarian Plain. *Communicationes Archaeologicae Hungariae, 2006,* 5-28.

Gyucha, A., Parkinson, W. A., & Yerkes, R. (2004). Kora rézkori településkutatás az Alföldön. Előzetes jelentés a Körös regionális régészeti program 1998–2002 között végzett munkájáról [Early Copper Age settlement research in the Great Hungarian Plain.

Preliminary report on the work of the Körös Regional Archaeological Program between 1998 and 2002]. *Móra Ferenc Múzeum Évkönyve, Studia Archaeologica, 10,* 25-52.

Hall, S. A. (1989). Pollen analysis and paleoecology of alluvium. *31(3),* 435-438.

Hertelendi, E., Csongor, É., Záborszky, L., Molnár, I., Gál, I., Győrffy, M., & Nagy, S. (1989). Counting system for high precision C-14 dating. *Radiocarbon, 32,* 399-408.

Hertelendi, E., Kalicz, N., Raczky, P., Horváth, F., Veres, M., Svingor, É., Futó, I., & Bartosiewicz, L. (1995). Re-evaluation of the Neolithic in eastern Hungary based on calibrated radiocarbon dates. *Radiocarbon, 37(2),* 239-244.

Hertelendi, E., Sümegi, P., & Szöőr, G. (1992). Geochronologic and paleoclimatic characterization of Quaternary sediments in the Great Hungarian Plain. *Radiocarbon, 34,* 833-839.

Hokr, A. (1951). A method of the quantitative determination of the climate in the Quaternary Period by means of mammal associations. *Sborník ústředního ústavu geologický, oddíl paleontologický, 18,* 209-219.

Horácek, I., & Ložek, V. (1988). Paleozoology and the Mid-European Quaternary past: Scope of the approach and selected results. *Rozpravy Ceskoslovenské akademie ved, Řada matematických a přírodovedných ved, 98/4,* 3-102.

Horvát, I. (1825). *Rajzolatok a magyar nemzet legrégibb történetéből [Sketches from the most ancient period of the history of the Hungarian nation].* Petrózai Trattner Mátyás Kiadó,.

Horváth, A., Illyés, E., Molnár, Zs., Molnár, Cs., Csathó, A. I., Bartha, S., Kun, A., Türke, I. J., Bagi, I., & Bölöni, J. (2011). Löszgyepek, kötött talajú sztyeprétek [Closed steppes on loess]. In J. Bölöni, Zs. Molnár, & A. Kun (Eds.), *Magyarország élőhelyei. Vegetációtípusok leírása és határozója [Habitats of Hungary. Description and Definition of Vegetation Types]. ÁNÉR 2011.* (pp. 174-181). MTA Ökológiai és Botanikai Kutatóintézete.

Horváth, T. (2011). Hajdúnánás-Tedej-Lyukas-halom: an interdisciplinary survey of a typical kurgan from the Great Hungarian Plain region: a case study (the revision of the kurgans from the territory of Hungary). In Á. Pető & A. Barczi (Eds.), *Kurgan Studies: An Environmental and Archaeological Multiproxy Study of Burial Mounds in the Eurasian Steppe Zone* (pp. 71-131). BAR International Series 2238.

Horváth, T., Dani, J., Pető, Á., Pospieszny, Ł., & Svingor, É. (2013). Multidisciplinary contributions to the study of Pit Grave culture kurgans of the Great Hungarian Plain. In V. Heyd, G. Kulcsár, & V. Szeverényi (Eds.), *Transitions to the Bronze Age: interregional interaction and socio-cultural change in the third millennium BC Carpathian Basin and neighbouring regions (No. 30)* (pp. 153-180). Archaeolingua Kiadó.

Horváth, T., Svingor, M., & Molnár, M. (2006). Újabb adatok a Baden–péceli kultúra keltezéséhez [New data on the formation of the Baden Pécel culture]. *Archeometriai Műhely, 2006/3,* 19-30.

Illyés, E., & Bölöni, J. e. (2007). *Löszsztyeppek, lejtőssztyeppek és erdős-sztyepp rétek Magyarországon*. Magánkiadás.

Inkey, B. (1895). Jelentés az 1895. évben Csongrád és Csanád megyékben végzett földtani felvételekről. *Magyar Királyi Földtani Intézet Jelentése,* 100-108.

Jacobson, G. L., Bradshaw, R.H.W. (1981). The selection of sites for palaeovegetational studies. *Quaternary Research, 16,* 80-96.

Jakab, G., Sümegi, P., & Magyari, E. (2004). New Quantative Method for the Paleobotanical Description of Late Quaternary Organic Sediments (Mire-Development Pathway and Paleoclimatic Records from Southern Hungary). *Acta Geologica Hungarica, 47,* 373-409.

Jakucs, P. (1976). A Hortobágy növényvilága. In G. Kovács & F. Salamon (Eds.), *Hortobágy - a nomád Pusztától a Nemzeti Parkig* (pp. 38-56). Natura.

Jánossy, D. (1962). Vorläufige Ergebnisse der Ausgrabungen in der Felsnische Rejtek 1. *Karszt- és Barlangkutatás, 3,* 49-57.

Jánossy, D. (1979). *A Magyarországi Pleisztocén Tagolása Gerinces Faunák Alapján [Pleistocene Vertebrate Faunas of Hungary].* Akadémiai Kiadó.

Jánossy, D., & Kordos, L. (1976). Pleistocene-Holocene mollusc and vertebrate fauna of two caves in Hungary. *Annales Historico-Naturales Musei Naturalis Hungarici, 68,* 5-29.

Jefferson, T. (1783). *Notes of the State of Virginia*. Prichard and Hall.

Jerney, J. (1851). *Jerney János' keleti utazása a 'magyarok' őshelyeinek kinyomozása végett, 1844 és 1845 [Eastern journey of János Jerney in order to find the ancestors of Hungarians 1844 and 1845] (I–II).* Private Edition.

Joó, K. (2003). Kunhalomkutatások (A Csípő-halom vegetációja). *Tájökológiai Lapok, 1,* 87-96.

Joó, K., Barczi, A., & Sümegi, P. (2007). Study of soil scientific, layer scientific and palaeoecological relations of the Csípő-mound kurgan. *Atti della Societa Toscana di Scienze Naturali, A112,* 141-144.

Karuczka, A. (1999). Időjárási viszonyok hatása a szikes talaj sómérlegére. *Agrokémia es Talajtan, 48,* 459-467.

Kashirskaya, N. N., Khomutova, T. E., Dmitriev, V. V., Duda, V. I., Suzina, N. E., & Demkin, V. A. (2010). The morphology of cells and the biomass of microorganisms in the buried paleosols and modern steppe soils of the Lower Volga region. *Eurasian Soil Science, 43,* 1140-1149.

Kelemen, A., Török, P., Deák, B., Valkó, O., Lukács, B. A., Lengyel, S., & Tóthmérész, B. (2010). Spontán gyepregeneráció extenzíven kezelt lucernásokban [Spontaneous grassland regeneration in extensively managed alfalfa fields]. *Tájökológiai Lapok, 8,* 33-34.

Kemenczei, T. (2001). Az Alföld szkíta kora. In *Hatalmasok a viadalokban* (pp. 7-36). Békés Megyi Múzeumok Igazgatósága Erkel Ferenc Múzeuma.

Kerényi, A. (1995). *Általános környezetvédelem. Globális gondok – lehetséges megoldások.* Mozaik Kiadó.

Kerényi, A. (2003). *Környezettan - Természet és társadalom - globális szempontból.* Mezőgazda Kiadó.

Kerner, A. (2004). *A Duna-menti országok növényvilága. A magyar Alföld és a Bihar-hegység.* (L. Madas, Trans.; Vol. LXII). Dr. Zólyomi Bálintné Barna Piroska Alapítvány és az Országos Erdészeti Egyesület.

Khomutova, T. E., Demkina, T. S., Borisov, A. V., Kashirskaya, N. N., Yeltsov, M. V., & Demkin, V. A. (2007). An assessment of changes in properties of steppe kurgan paleosoils in relation to prevailing climates over recent millennia. *Quaternary Research, 67,* 328-336.

Konert, M., & Vandenberghe, J. (1997). Comparison of layer grain size analysis with pipette and sieve analysis: a solution for the underestimation of the clay fraction. *Sedimentology*, *44*, 523-535.

Kordos, L. (1983). Palaeclimatologic and biostratigraphic studies in Holocene small mammals. *Geologische Jahrbuch, A71*(339-359).

Kovács, F., Szatmári, J., & Rakonczai, J. (2006). Assessment of the special soil degradation (bench erosion) with GIS methods from the Great Hungarian Plain. The 9th International Conference on Geographic Information Science: "Shaping the Future of Geographic Information Science in Europe", Visegrád, Hungary.

Kovács, M. (2013). Az Ecse-halom komplex földrajzi vizsgálata és bemutatása [Complex geographical analysis and presentation of Ecse mound]. *Természet Világa, 144*, 79-82.

Kováts, G. (1784-1787). Geometrica delineatio totius terreni privilegiati oppidi cumanicalis Kartzag Uj Szállás, 1:40,000. In: Jász-Nagykun-Szolnok Megyei Levéltár térképtára.

Kozáková, R., & Pokorný, P. (2007). Dynamics of the biotopes at the edge of a medieval town: pollen analysis of Vltava river sediments in Prague, Czech Republic. *Preslia*, *79,* 259-281.

Kőhegyi, M., & Vörös, G. (1999). A vaskúti halmok és földvár (Kutatástörténet és anyagközlés) [Die Hügel und der Erdwall von Vaskút (Forschungsgeschichte und Materialvorlage)] [The kurgans and earth fort of Vaskút (Research history and presentation of findings)]. *Studia Archaeologica*, *5,* 217-259.

Kőhegyi, M., & Vörös, G. (2000). Die Forschungsgeschichte der Hügel und des Erdwalles von Vaskút [History of the research of the kurgans and earth fort of Vaskút]. *Acta Archaeologica Academiea Scientiarum Hungaricae*, *51,* 327-339.

Kőhegyi, M., & Vörös, G. (2002). A vaskúti szarmata kori halomsírok [Sarmatian kurgans of Vaskút]. *Múzeumi kutatások Csongrád megyében*, *2001*, 5-11.

Kremenetski, K. V. (2003). Steppe and forest-steppe belt of Eurasia: Holocene environmental history. In M. Levine, Renfrew, C., Boyle, K. (Ed.), *Prehistoric steppe adaptation and the horse* (pp. 11-27). McDonald Institute for Archaeological Research, University of Cambridge.

Kretzoi, M. (1953). *A negyedkor taglalása gerinces faunák alapján [Quaternary on the basis of vertebrata fauna]* MTA Műszaki Tudományos Osztályának Alföldi Kongresszusa, Budapest.

Kretzoi, M. (1957). Wierbeltierfaunistische Angaben zur Quartärchronologie der Jankovich Höhle [Data on the vertebrate fauna of the Jankovich Cave to support its quaternary chronology]. *Folia Archeologica*, *9,* 16-21.

Kreybig, L. (1944). *Magyar tájak tájismereti és termeléstechnikai leírása: a Tiszántúl* (Vol. 1). Magyar Állami Földtani Intézet.

Kriván, P. (1955). A közép-európai pleisztocén éghajlati tagolása [Climate of the Central European Pleistocene]. *Annales of the Geological Institute of Hungary, 43,* 363-503.

Krolopp, E. (1961). *A Buda környéki alsó-pleisztocén mésziszapok csigafaunájának állatföldrajzi és ökológiai vizsgálata [Animal Geographical and Ecological Analysis of the Snail Fauna of the Lower Pleistocene Lime in Buda]* Budapest.

Krolopp, E. (1965). Mollusc fauna of the sedimentary formations of the Quaternary period, Hungary. *Acta Geologica Hungarica*, *9,* 153-160.

Krolopp, E. (1973). Quaternary malacology in Hungary. *Földrajzi Közlemények*, *21*, 161-171.

Krolopp, E. (1983). Biostratigraphic division of Hungarian Pleistocene Formations according to their Mollusc fauna. *Acta Geologica Hungarica, 26,* 62-89.

Kulcsár, V. (1989). Rómer Flóris és a vaskúti földépítmények [Flóris Rómer and the ground constructions of Vaskút]. *Cumania, 11,* 149-152.

Kvassay, J. (1876). Über die Natron und Székboden im Ungarischen Tieflande. *Jahrbuch der Kaiserlich und Königlich Geologischen Reichanstalt, 16,* 427-446.

Lehmkuhl, F., Bösken, J., Hošek, J., Sprafke, T., Marković, S. B., Obreht, I., Hambach, U., Sümegi, P., & Lindner, H. (2018). Loess distribution and related Quaternary sediments in the Carpathian Basin. *Journal of Maps, 14,* 673-682.

Lehmkuhl, F., Bösken, J., Pötter, S., Sprafke, T., Schulte, P., Jary, Z., Antoine, P., Wacha, L., Wolf, D., Zerboni, A., Hošek, J., Marković, S. B., Obreht, I., Sümegi, P., Veres, D., Boemke, B., Schaubert, V., Viehweger, J., & Hambach, U. (2021). Loess landscapes of Europe – mapping, geomorphology and zonal differentiation. *Earth-Science Reviews, 211,* 1-82.

Lesku, B., & Molnár, A. (2007). *A Hortobágy növényritkaságai*. Hortobágyi Nemzeti Park Igazgatóság.

Lewis, L. L., & Maslin, M. A. (2015). Defining the Anthropocene. *Nature, 519,* 171-180.

Liritzis, I., Singhvi, A. K., Feathers, J. K., Wagner, G. A., Kadereit, A., Zacharias, N., & Li, S. H. (2013). *Luminescence Dating in Archaeology, Anthropology, and Geoarchaeology: An Overview.* Springer.

Lóczy, L. (1910). Magyarország felsőpleisztocén és holocén korszakának klímájáról. *Magyar Királyi Földtani Intézet Népszerű kiadványai, 2,* 69-76.

Lomov, S. P., Lyganov, A. V., Khisyametdinova, A. A., Spiridonova, I. N., & Solodkov, N. N. (2017). Modern and buried soils of kurgans in the forest-steppe zone of the Middle Volga region (by the example of Komintern I kurgan). *Eurasian Soil Science, 50,* 539-548.

Ložek, V. (1964). Quartärmollusken der Tschechoslowakei. *Rozpravy Ústredniho ústavu geologického, 31,* 1-374.

Lőkös, L. (2001). *Diaria Itinerum Pauli Kitaibelii III.* Természettudományi Múzeum.

Mados, L. (1943). A szikesedés és a víz. *Hidrológiai Közlöny, 23,* 3-21.

Magyari, E., Chapman, J. C., Passmore, D. G., Allen, J. R. M., Huntley, J. P., & Huntley, B. (2010). Holocene persistence of wooded steppe in the Great Hungarian Plain. *Journal of Biogeography, 37,* 915-935.

Magyari, E. K. (2002). *Climatic versus human modification of the Late Quaternary vegetation in Eastern Hungary* Debrecen University]. Debrecen.

Magyari, E. K. (2011). Late quaternary vegetation history in the Hortobágy steppe and Middle Tisza floodplain, NE Hungary. *Studia Botanica Hungarica, 42,* 185-203.

Maher, L. J. J. (1972). Nomograms for computing 0.95 confidence limits of pollen data. *Review of Palaeobotany and Palynology, 13,* 85-93.

Makkay, J. (1964). Megjegyzések Gunda Béla: az aterrado-művelés és az alföldi kunhalmok kérdése c. cikkéhez [Notes to Gunda Béla's article: Aterrado cultivation and kurgans of the Great Hungarian Plain]. *Ethnográfia, 75,* 471-474.

Marosi, S., & Somogyi, S. E. (1990). *Magyarország kistájainak katasztere I-II.* MTA Földrajztudományi Kutató Intézet.

Masek, Z., Serlegi, G., & Vágvölgyi, B. (2019). Burial Mounds, Circular Enclosures and Beyond. Complex Archaeological Investigation of Roman Period Tumuli in the Great Hungarian Plain Using Non-Destructive Methods. *Hungarian Archaeology, 8(4),* 19-27.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. I. (1972). *The Limits to Growth; a Report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books.

Merpert, N. Y. (1974). *Drevneishije skotovody volzhsko-uralskogo mezhdurechja [The Most Ancient Cattle-Breeders in the Volga-Ural Steppes]*. Nauka.

Mesterházy, K. (1974). Régészeti adatok Hajdú-Bihar megye területe IX–XIII. századi településtörténetéhez II. *Déri Múzeum Évkönyve, 1975*, 212-216, 245-246.

Mesterházy, K. (2005). The Hortobágy in the Hungarian Conquest period. In E. Gál, I. Juhász, & P. Sümegi (Eds.), *Environmental Archaeology in North-Eastern Hungary. Varia Archaeologica Hungarica, XIX.* (pp. 387-393). MTA Archaeological Institute.

Michéli, E., Fuchs, M., Szegi, T., Kele, G., & Vajdulák, M. (2005). Nagy duzzadó agyagtartalmú talajok osztályozásának diagnosztikai szemléletű korszerűsítése [Diagnostic Modernization of Soil Classification Containing High-Swelling Clays]. In *Talajvédelem, Special Issue* (pp. 278-281). Talajvédelmi Alapítvány.

Miháltz, I. (1947). A Duna-Tisza csatorna geológiai viszonyainak tanulmányozása. In H. Lampl & F. Hallósy (Eds.), *A Duna-Tisza csatorna*. Egyetemi Nyomda.

Minasny, B., Mcbratney, A. B., & Hartemink, A. E. (2009). Global pedodiversity, taxonomic distance and the World Reference Base. *Geoderma, 155*, 132-139.

Módy, G. (1973). A falutelepülés külső kerete a honfoglaláskor utáni első évszázadokig. In I. Rácz (Ed.), *Hajdúnánés története* (pp. 21-31). Hajdúnánási Kiadó.

Módy, G. (1995/1996). Nyugat-Bihar és Dél-Szabolcs települései a XIII. század végéig. *Debreceni Déri Múzeum 1995-1996 Évkönyve, 1998*, 195-187.

Módy, G. (1998). Nyugat-Bihar és Dél-Szabolcs települései a XIV. században. *Déri Múzeum 1997-1998 Évkönyve, 1999*, 219-244.

Molnár, B. (1960). Pliocén és pleisztocén lehordási területek az Alföldön. *Földtani Közlöny, 89*, 403-413.

Molnár, B. (1964). A magyarországi folyók homoküledékeinek nehézásvány-összetétel vizsgálata. *Hidrológiai Közlöny, 44*, 347-355.

Molnár, B. (1965). Changes in Area and Directions of Stream Erosion in the Eastern Part of the Hungarian Basin (Great Plain) during the Pliocene and Pleistocene. *Acta Minerologica et Petrographica, 17*, 39-52.

Molnár, B. (1967). A Dél-Alföld feltöltődésének ritmusai és vízföldtani jelentőségük. *Hidrológiai Közlöny, 47,* 537-552.

Molnár, B. (1973). Az Alföld harmadidőszak-végi és negyedkori feltöltődési ciklusai. *Földtani Közlöny, 103,* 294-310.

Molnár, M., Janovics, R., Major, I., Orsovszki, J., Gönczi, R., Veres, M., Leonard, A. G., Castle, S. M., Lange, T. E., Wacker, L., Hajdas, I., & Jull, A. J. T. (2013). Status Report of the New AMS 14C Sample Preparation Lab of the Hertelendi Laboratory of Environmental Studies (Debrecen, Hungary). *Radiocarbon, 55*, 665-676.

Molnár, M., Joó, K., Barczi, A., Szántó, Z., Futó, I., Palcsu, L., & Rinyu, L. (2004). Dating of total soil organic matter used in kurgan studies. *Radiocarbon, 46*(1), 413-419.

Molnár, M., Rinyu, L., Veres, M., Seiler, M., Wacker, L., & Synal, H. (2013). EnvironMICADAS: Amini 14C AMS with enhanced gas ion source interface in the Hertelendi Laboratory of Environmental Studies (HEKAL), Hungary. *Radiocarbon, 55,* 228-244.

Molnár, M., & Svingor, É. (2011). An interpretation of the soil 14C results of the Hajdúnánás-Tedej-Lyukashalom kurgan. In Á. Pető & A. Barczi (Eds.), *Kurgan Studies. An Environmental and Archaeological Multiproxy Study of Burial Mounds in the Eurasian Steppe Zone. British Archaeological Reports International Series 2238* (pp. 255-258). Archaeopress.

Molnár, Zs. (1996). A Pitvarosi-puszták és környékük vegetáció- és tájtörténete a Középkortól napjainkig. *Natura Bekesiensis, 2,* 65-97.

Molnár, Zs. (2003). Tájtörténeti adatok a hazai szikesek növényzetének ismeretéhez. In A. Tóth (Ed.), *Ohattól Farkas-szigetig. Ökológiai kultúra – ökológiai nevelés* (pp. 71-95). Alföldkutatásért Alapítvány.

Molnár, Zs. (2007). *Történeti tájökológiai kutatások az Alföldön* University of Pécs]. Pécs, Hungary.

Molnár, Zs. (2008). A Duna – Tisza köze és a Tiszántúl fontosabb vegetáció típusainak holocén kori története: irodalmi értékelés egy vegetációkutató szemszögéből. *Kanitzia, 16,* 93-118.

Molnár, Zs. (2009). A Hortobágy hazánk egyik legősibb növényzetű tája. In K. Török, K. T. Keve, & M. Kertész (Eds.), *Válogatás az MTA Ökológiai és Botanikai Kutatóintézet kutatási eredményeiből, ÖBKI Műhelyfüzetek 2* (pp. 143-148). MTA Ökológiai és Botanikai Kutatóintézet.

Molnár, Zs., & Bíró, M. (1997). Vegetation history of the Kardoskút area (SE Hungary) I: History of the steppes from the Middle Ages to the present. *Tiscia, 30,* 15-25.

Molnár, Zs., & Borhidi, A. (2003a). Continental alkali vegetation in Hungary: syntaxonomy, landscape history, vegetation dynamics, and conservation. *Phytocoenologia, 21,* 235-245.

Molnár, Zs., & Borhidi, A. (2003b). Hungarian alkali vegetation: Origins, landscape history, syntaxonomy, conservation. *Phytocoenologia, 33(2/3),* 377-408.

Molnár, Zs., Horváth, A., Csathó, A. I., Lendvai, G., & Bartha, S. (2014). Síksági pannon löszsztyeppek [Pannonian lowland loess steppe]. In L. Haraszthy (Ed.), *Fajok és Élőhelyek Magyarországon [Natura 2000 species and habitats in Hungary]* (pp. 810-816). Pro Vértes Közalapítvány.

Molnár, Zs., & Kun, A. (2000). *Alföld erdőssztyepp maradványok Magyarországon [Forest Steppe Remains in the Great Hungarian Plain]*. WWF Publishing.

Molnár, Zs., M., B., Bartha, S., & Fekete, G. (2012). Past trends, present state and future prospects of Hungarian forest-steppes. In M. J. A. Werger, van Staalduinen, M.A. (Ed.), *Ecological Problems and Livelihoods in a Changing World* (pp. 209-252). Springer.

Moore, P. D., Webb, J.A.; Collinson, M.E. (1991). *Pollen Analysis*. Blackwell Scientific Publications.

Morgunova, N. L., & Khokhlova, O. S. (2006). Kurgans and nomads: New investigations of mound burials in the southern Ural. *Antiquity, 80,* 303-317.

Morgunova, N. L., & Khokhlova, O. S. (2013). Chronology and periodization of the pit-grave culture in the Region between the Volga and Ural rivers based on radiocarbon Dating and paleopedological research. *Radiocarbon, 55*, 1286–1296.

Mucsi, M. (1963). Finomrétegtani vizsgálatok a kiskunsági édesvízi karbonát-képződményeken. *Földtani Közlöny, 93,* 373-386.

Munsell, A. H. (2000). *Munsell soil color charts*. Munsell Color Company.

Muraközy, K. (1902). A talajról. *Természettudományi Közlöny, 34*, 593-667.

Nagy, E. G. (1998). Die Herausbildung der Alfölder Linearbandkeramik I-II. *Debreceni Déri Múzeum Évkönyve, 73,* 53-150.

Németh, A., Bárány, A., Csorba, G., Magyari, E., Pazonyi, P., & Pálfy, J. (2017). Holocene mammal extinctions in the Carpathian Basin: A review. *Mammal Review, 47(1),* 38-52.

Németh, A., Bárány, A., Csorba, G., Magyari, E., Pazonyi, P., Pálfy, J. (2017). Holocene mammal extinctions in the Carpathian Basin: A review. *Mammal Review, 47(1),* 38-52.

Njalsson, T., Novosselov, I. (2018). Design and optimization of a compact low-cost optical particle sizer. *Journal of Aerosol Science, 119,* 1-12.

Nyilas, I., & Sümegi, P. (1991). The Mollusc fauna of Hortobágy at the end of the Pleistocene (Würm3) and in the Holocene. Tenth International Malacological Congress, Tubingen, Germany.

Oldfield, F., Thompson, R., Barber, K.E. (1978). Changing atmospheric fallout of magnetic particles recorded in recent ombrotrophic peat sections. *Science, 199,* 679-680.

Pálfai, I. (1989). Az Alföld aszályossága. *Alföldi Tanulmányok, 13,* 7-25.

Pálfai, I. (1993). Talajvízsüllyedés a Duna-Tisza közén. *Vízügyi Közlemények, 75,* 431-434.

Pálfai, I. (1994). *A Duna-Tisza közi hátság vízgazdálkodási problémái*. Nagyalföld Alapítvány.

Párducz, M. (1959). Hunkori halmok Vaskút határában [Hun kurgans in the border of Vaskút]. *Folia Archaeologica, 11,* 95-104.

Parkinson, W. A. (2006). The social organisation of early copper age tribes on the Great Hungarian Plain. *British Archaeological Reports, 1573,* 123-156.

Pásztor, E. (2004). *Útikalauz. Bronzkori, vaskori földvárak és halomsírok a Dunántúlon [Kurgans in Transdanubia from the Bronze and Iron Age]*. Magistratum Stúdió.

Pełechata, A., Pełechaty, M., Pukacz, A. (2016). Factors influencing cyanobacteria community structure in Chara-lakes. *Ecological Indicators, 71,* 477-490.

Penksza, K., Kiss, T., Herczeg, E., Nagy, A., & Á., M. (2011). Anthropogenic impacts and management of natural grasslands on kurgans. In Á. Pető & A. Barczi (Eds.), *Kurgan Studies: An Environmental and Archaeological Multiproxy Study of Burial Mounds in the Eurasian Steppe Zone* (pp. 329-338). Archeopress, British Archaeological Reports, 2238.

Persaits, G., Gulyás, S., Sümegi, P., & Imre, M. (2008). Phytolith analysis: Environmental reconstruction derived from a Sarmatian kiln used for firing pottery. In P. Szabó & R. Hédl (Eds.), *Human Nature: Studies in Historical Ecology and Environmental History* (pp. 116-122). Institute of Botany of the Czech Academy of Sciences.

Persaits, G., & Sümegi, P. (2011). A fitolitok szerepe a régészeti geológiai és környezettörténeti minták értékelésében [The role of phytoliths in archeogeological and environment historical analysis]. In J. Unger & E. Pál-Molnár (Eds.), *Geoszférák 2010 [Geospheres 2010]* (pp. 307-354). GeoLitera.

Persaits, G., & Sümegi, P. (2015). Régészeti lelőhelyekről származó fitolit vizsgálatok jelentősége az archeobotanikában [The importance of phytolith analysis of archaeological sites in archaeobotany]. In T. Törőcsik, K. Náfrádi, & S. P. (Eds.), *Komplex archeobotanika [Complex archaeobotany]* (pp. 145-154). GeoLitera.

Persaits, G., Sümegi, P., & Törőcsik, T. (2014). A solti Tételhegy környezettörténete pollen- és phytolitelemzés alapján [The environmental history of Solt–Tételhegy based on pollen and phytolith analyses]. In Á. Somogyvári & J. Szentpéteri (Eds.), *Településtörténeti kutatások. Solt–Tételhegy, Kiskunfélegyháza, Amler-bánya [Studies on the history of settlements. Solt-Tételhegy, Kiskunfélegyháza, Amler Mine]. Archaeologica Cumania* (Vol. 3, pp. 159-204). Katona József Múzeum.

Peterson, G. M. (1983). Recent pollen spectra and zonal vegetation in the western USSR. *Quaternary Science Reviews, 2(4),* 281-321.

Pető, Á., & Barczi, A. (2011). *Kurgan Studies. An Environmental and Archaeological Multiproxy Study of Burial Mounds in the Eurasian Steppe Zone*. Archaeopress.

Pigati, J. S., McGeehin, J. P., Muhs, D. R., & Bettis, E. A. I. (2013). Radiocarbon dating late Quaternary loess deposits using small terrestrial gastropod shells. *Quaternary Science Reviews, 76,* 114-128.

Pigati, J. S., Quade, J., Shanahan, T. M., & Haynes, C. V. J. (2004). Radiocarbon dating of minute gastropods and new constraints on the timing of springdischarge deposits in southern Arizona, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology, 204,* 33-45.

Pigati, J. S., Rech, J. A., & Nekola, J. C. (2010). Radiocarbon dating of small terrestrial gastropod shells in North America. *Quaternary Geochronology, 5,* 519-532.

Pók, J. (1994). *Szabolcs vármegye katonai leírása 1782-1785* (Vol. II). Szabolcs-Szatmár-Bereg megyei Levéltár Kiadványa.

Prentice, I. C. (1985). Pollen representation, source area, and basin size: toward a unified theory of pollen analysis. *Quaternary Research, 23,* 76-86.

Prentice, I. C., Cramer W., Harrison, S.P., Leemans, R., Monserud, R.A., Solomon, A.M. . (1992). A global biome model based on plant physiology and dominance, soil properties and climate. *Journal of Biogeography, 19,* 1177-1134.

Prentice, I. C., Guiot, J., Huntley, B., Jolly, D., Cheddadi, R. (1996). Reconstructing biomes from palaeoecological data: a general method and its application to European pollen data at 0 and 6 ka. *Climate Dynamics, 12,* 185-194.

Prentice, I. C., Webb III, T. (1988). BIOME 6000: reconstructing global mid-Holocene vegetation patterns from palaeoecological records. *Journal of Biogeography, 25,* 997-1005.

Rachkovskaya, E. I., & Bragina, T. M. (2012). Steppes of Kazakhstan: diversity and present state. In M. J. A. Werger & M. A. van Staalduinen (Eds.), *Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World* (pp. 103-148). Springer.

Raczky, P. (1988). *Tiszavidék kulturális és kronológiai kapcsolatai a Balkánnal és az Égeikummal a neolitikum, rézkor időszakában [The Cultural and Chronological Connections of the Tisza Region with the Balkan and Aegean at the Time of the Neolithic and Chalcolithic]*. Szolnok County Museums Directorate and ELTE University, Department of Archaeology.

Raczky, P. (1995). New data on the absolute chronology of the Copper Age in the Carpathian Basi. *Inventarja Praehistorica Hungariae, 7,* 51-60.

Raczky, P., & Anders, A. (2006). Social dimensions of the Late Neolithic settlement of Polgár-Csőszhalom (eastern Hungary). *Acta Archaeologica, 57(1-3),* 17-33.

Raczky, P., & Anders, A. (2016). Polgár-Bosnyákdomb, a Late Neolithic tell-like settlement on Polgár Island (NE Hungary). Preliminary results of the investigations. *Folia Quaternaria, 2016,* 99-122.

Rakonczai, J. (2006). Klímaváltozás – aridifikció - változó tájak. In A. Kiss, G. Mezősi, & Z. Sümeghy (Eds.), *Táj, környezet és társadalom. Ünnepi tanulmányok Keveiné Bárány Ilona professzor asszony tiszteletére* (pp. 593-601). Szegedi Tudományegyetem.

Rakonczai, J., & Kovács, F. (2006). A padkás erózió folyamata és mérése az Alföldön. *Agrokémia es Talajtan*, *55,* 329-346.

Ralska-Jasiewiczowa, M., Goslar, T., Różanski, K., Wacnik, A., Czernik, J., & Chróst, L. (2003). Very fast environmental changes at the Pleistocene/Holocene boundary, recorded in laminated sediments of Lake Gósciaż, Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *193*, 225-247.

Rapaics, R. (1916). A Hortobágy növényföldrajza. *Gazdasági Lapok*, *68*, p. 88-89, 102-103, 115-116, 124-126.

Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggaard-Andersen, S. J., Larsen, L. B., Dahl-Jensen, D., Bigler, M., Rhöthlisberger, R., Fischer, H., Hansson, M. E., & Ruth, U. (2006). A new Greenland ice core chronology for the last glacial termination. *Journal of Geophysical Research: Atmospheres*, *111*(D6). https://doi.org/10.1029/2005JD006079

Rassamakin, Y. (1994). The main directions of the development of early pastoral societies of Northern Pontic Zone: 4500–2450 BC (Pre-yamnaya cultures and Yamnaya culture). *Baltic–Pontic Studies*, *2*, 29-70.

RBacon. *Age-Depth Modelling using Bayesian Statistics*. Retrieved 29 August 2023 from https://cran.r-project.org/web/packages/rbacon/index.html

Reille, M. (1992). *Pollen et spores d'europe et d'afrique du nord*. Laboratoire de Botanique historique et Palynologie.

Reille, M. (1995). *Pollen et Spores d'Europe et d'Afrique du Nord, Supplément 1*. Laboratoire de Botanique historique et Palynologie.

Reille, M. (1998). *Pollen et spores d'Europe et d'Afrique du Nord: Supplément 2*. Laboratoire de botanique historique et palynologie.

Reimer, P., Austin, W., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T..J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon, 62,* 725-757.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., . . . van der Plicht, J. (2014). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon*, *55*(4), 1869-1887.

Réthly, A. (1933). Kísérlet Magyarország klímatérképének szerkesztésére a Köppen-féle klímabeosztás értelmében. *Időjárás, 37,* 105-115.

Rómer, F. (1868a). Kivonat a m. tud. Akadémiai archaeológiai bizottságának jegyzőkönyvéből. October 6-án tartott VIII. rendes ülésében. *Archeológiai Értesítő*, *1*, 13-14.

Rómer, F. (1868b). Kivonat a m. tud. Akadémiai archaeológiai bizottságának jegyzőkönyvéből. Jun. 23-án tartott VI-dik rendes ülésében. *Archaeologiai Értesítő*, *1*, 11-12.

Rómer, F. (1868c). Kivonat a m tud. Akadémiai archaeológiai bizottságának jegyzőkönyvéből. Július 7-én tartott VII-dik rendes ülésben. *Archaeologiai Értesítő*, *1*, 12-13.

Rómer, F. (1878). *Compte-rendu de la huitième session à Budepest 1876. I. Résultats généreaux du mouvement archéologique en Hongrie*. Magyar Nemzeti Múzeum.

Rónai, A. (1964). A síkvidékek földtani kutatásának jelentősége. *Földtani Intézet Évi Jelentése 1961-ről*, 5-17.

Rónai, A. (1972). *Negyedkori üledékképződés és éghajlattörténet az Alföld Medencéjében: Quartärsedimentation und Klimageschichte im Becken der ungarischen Tiefebene (Alföld). Magyar Állami Földtani Intézet évkönyve 56. köt. 1. füz.* Műszaki Könyvkiadó.

Rónai, A. (1977). Negyedidőszaki kéregmozgások a Magyar medencében. *Földtani Közlöny*, *107,* 431-436.

Rónai, A. (1982). Komplex síkvidéki földtani kutatások és agrogeológiai kapcsolataik. *MTA X. Osztály Közleményei*, *15*, 183-188.

Rónai, A. (1985). Az Alföld földtana. *Acta Geologica Hungarica*, *21*, 1-445.

Rousseau, D. D., & Kukla, G. (1994). Late Pleistocene climate record in the Eustis loess section, Nebraska, based on land snail assemblages and magnetic susceptibility. *Quaternary Research*, *42*, 176-187.

RStudio. *Desktop Posit*. Retrieved 29 August 2023 from https://posit.co/download/rstudio-desktop/

Ruddiman, W. F. (2003). The anthropogenic greenhouse era began thousands of years ago. *Climatic Change*, *61*, 261-293.

Ruddiman, W. F. (2005). *Plows, Plagues, and Petroleum: How Humans Took Control of Climate*. Princeton University Press.

Sahney, S., Benton, M. J., & Ferry, P. A. (2010). Links between global taxonomic diversity, ecological diversity and the expansion of vertebrates on land. *Biology Letters*, *6 (4)*, 544-547.

Sajó, E., & Trummer, Á. (1934). *A magyar szikesek*. Pátria.

Scherf, E. (1935). Alföldünk pleisztocén és holocén rétegeinek geológiai és morfológiai viszonyai és ezeknek összefüggése a talajkutatással, különösen a sziktalajképződéssel. *Magyar Királyi Földtani Intézet Jelentése 1925-1928 évekről*, 265-273.

Sherratt, A. (1982). The development of neolithic and copper age settlement in the Great Hungarian plain part I: the regional setting. *Oxford Journal of Archaeology*, *1(3)*, 287-316.

Sherratt, A. (1983). The development of Neolithic and copper age settlement in the Great Hungarian plain part II: site survey and settlement dynamics. *Oxford Journal of Archaeology*, *2(1),* 13-41.

Sigmond, E. (1906). Alföldünk szikeseinek válfajairól. *Földtani Közlöny*, *36,* 389-403.

Sigmond, E. (1923). A hidrológiai viszonyok szerepe a szikesek képződésében. *Hidrológiai Közlöny, 3,* 5-9.

Sigmond, E. (1934). A Magyar Alföld szikeseinek jellemzése. In E. Sajó & A. Trummer (Eds.), *A magyar szikesek* (pp. 1-20). Patria Press.

Sparks, B. W. (1964). Non-marine Mollusca and Quaternary ecology. *The Journal of Animal Ecology, 33,* 87-98.

Stefanovits, P. (1963). *Magyarország talajai* (2nd edition ed.). Akadémiai Kiadó.

Stefanovits, P. (1972). *Talajtan*. Mezőgazda Kiadó.

Stieber, J. (1956). Anthrakotomische Untersuchung [Anthracological research]. *Folia Archaeologica, 8,* 3-11.

Stockmarr, J. (1971). Tablets with spores used in absolute pollen analysis. *Pollen et Spores, 13,* 614-621.

Strömpl, G. (1931). A szik geomorfológiája. *Földrajzi Közlemények, 4-5,* 62-74.

Stuiver, M., Reimer, P.J., Braziunas, T.F. (1998). High-precision radiocarbon age calibration for terrestrial and marine samples. *Radiocarbon, 40,* 1127-1151.

Sudnik-Wójcikowska, B., & Moysiyenko, I. I. (2013). Ukrainian kurgans as refugia of steppe flora and their role in steppe restoration. In H. Baumbach & P. S. (Eds.), *Steppenlebensräume Europas – Gefährdung, Erhaltungsmaßnahmen und Schutz [European Steppe Habitats – Threats, management and protection]* (pp. 201-210). Thüringer Ministerium für Landwirtschaft, Forsten, Umwelt und Naturschutz.

Sudnik-Wójcikowska, B., Moysiyenko, I. I., Zachwatowicz, M., & Jabłónska, E. (2011). The value and need for protection of kurgan flora in the anthropogenic landscape of steppe zone in Ukraine. *Plant Biosystems, 145,* 638-653.

Sugita, S. (1994). Pollen representation of vegetation in Quaternary sediments: theory and method in patchy vegetation. *Journal of Ecology, 82,* 881-897.

Sun, J., & Liu, T. (2000). Multiple origins and interpretations of the magnetic susceptibility signal in Chinese wind-blown sediments. *Earth and Planetary Science Letters, 180,* 287-296.

Sümeghy, J. (1937). A Nagykunság felszíni képződményei. In *Magyar Királyi Földtani Intézet Jelentése 1929-1932-ről* (pp. 409-436).

Sümegi, P. (1988). Jelentés a Hortobágy-Szálkahalmon végzett geomorfológiai, üledékföldtani és quartermalakológiai vizsgálatokról [Report of the geomorphological, sedimentological and quartermalacological analysis of Hortobágy-Szálkahalom]. In D. o. M. a. G. University of Debrecen (Ed.). Debrecen.

Sümegi, P. (1989). *Hajdúság felső-pleisztocén fejlődéstörténete finomrétegtani (üledékföldtani, őslénytani, geokémiai) vizsgálatok alapján* Debreceni Egyetem]. Debrecen.

Sümegi, P. (1992). Jelentés a sárrétudvari Őr-halmon végzett geomorfológiai, üledékföldtani vizsgálatokról [Report of the geomorphological, sedimentological analysis of Őr mound in Sárrét]. In D. o. M. a. G. Déri János Museum and University of Debrecen (Ed.).

Sümegi, P. (1994-1999). Régészeti geológia hivatalos speciális kollégium előadás és gyakorlat jegyzet- és ábraanyaga [The official notes and figures of archeogeology special course]. In D. o. M. a. G. University of Debrecen (Ed.), (pp. 211).

Sümegi, P. (1997). The Process of Sodification on Hortobágy in Space and Time according to geopedological investigation. In *Hydro-Petro-Geology and Hungary. A field trip across the country. Excursion guide.* (pp. 237-242). Magyarhoni Földtani Társulat.

Sümegi, P. (1998). Az utolsó 15000 év környezeti változásai és hatásuk az emberi kultúrákra Magyarországon [Environmental changes and their impact on human cultures in Hungary during the last 15000 years]. In G. Ilon (Ed.), *A régésztechnikusok kézikönyve [Manual for archaeological technicians]* (pp. 367-397). Savaria Múzeum.

Sümegi, P. (2001). *A negyedidőszak földtanának és őskörnyezettanának alapjai*. JATEPress.

Sümegi, P. (2002). *Régészeti geológia és történeti ökológia alapjai*. JATEPress.

Sümegi, P. (2003). *Régészeti geológia – tudományos interdiszciplinák találkozása [Archaeogeology – encounter of scientific interdisciples]* University of Szeged]. Szeged.

Sümegi, P. (2004a). *Jelentés a sárrétudvari Őr-halmon végzett környezettörténeti vizsgálatok eredményéroől [Report of the results of environmental historical analysis of Őr-mound in Sárrétudvar].*

Sümegi, P. (2004b). Hortobágy fejlődéstörténete. In Z. Ecsedi (Ed.), *Hortobágy madárvilága* (pp. 33-38). Hortobágyi Természetvédelmi Egyesület.

Sümegi, P. (2005). *Loess and Upper Paleolithic environment in Hungary*. Aurea Kiadó.

Sümegi, P. (2009). Ember és környezet kapcsolata a középső-bronzkorban: az őskori gazdasági tér fejlődése egy bronzkori tell geoarcheológiai és környezettörténeti feldolgozása nyomán [The relationship of man and environment during the Late Bronze Age: The evolution of a Bronze Age tell on the basis of geoarchaeological and environment historical analysis]. *Tiscium, 19,* 130-154.

Sümegi, P. (2012). Report on the results of the sedimentological survey of the Ecse Mound. In H. N. P. Directorate (Ed.). Debrecen.

Sümegi, P. (2013). Comparative geoarcheological report and environmental history of the Bronze Age tell of Polgár–Kenderföld. In M. Vicze, Poroszlai, I., Sümegi, P. (Ed.), *Hoard, Phase, Period? Round Table Conference on the Koszider Problem* (pp. 155-192). Matrica Múzeum.

Sümegi, P., Bede, Á., & Szilágyi, G. (2015a). Régészeti geológiai, geoarcheológiai és környezettörténeti elemzések régészeti lelóhelyeken–a földtudományok és a régészet kapcsolata [Archaeogeological, geoarchaeological and environment historical analysis in archaeological sites– the relationship of earth sciences and archaeology]. *Archeometriai Műhely, 12,* 135-150.

Sümegi, P., Bodor, E., & Törőcsik, T. (2005). The origins of sodification in the Hortobágy region in the light of the palaeoenvironmental studies at Zám–Halasfenék. In E. Gál, I. Juhász, & P. Sümegi (Eds.), *Environmental Archaeology in North-Eastern Hungary*. MTA Régészeti Intézet.

Sümegi, P., Bodor, E., & Törőcsik, T. (2006). A hortobágyi szikesedés eredete. In A. Kiss, G. Mezősi, & Z. Sümeghy (Eds.), *Táj, környezet és társadalom. Ünnepi tanulmányok Keveiné Bárány Ilona professzor asszony tiszteletére* (pp. 633-641). Szegedi Tudományegyetem.

Sümegi, P., & Boros, E. (2013). Origin and development of soda pans in the Carpathian Basin. In E. Boros, Z. Ecsedi, & J. Oláh (Eds.), *Ecology and Management of Soda Pans in the Carpathian Basin.* Hortobágy Environmental Association.

Sümegi, P., Gulyás, S., Molnár, D., Sümegi, B. P., Almond, P. C., Vandenberghe, J., Zhou, L., Pál-Molnár, E., Törőcsik, T., Hao, Q., Smalley, I., Molnár, M., & Marsi, I. (2018). New chronology of the best developed loess/paleosol sequence of Hungary capturing the past 1.1 ma: Implications for correlation and proposed pan Eurasian stratigraphic schemes. *Quaternary Sciences Reviews, 191,* 144-166.

Sümegi, P., & Hertelendi, E. (1998). Reconstruction of microenvironmental changes in Kopasz Hill loess area at Tokaj (Hungary) between 15,000–70,000 BP years. *Radiocarbon, 40,* 855-863.

Sümegi, P., Kozák, J., Magyari, E., & Tóth, Cs. (1998). A Szakáld-Testhalmi bronzkori tell geoarcheológiai vizsgálata [Geoarchaeological analyses of the Bronze Age tell of Szakáld-Testhalom]. *Acta Geographica, Geologica et Meteorologica Debrecina, 34,* 181-202.

Sümegi, P., Magyari, E., Dániel, P., Hertelendi, E., & Rudner, E. (1999). A kardoskúti Fehér-tó negyedidőszaki fejlődéstörténetének rekonstrukciója. *Földtani Közlöny, 129,* 479-519.

Sümegi, P., Magyari, E., Szántó, Z., Gulyás, S., & Dobó. (2002). Man and environment in the Late Neolithic of the Carpathian Basin – A preliminary geoarcheological report of Polgár–Csőszhalom. In R. Aslan, S. Blum, G. Kastl, F. Schweizer, & D. Thumm (Eds.), *MauerSchau, 2. Festschrift für Manfred Korfmann* (pp. 838-840). Verlag Bernard Albert Greiner.

Sümegi, P., Molnár, A., & Szilágyi, G. (2000). Szikesedés a Hortobágyon. *Természet Világa, 131,* 213-216.

Sümegi, P., Molnár, M., Jakab, G., Persaits, G., Majkut, P., Páll, D. G., Gulyás, S., Jull, A. J. T., & Törőcsik, T. (2011). Radiocarbon-dated paleoenvironmental changes on a lake and peat sediment sequence from the central part of the Great Hungarian Plain (Central Europe) during the last 25.000 years. *Radiocarbon*, *52,* 85-97.

Sümegi, P., & Molnár, S. (2007). The Kiritó meander: Sediments and the question of flooding. In A. Whittle (Ed.), *The Ecsegfalva project* (Vol. 21, pp. 67-82). Varia Archaeologica Hungarica.

Sümegi, P., Molnár, S., Herbich, K., Imre, M., Szegvári, G., Gulyás, S., & Timár, G. (2013b). Late Neolithic man and environment in the Carpathian Basin: A preliminary geoarcheological report from Csőszhalom at Polgár. In M. O. Baldia, T. K. Perttula, & D. S. Frink (Eds.), *Comparative archaeology and paleoclimatology. Socio-cultural responses to a changing world* (pp. 139-145).

Sümegi, P., & Náfrádi, K. (2015). A radiocarbon-dated cave sequence and the Pleistocene/Holocene transition in Hungary. *Open Geosciences*, *7,* 783-798.

Sümegi, P., Náfrádi, K., Molnár, D., & Sávai, S. (2015b). Results of paleoecological studies in the loess region of Szeged-Öthalom (SE Hungary). *Quaternary International*, *372,* 66-78.

Sümegi, P., Persaits, G., & Gulyás, S. (2012). Woodland-Grassland Ecotonal Shifts in Environmental Mosaics: Lessons Learnt from the Environmental History of the Carpathian Basin (Central Europe) During the Holocene and the Last Ice Age Based on Investigation of Paleobotanical and Mollusk Remains. In R. W. Myster (Ed.), *Ecotones Between Forest and Grassland* (pp. 17-57). Springer Press.

Sümegi, P., Rudner, E., & Törőcsik, T. (2012). Magyarországi pleisztocén végi és kora-holocén környezeti változások kronológiai, tér és időbeli rekonstrukciós problémái [Chronological and spatial resonstruction problems of environment changes in Hungary during the Late Pleistocene and Early Holocene]. In B. Kolozsi (Ed.), *Proceedings of the IV. MOMOSZ Meeting of Prehistoric Researchers* (pp. 279-298). Déri Múzeum.

Sümegi, P., & Szilágyi, G. (2010). A Hortobágy új felszínfejlődési modellje és a szikesedés eredete. *Acta Biologica Debrecina, 22,* 37-36.

Sümegi, P., & Szilágyi, G. (2011). A quarter-malacological inventory of Hungarian kurgans. In Á. Pető & A. Barczi (Eds.), *Kurgan Studies: An environmental and archaeological multiproxy study of burial mounds in the Eurasian steppe zone*. Archeopress, British Archaeological Reports 2238.

Sümegi, P., Szilágyi, G., Gulyás, S., Jakab, G., & Molnár, A. (2013). The Late Quaternary Paleoecology and Environmental History of the Hortobágy, a unique Mosaic Alkaline Steppe from the Heart of the Carpathian Basin, Central Europe. In M. B. M. Prieto & T. B. Diaz (Eds.), *Steppe Ecosystems Biological Diversity, Management and Restoration* (pp. 165-194). Nova Publishers.

Sümegi, P., & Törőcsik, T. (2010). Magyarország növényzetének története. *Rosalia, 1,* 11-13.

Svensson, A., Andersen, K.K., Bigler, M., Clausen, H.B., Dahl-Jensen, D., Davies, S.M., Johnsen, S.J., Muscheler, R., Parrenin, F., Rasmussen, S.O. (2008). A 60 000 year Greenland stratigraphic ice core chronology. *Climate of the Past, 4,* 47-57.

Szabó, J. (1864). Hevesmegye földtani leírása. In A. F. Montedégói (Ed.), *Heves és Külső Szolnok törvényesen egyesült vármegyéknek leírása*. Érseki Lyceum Könyv- és Kőnyomda.

Szabolcs, I. (1957). Szikes talajaink genetikája és jelentősége hasznosításuk szempontjából. *MTA Agrártudományi Osztály Közleményei, XI*, 297-306.

Szabolcs, I. (1961). *A vízrendezések és öntözések hatása a tiszántúli talajképződési folyamatokra*. Akadémiai Kiadó.

Szabolcs, I. (1966). *A genetikus üzemi talajtérképezés m´odszerkönyve [Methods of genetic soil mapping]*. OMMI.

Székyné Fux, V., & Szepesi, K. (1959). Az "alföldi" lösz szerepe a szikes talajképződésben. *Földtani Közlöny, 89,* 53-64.

Szelepcsényi, Z., Breuer, H., Ács, F., & Kozma, I. (2009a). Biofizikai klímaklasszifikációk (1. rész: a módszerek bemutatása). *Légkör, 54*(3), 21-26.

Szelepcsényi, Z., Breuer, H., Ács, F., & Kozma, I. (2009b). Biofizikai klímaklasszifikációk (2. rész: magyarországi alkalmazások). *Légkör*, *54*(4), 18-22.

Szelepcsényi, Z., Breuer, H., Kis, A., Pongrácz, R., & Sümegi, P. (2018). Assessment of projected climate change in the Carpathian Region using the Holdridge life zone system. *Theoretical and Applied Climatology, 131,* 593-610.

Szelepcsényi, Z., Breuer, H., & Sümegi, P. (2014a). Hogyan változtak a Kárpát-medence régiójának életzónái a múlt században? [How did the lifestyle of the Carpathian Basin region change in the last century?]. In P. Sümegi (Ed.), *Környezetföldtani és környezettörténeti kutatások a dunai Alföldön* (pp. 163-172). GeoLitera Kiadó.

Szelepcsényi, Z., Breuer, H., & Sümegi, P. (2014b). The climate of Carpathian Region in the 20th century based on the original and modified Holdridge life zone system. *Central European Journal of Geosciences, 6,* 293-307.

Szendrei, G., & Tóth, T. (2006). A magyarországi szikes talajok felszíni sóásványai. *Topographia Mineralogica Hungariae, 9,* 47-60.

Szilágyi, G., Gulyás, S., Vári, T. Z., & Sümegi, P. (2024). Late Quaternary Paleoecology and Environmental History of the Hortobágy, an Alkaline Steppe in Central Europe. *Diversity*, *16*(1). https://doi.org/10.3390/d16010067

Szilágyi, G., Náfrádi, K., & Sümegi, P. (2019). A preliminary chronological study to understand the construction phases of a Late Copper–Early Bronze Age kurgan (kunhalom). *Central European Geology*, *62(3)*, 1-29.

Szilágyi, G., Sümegi, P., Gulyás, S., & Molnár, D. (2018). Revision of the Age of Construction Phases of a Mound Dated to the Late Copper–Early Bronze Age in Eastern Hungary Relying on 14C-Based Chronologies. *Radiocarbon*, *60(5)*, 1403–1412.

Szilágyi, G., Sümegi, P., Molnár, D., & Sávai, S. (2013). Mollusc-based paleoecological investigations of the Late Copper–Early Bronze Age earth mounds (kurgans) on the Great Hungarian Plain. *Central European Journal of Geosciences*, *5*, 465-479.

Szilágyi, M. (2008). Változások az Alföldön az i.e. 5. évezred derekán [Changes in the Great Hungarian Plain in the middle of the 5th millennia]. *Első Század*, *2*, 361-427.

Szirmai, O., Czóbel, S., & Nagy, J. (2005). Relationship between landuse changes and forest steppe species in new Hungarian forest steppe area. *Cereal Research Communications*, *33*, 313-316.

Szöőr, G., Sümegi, P., & Balázs, É. (1991). Sedimentological and geochemical facies analysis Upper Pleistocene fossil soil zones discovered in the Hajdúság region, NE Hungary. In M. Pécsi & F. Schweitzer (Eds.), *Quaternary environment in Hungary*. Akadémiai Kiadó.

Szöőr, G., Sümegi, P., & Balázs, É. (1992). A Hajdúság területén feltárt felső pleisztocén fosszilis talajok szedimentológiai és geokémiai fácieselemzése. In G. Szöőr (Ed.), *Fáciesanalitikai, paleobiogeokémiai és paleoökológiai kutatások* (pp. 81-91). MTA Debreceni Bizottsága.

Tarasov, P. E., Volkova, V. S., Webb III, T., Guiot, J., Andreev, A. A., Bezusko, L. G., Bezusko, T. V., Bykova, G. V., Dorofeyuk, N. I., Kvavadze, E. V., Osipova, I. M., Panova, N. K., & Sevastyanov, D. V. (2000). Last glacial maximum biomes reconstructed from pollen and plant macrofossil data from northern Eurasia. *Journal of Biogeography*, *27*, 609-620.

Tarasov, P. E., Webb III, T., Andreev, A. A., Afanaseva, N. B., Berezina, N. A., Bezusko, L. G., Blyakharchuk, T. A., Bolikhovskaya, N. S., Cheddadi, R., Chernavskaya, M. M., Chernova, G. M., Dorofeyuk, N. I., Dirksen, V. G., Elina, G. A., Filimonova, L. V., Glebov, F. Z., Guiot, J., Gunova, V. S., Harrison, S. P., . . . Zernitskaya, V. P. (1998). Present-day and mid-Holocene biomes reconstructed from pollen and plant macrofossil data from the Former Soviet Union and Mongolia. *Journal of Biogeography*, *25*, 1029-1053.

Teschedik, S. (1804). Über die Kultur und Benützung der sogenannte Székes-. Felder in der Gegend an der Theiss. In *In: Patriotisches Wochenblatt für der Gegend an der Theiss. In: Patriotisches Wochenblatt für Ungarn*. Jon K. Lübeck.

Tímár, G., Gábris, G. (2008). Estimation of water conductivity of the natural flood channels on the Tisza flood-plain, the Great Hungarian Plain. *Geomorphology*, *98(3-4)*, 250-261.

Timár, G., Sümegi, P., & Horváth, F. (2005). Late Quaternary dynamics of Tisza River: Evidence of climatic and tectonic controls. *Tectonophysics*, *410*, 97-110.

Timmermann, A., Menviel, L., Okumura, Y., Schilla, A., Merkel, U., Timm, O., Hu, A., Otto-Bliesner, B., Schulz, M. (2010). Towards a quantitative understanding ofmillennial-scale Antarctic warming events. *Quaternary Science Reviews, 29,* 74-85.

Tóth, A. (1998). Veszélyeztetett löszgyep reliktum foltok a nagykunsági kunhalmokon [Threatened loess relict patches on the kurgans of the Nagykunság]. *Kitaibelia, 3,* 329-330.

Tóth, A., & Tóth, Cs. A. (2003). Kunhalmok állapotfelmérése a Hortobágy déli pusztáin és a szomszédos hajdúsági területeken [Kurgan survey in the southern plains of Hortobágy and the adjacent area of Hajdúság]. In A. Tóth (Ed.), *Tisza-völgyi tájváltozások [Landscape changes in the Tisza Valley]* (Vol. 95-111). Alföld-kutatásért Alapítvány.

Tóth, Cs., Joó, K., & Barczi, A. (2015). Lyukas Mound: One of the many prehistoric tumuli in the Great Plain. In D. Lóczy (Ed.), *Landscapes and Landforms of Hungary* (pp. 255-262). Springer.

Tóth, Cs. A. (2006). Az országos kunhalom-felmérés eredményei és tapasztalatai: A természetvédelmi szempontból értékes kunhalmok kijelölése [Results and experiences of the national kurgan survey: Designation of valuable kurgans in a natural conservation point of view]. III. Conference of Hungarian Geography, Budapest.

Tóth, Cs. A., Pethe, M., & Hatházi, A. (2014). The application of earth science-based analyses on a twin-kurgan in Northern Hungary. *Carpathian Journal of Earth And Environmental Sciences, 9,* 11-20.

Tóth, Cs. A., Prónay, Z., Braun, M., Nagy, P., Pethe, M., Tildy, P., Buró, B., Kertész, T., McIntosh, R. W., & Molnár, M. (2018). Geoarchaeological study of Szálka and Vajda kurgans (Great Hungarian Plain) based on radiocarbon and geophysical analyses. *Radiocarbon, 60(5),* 1425-1437.

Tóth, T., Kuti, L., Fórizs, I., & Kabos, S. (2001). A talaj sótartalmának változása a hortobágyi Nyírőlapos mintaterületen. *Agrokémia es Talajtan, 50,* 409-426.

Townson, R. (1797). *Travels in Hungary, with a short account of Vienna in the year 1793*. G G & J Robinson.

Török, P., Vida, E., Deák, B., Lengyel, S., & Tóthmérész, B. (2011). Grassland restoration on former croplands in Europe: An assessment of applicability of techniques and costs. *Biodiversity and Conservation, 20,* 2311-2331.

Treitz, P. (1898). Szikes talajok Magyarországon. *Természettudományi Közlöny, 45-48,* 121-128, Article 1.

Treitz, P. (1917). Jelentés az 1916. évben végzett agrogeológiai munkálatról. II. rész: A szikes talajok szerkezete Kiskunfélegyháza határában. *Magyar Királyi Földtani Intézet Jelentése 1916-ról,* 499-510.

Treitz, P. (1925). Az agrogeológia múltja és feladatai hazánkban. *Földtani Közlöny, 55,* 20-25.

Troels-Smith, J. (1955). Karakterisering af lose jordater (Characterisation of Unconsolidated Sediments). *Danmarks Geologiske Undersogelse, 3,* 39-73.

Újvári, G., Molnár, M., Novothny, Á., Páll-Gergely, B., Kovács, J., & Várhegyi, A. (2014). AMS 14C and OSL/IRSL dating of the Dunaszekcső loess sequence, Hungary: Chronology for 20 to 150 ka and implications for establishing reliable age-depth models for the last 40 ka. *Quaternary Science Reviews, 106,* 140-154.

Vaday, A. (2004). Chronological tables. In Z. Visy (Ed.), *Hungarian Archeology at the Millenium* (pp. 473-477). Nemzeti Kulturális Örökség Minisztériumának (Teleki László Alapítvány) Kiadványa.

Van Meerbeeck, C. J., Renssen, H., & Roche, D. M. (2009). How did Marine Isotope Stage 3 and Last Glacial Maximum climates differ? – Perspectives from equilibrium simulations. *Clim. Past, 5,* 33–51

Vanuxem, L. (1843). On the ancient oyster shell deposits observed near the Atlantic coast of the United States. In *Reports of the Association of the First, Second and Third meetings of the American Geologists and Naturalists* (pp. 21). Gould, Kendall and Lincoln Press.

Várallyay, G. (1967). A Duna-völgyi talajok sófelhalmozódási folyamatai. *Agrokémia es Talajtan*, *16,* 327-356.

Várallyay, G. (1989). Soil water problems in Hungary. *Agrokémia es Talajtan*, *38(3-4),* 577-595.

Várallyay, G. (1993). Soils in the region between the rivers Danube and Tisza (Hungary). In J. Szujkó-Lacza & D. Kováts (Eds.), *The flora of the Kiskunság National Park*. Magyar Természettudományi Múzeum.

Várallyay, G. (1999). Szikesedési folyamatok a Kárpát-medencében. *Agrokémia es Talajtan, 48,* 399-418.

Vári, T. Z., Gulyás, S., & Sümegi, P. (2023). Reconstructing the Paleoenvironmental Evolution of Lake Kolon (Hungary) through Integrated Geochemical and Sedimentological Analyses of Quaternary Sediments. *Quaternary, 6(3),* 39.

Vértes, L., Jánossy, D., Herrmann, M., & Stieber, J. (1956). Ausgrabungen in der Petényi und Peskő Höhle (Bükk Gebirge) [Excavations in the Petényi and Peskő Caves (Bükk Hills)]. *Folia Archaeologica, 8,* 3-22.

Vona, M., & Penksza, K. (2004). A szentesi Kántor-halom vegetációjának változása és ennek összefüggése a talaj vízháztartásával [Change of the vegetation on the Kantor kurgan and its relations with the soil water regime]. *Tájökológiai Lapok, 2,* 341-348.

Vörös, G. (2002). A vaskúti szarmata halmok leletei. Adatok a szarmata koporsók és gerendakamrák köréhez [Findings of the Sarmatian mounds in Vaskút. Data about the Sarmatian coffins and timber chambers]. *Les annales du Musée Ferenc Móra, Studia Archaeologica, 8,* 157-176.

Walker, M., Johnsen, S., Rasmussen, S. O., Popp, T., Steffensen, J. P., Gibbard, P., Hoek, W., Lowe, J., Adrews, J., Björck, S., Cwynar, W., Hughen, K., Kershaw, P., Kromer, B., Litt, T., Lowe, D. J., Nakagawa, T., Newnham, R., & Schwander, J. (2009). Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. *Journal of Quaternary Science, 24,* 3-17.

Walker, M. J. C., Björck, S., Lowe, J.J., Cwynar, L.C., Johnsen, S., Knudsen, K.L., Wohlfarth, B. and INTIMATE GROUP. (1999). Isotopic "events" in the GRIP ice core: A stratotype for the Late Pleistocene. *Quaternary Science Reviews, 18,* 1143–1150.

Welter-Schultes, F. (2012). *European non-marine mollusc, a guide for species identification*. Planet Poster Edition.

Wesche, K., & Treiber, J. (2012). Abiotic and biotic determinants of steppe productivity and performance – a view from Central Asia. In M. J. A. Werger & M. A. van Staalduinen (Eds.), *Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World* (pp. 3-43). Springer.

Willis, K. J. (2007). Impact of the early Neolithic Körös culture on the landscape: evidence from palaeoecological investigations of Kiri-tó. In A. Whittle (Ed.), *The Early Neolithic on the Great Hungarian Plain: investigations of the Körös culture site of Ecsegfalva 23, Co. Békés* (pp. 83-99).

Willis, K. J., Braun, M., Sümegi, P., & Tóth, A. (1997). Does soil change cause vegetation change or vice-versa? *Ecology, 78*, 740-750.

Willis, K. J., Rudner, E., Sümegi, P. (2000). The full-glacial forests of central and southeastern Europe: Evidence from Hungarian palaeoecological records. *Quaternary Research*, *53*, 203-213.

Willis, K. J., Sümegi, P., Braun, M., Bennett, K. D., & Tóth, A. (1998). Prehistoric land degradation in Hungary: who, how and why? *Antiquity*, *72*, 101-113.

Willis, K. J., Sümegi, P., Braun, M., & Tóth, A. (1995). The Late Quaternary environmental history of Bátorliget, N.E. Hungary. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *118*, 25-47.

Willis, K. J., Sümegi, P., Braun, M., Bennett, K.D., Tóth, A. (1998). Prehistoric land degradation in Hungary: who, how and why? *Antiquity*, *72*, 101-113.

Xu, X. W., Qiang, X. K., Fu, C. F., Zhao, H., Chen, T., Sun, Y. F. . (2012). Characteristics of frequency-dependent magnetic susceptibility in Bartington MS2 and Kappabridge MFK1-FA, and its application in loess-paleosol, red clay and lacustrine sediments. *Chinese Journal of Geophysics*, *55(1)*, 197-206.

Yiou, P., Jouzel, J., Johnsen, S., Rögnvaldsson, Ö. E. (1995). Rapid oscillations in Vostok and GRIP Ice Cores. *Geophyical Research Letters*, *22*, 2179–2182.

Zhu, R., Q. Liu, Q., & Jackson, M. J. (2004). Paleoenvironmental significance of the magnetic fabrics in Chinese loess-paleosols since the last interglacial (<130 ka). *Earth and Planetary Science Letters*, *221*, 55-69.

Zoltai, L. (1925). *Települések, egyházas és egyházatlan falvak Debrecen város mai határa és külső birtokai területén a XI–XV-ik századokban*. Melius Kiadó.

Zoltai, L. (1938). *Debreceni halmok, hegyek*. Városi Nyomda.

Zólyomi, B. (1952). Magyarország növénytakarójának fejlődéstörténete az utolsó jégkorszaktól. *MTA Biológiai Osztályának Közleményei*, *1*, 491-544.

Zólyomi, B. (1957). Der Tatarenahorn-Eichen-Lösswald der zonalen Waldsteppe [Oak forests with Tatarian Maple in the forest steppe zone]. *Acta Botanica Hungarica*, *3*, 401-424.

Zólyomi, B. (1969). Földvárak, sáncok, határmezsgyék és a természetvédelem [Earthworks, earthen fortifications, unplowed land strips and nature conservation]. *Természet Világa*, *100*, 550-553.

Zólyomi, B. (1987). Coenotone, ecotone and their role in preserving relic species. *Acta Botanica Hungarica*, *33*, 3-18.

Zólyomi, B., & Fekete, G. (1994). The Pannonian loess steppe: Differentation in space and time. *Abstracta Botanica*, *18*, 29-41.

Summary

In the first and still the only monograph of the Hortobágy National Park (Béres, Bodó, & Jakucs, 1976) the secondary character of the alkaline grassland-wetland mosaics was assumed as a starting point for the management of the grassland-wetland mosaics of the Park. According to the prevailing academic views at the time of the foundation of the Hortobágy National Park there were two major human activities that significantly changed the original character of the flat landscape of the Hortobágy region. The first one was supposed to be, like in other lowland areas of Europe, the cutting down of forests to create pastures for grazing domestic animals, mostly cattle and sheep. In the only monograph of the Hortobágy National Park (Béres, Bodó, & Jakucs, 1976) the secondary character of the alkaline grassland-wetland mosaics was assumed as a starting point for the future management of the grassland-wetland mosaics of the National Park. However, according to a recent critical source analysis, the presence of continuous forests in the Hortobágy region was assumed on the basis of the misinterpretation of a royal charter issued in the mid-15th century (Molnár, 2009). Based on this source the presence of extensive woodlands was presumed for the period preceding the flood control measures. Thus extensive deforestation and desiccation was blamed to initiate alkalinization. However, *Zsolt Molnár* was the first to point out that no information was given regarding the presence of woodlands in the Hortobágy area in the referred charter.

The second significant human intervention that was supposed to play an important role in the significant extension alkaline areas was the landscape scale change of the water regime of the Hortobágy by the major river regulation and drainage works started in the mid-19th century. This assumption is contradicted by descriptions of naturalists, such as *Pál Kitaibel* (Lőkös, 2001) and *Robert Townson* (Townson, 1797), indicating the presence of alkaline soils and vegetation in large areas before the start of hydroregulation measures in the Hortobágy region. These observations are also supported by the relevant map sheets of the first military mapping survey of Hungary and their description (Pók, 1994), undertaken in the second half of the 18th century. In addition, the presence of endemic plant species in the Hortobágy National Park, which occur exclusively in alkaline habitats, also indicates a much earlier appearance of such vegetation in the region (Lesku & Molnár, 2007).

The secondary character of the Hortobágy landscape seemed to be confirmed by the theories on the development of alkaline soils, which completely excluded the possibility of alkalinization during the glacial periods, stating that the environmental conditions in the Hungarian Lowlands were not favourable for the process (Miháltz, 1947). As a result, the presence of glacial alkaline deposits, or signs of prehistoric alkalization were not assumed and searched for in the Great Hungarian Plain.

In 1988 a multi-proxy paleoecological study of an undisturbed core series from the eastern edge of the Hortobágy landscape succeeded in identifying an alkaline paleosol horizon dated between 30-40,000 years beneath the glacial loess deposits (Sümegi, 1989, 2001, 2003; Szöőr, Sümegi, & Balázs, 1991, 1992). These studies provided consistent evidence that conditions favourable to alkalinization may have developed during the last glacial cycle dated to MIS3 as part of an intense brief interstadial warming (Sümegi, 1989). In addition, cores taken from Bronze Age burial mounds also revealed the presence of buried chernozem and alkaline soils in the Hortobágy region in the Early Holocene as well (Sümegi, 1989; Sümegi & Szilágyi, 2011).

The general objective of my research was to contribute to the future conservation management of the Hortobágy National Park through the identification of the milestones of the late Quaternary environmental history of the Hortobágy landscape. To achieve this, I have implemented a multi-proxy study and analysis of a complete fluvial cycle dating back to 50,000 years in the largest wetland-grassland mosaic habitat complex of the Hortobágy National Park, the Kunkápolnás marsh system (Szilágyi et al., 2024).

The specific objectives of my research and the main questions to be answered were as follows:

- Are the alkaline soils of the Hortobágy of primary or secondary origin?
- How the water regime of the Hortobágy landscape developed and functioned until the hydroregulation measures started in the mid-19th century?
- What were the major stages of vegetation changes of the area over the last 50,000 years, particularly with regard to the occurrence of alkaline habitats?
- How much did human activity change the landscape of Hortobágy in the second half of the Holocene?
- What lessons can be learned from environmental history and landscape change for conservation management?

The study area of my research is located in the southwestern part of the Hortobágy National Park, including two sampling points, a former riverbed (Róna Basin) and a kurgan built by the people of the Yamnaja culture. Samples were taken by undisturbed core drilling for both sampling points, which are only 700 m apart. The overall sampling and processing procedure was based on the international Quaternary paleoecological method of Birks & Birks (Birks & Birks, 1980). A full range of analyses, including geochronological, sedimentological, geochemical, macrobotanical, malacological and palynological examinations, were carried out on the samples from the Róna Basin, while only the first three (geochronology, sedimentology and geochemistry) were undertaken on the samples of the Ecse mound.

The following conclusions and recommendations can be drawn from the information obtained from the studies.

- The Hortobágy alkaline soils developed as a result of natural geological processes and have been present in the central and southern part of the Hortobágy National Park for tens of thousands of years. Conditions favourable to alkalinization had already developed during the last glacial cycle, dated to MIS3, as part of an intense brief interstadial between 25-30,000 years BP.
- Based on sedimentological and geochemical data, the following major hydrological changes lead to the development of the water regime characterizing the landscape until the middle of the 19th century. A fluvial sedimentary phase had characterized the studied riverbed until 25-27,000 years BP, followed by a cut-off meander one to 15-18,000 years, when River Tisza had occupied its current valley, separating the Hortobágy on its left side from the alkaline areas of the Borsodi Mezőség on the right, and the region was no longer the floodplain of the Sajó-Hernád river-system.

- By the collective analysis and interpretation of the pollen, macrobotanical, and malacological data I have been able to demonstrate that the first patches of alkaline vegetation were established during the cold maximum of the glacial period in the study area. General alkalinization and a drier steppe phase became widespread in the region with the gradual warming of the climate from the Late Glacial to about 12,000–13,000 years. It appears that no forest phase was established in the area at the beginning of the Early Holocene, but a mosaic vegetation structure of a forest–steppe developed, where trees occurred only at the margins of the former watercourses.
- Through the joint interpretation of the results of my paleoecological studies and the available archaeological information I have shown that it is unlikely that there were significant human-induced changes in the character of the Hortobágy landscape in the second half of the Holocene, which was most probably only suitable for animal keeping in the last 5-6000 years. The Yamnaja culture was represented by large livestock keeping human communities, therefore it is unlikely that they changed the character of the Hortobágy landscape beyond the construction of the kurgans. Their massive appearance in the period of 3100/3000-2600/2500 BC in the Great Hungarian Plain, including the Hortobágy landscape indicate the beginning of the period, during which the land management by domestic animals gradually increased and eventually completely took over habitat management, i.e., the grazing role of large ungulates, such as the wild horse, aurochs and the European bison.
- Hortobágy National Park, Hungary's largest protected area, was established in 1973 in the central part of the Hortobágy landscape, which was little affected by the human interventions of the past 150 years, therefore the natural alkaline grassland–wetland complexes continue to dominate the landscape to this day. The two critical issues of the management of the steppe ecosystem are the establishment of a proper grazing and hydrological, i.e. water supply system. The recently legislated zoning system, including not only a management-oriented zonation within the park, but also the designation of a more than 90,000 ha large buffer zone around it, provides a sound basis for the conservation management of the Hortobágy National Park in the future. Of all the management tasks, the reconstruction of the hydrological system at landscape level appears to be the most important, the importance of which is underlined by the challenges posed by climate change.

In 1999, the Hortobágy National Park – the *Puszta* property was inscribed on the UNESCO World Heritage List under cultural criteria as a cultural landscape. In light of the recent scientific results providing evidence on the primary, natural origin of the alkaline grassland–wetland complexes of the site, as well as based on the limited occurrence of alkaline and sodic areas in Eurasia (Boros & Kolpakova, 2018), it is suggested to the relevant Hungarian authorities to nominate at least the southern "puszta" units of the Hortobágy National Park (Kunmadarasi, Nagyiváni, Zám, Pentezug, Angyalháza, Szelencés and Borzas) to the World Heritage List under natural criteria as well.

Összefoglalás

A Hortobágyi Nemzeti Parkról szóló máig egyetlen monográfiában (Béres, Bodó, & Jakucs, 1976) a szikes gyep - vizes élőhely mozaikok másodlagos jellegét vették alapul a Nemzeti Park későbbi kezelésének kiindulópontjaként. A Hortobágyi Nemzeti Park alapításának idején uralkodó tudományos nézetek szerint két olyan jelentős emberi beavatkozás történt, amelyek jelentősen megváltoztatták a Hortobágy kistáj eredeti, ősi, nagyrészt erdők által borított jellegét.

Az első ilyen tájléptékű hatás - Európa más alföldi területeihez hasonlóan - az erdők kiirtása volt annak érdekében, hogy legelőket hozzanak létre a háziállatok, főként szarvasmarhák és juhok tartására. Egy nemrégiben készült kritikai forráselemzés szerint azonban a Hortobágy térségében az összefüggő erdők jelenlétét egy 15. század közepén kiadott királyi oklevél téves értelmezése alapján feltételezték (Molnár, 2009). E forrás alapján, a neolitikum hajnalán összefüggő erdőségek jelenlétét vélelmezték a Hortobágyon, és a szikes területek térhódításának legfőbb okaiként az erdőirtást és a kiszáradást azonosították. Elsőként *Molnár Zsolt* hívta fel a figyelmet arra, hogy a hivatkozott oklevélben valójában semmi nem utal erdőségek jelenlétére a Hortobágyon.

A második jelentős emberi beavatkozás, ami a feltételezések szerint fontos szerepet játszott a szikes területek jelentős kiterjedésében, a Hortobágy vízháztartásának táji léptékű megváltoztatása volt a 19. század közepén megkezdett nagy folyószabályozási és lecsapolási munkálatok révén. Ennek olyan természettudósok leírásai mondanak ellent, mint *Kitaibel Pál* (Lőkös, 2001) és *Robert Townson* (Townson, 1797), melyek szerint nagy területeken szikes talajok és növényzet volt jelen a Hortobágy térségében a XVIII. században, már a vízszabályozási és mentesítési munkák megkezdése előtt. Ezeket a megfigyeléseket Magyarország 18. század végi, első katonai felmérésének vonatkozó térképlapjai, és azok leírása is alátámasztják (Pók, 1994). Emellett a Hortobágyi Nemzeti Parkban kizárólag szikes élőhelyeken előforduló, endemikus növényfajok jelenléte is arra utal, hogy az ilyen növényzet sokkal korábban jelent meg a térségben.

A hortobágyi táj másodlagos jellegét látszottak megerősíteni a szikes talajok kialakulásáról szóló elméletek is, melyek teljesen kizárták a szikesedés lehetőségét a jégkorszak folyamán azzal, hogy az Alföldön nem voltak adottak a szikesedés környezeti feltételei (Miháltz, 1947). Ennek következtében nem feltételezték, illetve nem is keresték a jégkori szikes lerakódások jelenlétét, vagy az őskori szikesedés jeleit az Alföldön.

1988-ban a Hortobágy keleti peremén mélyített zavartalan magfúrás paleoökológiai vizsgálatával sikerült egy 30-40.000 év közé datált paleoszikes talajhorizontot azonosítani a jégkorszaki löszlerakódások alatt (Sümegi, 1989, 2001, 2003; Szöőr, Sümegi és Balázs, 1991, 1992). A fúrásmintán végzett vizsgálatok egyértelműen bizonyították, hogy a szikesedés számára kedvező körülmények már a MIS3-ra datált, utolsó jégkorszaki ciklus folyamán alakultak, egy rövid, de intenzív interstadiális felmelegedés részeként (Sümegi, 1989). Ezen felül, a bronzkori sírhalmokból vett mintákban a kora holocénben is kimutatták eltemetett hidromorf csernozjom és szikes talajok jelenlétét a Hortobágyon (Sümegi, 1989; Sümegi és Szilágyi, 2011).

Kutatásom általános célkitűzése az volt, hogy a Hortobágy késő negyedidőszaki környezettörténete legfontosabb mérföldköveinek azonosításával hozzájáruljak a Hortobágyi Nemzeti Park jövőbeni természetvédelmi kezelésének megalapozásához. Ennek érdekében a Hortobágyi Nemzeti Park legnagyobb gyep-vizes élőhely komplexuma, a Kunkápolnási-mocsár területén egy 50.000 évre visszanyúló, teljes fluviális ciklus komplex vizsgálatát és elemzését végeztem el (Szilágyi et al., 2024).

Kutatásom konkrét célkitűzései és a megválaszolandó fő kérdések a következők voltak:

- A Hortobágy szikes (szolonyec) talajai elsődleges vagy másodlagos eredetűek-e?
- Hogyan alakult ki és működött a hortobágyi táj vízrendszere a XIX. század közepén megkezdett vízszabályozási intézkedésekig?
- Melyek voltak a terület vegetációjának főbb változásai az elmúlt 50 000 év során, különös tekintettel a szikes élőhelyek megjelenésére és előfordulására?
- Mennyire változtatta meg az emberi tevékenység a Hortobágy tájképét a holocén második felében?
- Milyen, a természetvédelemi kezelés szempontjából releváns következtetéseket lehet levonni a táj környezeti történetéből és változásaiból?

Kutatásom vizsgálati területe a Hortobágyi Nemzeti Park délnyugati részén helyezkedik el, és két mintavételi pontot, egy egykori folyómedret (Róna-fenék) és egy a Yamnaja kultúra képviselői által épített kurgánt foglal magában. A mintavétel az egymástól légvonalban mindössze 700 m távolságra elhelyezkedő két mintavételi ponton zavartalan magfúrással történt. A teljes mintavételi és feldolgozási eljárás Birks & Birks nemzetközi negyedidőszaki paleoökológiai módszerén alapult (Birks & Birks, 1980). A Róna-fenékből származó mintákon teljes körű elemzések - geokronológiai, szedimentológiai, geokémiai, makrobotanikai, malakológiai és palinológiai - elvégzésére került sor, míg az Ecse-halom esetében az első három elemzést (geokronológia, szedimentológia és geokémia) végeztük el.

A kutatásom során feldolgozott adatokból és információkból az alábbi következtetések vonhatók le, illetve ajánlások fogalmazhatók meg:

- A hortobágyi szikes talajok természetes geológiai folyamatok eredményeként alakultak ki, és a Hortobágyi Nemzeti Park középső és déli részén több tízezer éve jelen vannak. A szikesedésnek kedvező feltételek már az utolsó, MIS3-ra datált jégkorszak során kialakultak, egy intenzív, rövid interstadiális időszak részeként, 25-30.000 év BP között.
- A szedimentológiai és geokémiai adatok alapján a következő főbb hidrológiai változások vezettek a tájat a 19. század közepéig jellemző vízrendszer kialakulásához. A vizsgált folyómedret BP 25-27.000 évig egy fluviális üledékképződési fázis jellemezte, majd a 15-18.000 év közötti időszakig egy lefűződött meander szakasz következett, amikor a Tisza folyó elfoglalta jelenlegi helyét, elválasztva a bal parti Hortobágyot a folyó jobb partján fekvő Borsodi Mezőség szikes területeitől. Innentől kezdve a Hortobágy megszűnt a Sajó-Hernád folyórendszer árterületének lenni.

- A pollen-, makrobotanikai és malakológiai adatok együttes elemzésével és értelmezésével sikerült kimutatnom, hogy a szikes növényzet első foltjai a jégkorszak hidegmaximuma idején alakultak ki a vizsgált területen. Az általános szikesedés és a szárazabb sztyeppfázis az éghajlat fokozatos felmelegedésével a késő-glaciális időszaktól körülbelül 12-13.000 éves korig terjedt el a térségben. Úgy tűnik, hogy a korai holocén kezdetén nem erdőfázis, hanem egy erdősztyepp mozaikos vegetációs struktúrája alakult ki a Hortobágy déli részén, ahol fák csak az egykori vízfolyások mentén fordultak elő.
- Paleoökológiai vizsgálataim eredményeinek, és a rendelkezésre álló régészeti adatok együttes értelmezésével nem valószínűsíthető, hogy a holocén második felében jelentős ember okozta változások történtek volna a Hortobágy tájkarakterében, ami az elmúlt 5-6000 évben nagyrészt csak legeltető állattartásra volt alkalmas. A Yamnaja kultúrát állattartó emberi közösségek képviselték, akik a kurgánok építésén túl nem változtatták meg a hortobágyi táj jellegét. Tömeges megjelenésük a Kr. e. 3100/3000-2600/2500 közötti időszakban az Alföldön, azon belül is a Hortobágyi tájban annak az időszaknak a kezdetét jelzi, amikortól a háziállatok által végzett földhasználat fokozatosan erősödött, majd végül teljesen átvette az élőhelyek természetes kezelését végző nagytestű patás állatok - a vadló, az őstulok és az európai bölény legelési szerepét.
- A Hortobágyi Nemzeti Parkot, Magyarország legnagyobb védett területét 1973-ban hozták létre a hortobágyi táj központi részén, amelyet az elmúlt 150 év emberi beavatkozásai alig érintettek, így a természetes szikes gyep-vizes élőhely-komplexumok a mai napig meghatározzák a tájképet. A sztyeppi ökoszisztéma kezelésének két kritikus kérdése a megfelelő legeltetési és hidrológiai, azaz vízellátási rendszer kialakítása. A közelmúltban jogszabályban kihirdetett övezeti rendszer, ami nemcsak a Nemzeti Parkon belüli természetvédelmi célú zonációt, hanem az azt körülvevő, több mint 90 ezer hektáros védőövezet kijelölését is tartalmazza, a jövőben jó alapot biztosít a Hortobágyi Nemzeti Park természetvédelmi kezeléséhez. A kezelési feladatok közül a legfontosabbnak a hidrológiai rendszer táji szintű rekonstrukciója tűnik, aminek a fontosságát a klímaváltozás okozta kihívások is növelik.

1999-ben a Hortobágyi Nemzeti Park – a *Puszta* helyszínt kulturális kritériumok alapján, kultúrtáj kategóriában vette fel a Világörökségi Listára az UNESCO Világörökség Bizottsága. A világörökségi helyszín szikes gyep-vizes élőhely-komplexumainak elsődleges, természetes eredetét bizonyító legújabb tudományos eredmények tükrében, valamint a szikes területek eurázsiai korlátozott előfordulása (Boros & Kolpakova, 2018) alapján javaslom, hogy az illetékes magyar hatóságok vegyék fontolóra legalább a helyszín egy részének, a Nemzeti Park déli pusztaterületeinek (Kunmadarasi-puszta, Nagyiváni-puszta, Zám, Pentezug, Angyalháza, Szelencés és Borzas) természeti kritériumok alapján történő jelölését a Világörökségi Listára.

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As supervisor, I declare that this thesis written by Gábor Szilágyi, titled *The late Quaternary environmental history of the Hortobágy landscape* is his own writing prepared under my supervision, the candidate's contribution to the result used in the discussion of the thesis is approved. I also declare that the thesis meets the formal and professional requirements of the Doctoral School of Geoscience of the University of Szeged and the Faculty of Science and Informatics/Department of Geology and Paleontology, thus I suppor its submission.

Szeged, 21/06/2024

Sümegi

Dr Pál Sümegi, supervisor