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Neolithic land-use, subsistence, and mobility patterns in Transdanubia: A multiproxy isotope and environmental analysis from Alsónyék – Bátaszék and Mórágy – Tűzkődomb

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ABSTRACT

A variety of interdisciplinary research on mobility and migration patterns in Neolithic Hungary has recently contributed to the explanatory models of the Neolithisation across Europe. Most of these models were based on a combination of the spatial distribution of material culture or bioarchaeological and genetic analyses to determine large-scale migration and social or population-dynamic development. This paper aims at contributing to the current discussion by introducing a comprehensive and interdisciplinary multivariate environmental and multiproxy strontium and oxygen isotope analyses in combination with detailed archaeological interpretation of unique Neolithic site-complexes in southern Transdanubia. The integration of historical and modern environmental attributes, bioarchaeological data, and material typology allows for the determination of small- and large-scale mobility patterns and subsistence strategies in southern Hungary.

1. Introduction

The Carpathian Basin played a major role in the spread of the Neolithic in Central and western Europe. Although Neolithic research is an essential part of Hungarian Archaeology since the 19th century, certain areas were poorly investigated. Scientific interest in the region has significantly increased after the discovery of the Early Neolithic Starčevo settlements in southern Transdanubia in the late 1970s (Kalicz, 1990, 2011) and the first Sopot assemblages recognized in western Hungary somewhat earlier (Kalicz and Makkay, 1972a,b). Furthermore, recent field work and large-scale rescue excavations in particular, provided new insights into the area south of Lake Balaton (Jakucs and Voicsek, 2015; Marton and Oross, 2012; Oross, 2004; Osztás et al., 2012). Based on this data, several research projects were focusing not only on spatial dimensions of the respective site, but also on a larger regional framework. Among others, the aim of these projects that included geomagnetic surveys, radiocarbon dating, and aDNA analysis, was to provide innovative interpretations of cultural adaptation, chronological categorisation, and the relationship between the respective cultural communities during the Neolithic in the Carpathian Basin (Jakucs et al., 2016; Rassmann et al., 2020; Szécsényi-Nagy et al., 2015). In this context, the socio-cultural relations among Neolithic settlements and the spatial organisation of communities in larger networks are of central importance in current Neolithic archaeology (Bánffy et al., 2016; Furholt et al., 2020). Although sufficient material culture knowledge and several typo-chronological models have been

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developed, the spatial extent of Neolithic human activity ranges, agricultural subsistence economies, and the organisation of social networks and communication patterns on the small-, micro-, and supra-regional scale remain hypothetical. In this context, aDNA and (stable) isotope studies have focused on the 'verification' of migration and mobility patterns of Neolithic peoples through tracing human social behavior, dietary habits, and kinship relations on various spatial scales and over long chronological periods (Alt et al., 2014; Giblin et al., 2013; Szécsényi-Nagy et al., 2015). The data offered wide-ranging complementary information to further elucidating the process of genetic differentiation across Europe and the development of agricultural strategies and opportunities from the Early Neolithic onwards. Furthermore, recent landscape archaeological analyses and the reconstruction of potential land-use strategies in Neolithic Hungary have proven to be useful tools to determine human land-use systems and strontium isotope baselines, thus enabling the interpretation of mobility patterns on the site-specific and the micro-regional scale (Depaermentier, in preparation; Kempf, in preparation; Kempf, submitted). In this context, the integration of multivariate environmental data, archaeological records, and (stable) isotope values into one multiproxy analysis is the key to understand the dynamic and manifold interconnections between environmental stressors, socio-economic vulnerability, landscape development, and human adaptation processes that control the establishment of (spatially) local subsistence agriculture and animal husbandry (Ivanova et al., 2018).

As part of a German-Hungarian interdisciplinary research project that aimed to investigate the structure and dynamics of settlement and population development during the Neolithic in the Carpathian Basin, this paper presents a case study from the Neolithic site-complex at Alsónyék–Bátaszék and the adjacent site at Mórágy-Tűzkődomb (Fig. 1) in south-east Transdanubia (abbreviated as Alsónyék and Mórágy hereinafter). The results include the first strontium and oxygen isotope data published for Starčevo, Sopot, and Lengyel cultures in Transdanubia. The aim of this paper is to integrate archaeological data and multivariate environmental analyses to interpret strontium and oxygen stable isotope data in terms of mobility patterns from the site-specific to the regional and supra-regional scale. This dataset enables the discussion about different forms of mobility in a diachronic perspective that include not only potential large-scale migrations (which are usually expected in a Neolithisation context), but also socio(-political) relationships in an exogamy context as well as mobility related to land-use strategies. According to the project outlines, a strong interdisciplinary research framework allowed for the determination of a potential palaeolandscape, spatially local agricultural opportunities, Neolithic site continuities, and an intense supra-regional exchange and communication (Depaermentier, in preparation; Kempf, in preparation; Kempf, submitted).

2. Archaeological settings

Mórágy and Alsónyék are among the most thoroughly investigated Lengyel sites in southeastern Transdanubia. Over 300 Lengyel sites are currently known in Hungary, about half of them are located in southern Transdanubia (Zalai-Gaál, 2008), which points towards a dense settlement network during the Late Neolithic. In this chapter, we primarily focus on the contexts of the samples and present the burials from each subsite.

2.1. The Alsónyék site

The Alsónyék site is located between the foothill zone of the Szekszárd Hills and the large alluvial plains of the river Danube palaeochannel system (Fig. 1A). It was excavated between 2006 and 2009 in the course of the construction of the M6 motorway (Osztás et al., 2016a). The excavated area covers about 25 ha and brought to light about 15,000 archaeological features spanning almost the entire 6th millennium and the first and second third of the 5th millennium cal BC, encompassing four main Neolithic occupations (Table 1): the Starčevo (ca. 5800–5500 BCE), the LBK (*Linearbandkeramik,* ca. 5360–4860 BCE), the Sopot (ca. 5200–4680 BCE), and the Lengyel period (ca. 4900–4400 BCE) (Osztás et al., 2012). One of the main reasons for the long-lasting and almost continuous site occupation is the location at the transition from the hilly margins to the marshy lowlands, which provided potential agricultural zones, pasture, and fresh-water access (Kempf, submitted). Furthermore, the area is situated in a contact zone between Neolithic populations of the northern Balkans and Central Europe, which triggered a constant flow of goods and ideas and favored a strong mobility of people, particularly from the south (Osztás et al., 2012).

2.1.1. The Starčevo period

The Starčevo occupation concentrated in the southern part of the site (5603, Bátaszék-Mérnökségi Telep subsite, BAM in Fig. 1A) and its archaeological features, the amount of findings, and the large scale of the site represent a unique Starčevo complex in Hungary (Osztás et al., 2016a; Osztás et al., 2012). In total, 25 Starčevo human individuals have been identified on subsite 5603 (BAM). Among them were seven subadults, six males, ten females, and two adults of undeterminable sex (Köhler, 2015). The graves were scattered randomly across the site, with some small clusters that included 2–4 individuals. The orientation of the skeletons did not show any consistent pattern, but the left-crouched body position dominated. Human remains were mostly buried in the fillings of different types of settlement pits, however, also some isolated burials were found. Among the frequently recorded vicinity to ovens, the most interesting burials can be considered the five individuals that were buried inside the ovens without any burning traces (graves 792, 1398, 1362, 1449, and 153 (Bánffy et al., 2017). This phenomenon has not yet been observed within a Starčevo context so far. Only one Starčevo individual (grave 727) was buried with grave goods. In this paper, the isotope samples from Early Neolithic contexts deriving from this part of the site are labelled BAM.

2.1.2. The LBK period

The LBK settlement at Alsónyék represents one of the southernmost LBK occupations in Transdanubia. LBK features concentrated in the central part of the excavated area (Fig. 1A) which is supposed to form a coherent settlement (Osztás et al., 2012). The remains of some 50 houses were identified in total. Five graves can be assigned to the LBK, which were dug into the long pits of houses (Oross et al., 2016b). One sample collected for this project was radiocarbon dated to LBK (BAL25, 5208–4948 cal BC, 2 σ). The dating was conduted at the Poznañ Radiocarbon Laboratory (lab code: POZ).

2.1.3. The Sopot period

A very rich and important assemblage of Sopot material was found in approximately 1.5 km distance to the east of the LBK site (Fig. 1A). The settlement, which featured a broad variety of pits and ditches, was surrounded by a system of two overlapping double ditches that were limited to the north by a former river channel of the river Sárvíz (Rassmann et al., 2015). During the excavation, eighteen skeletal graves with the remains of twenty individuals and two cremations were recorded at the Alsónyék, Hosszú dűlő (5603/2 = ALE) subsite (Oross et al., 2016c; Osztás et al., 2012). Some of the Sopot graves sealed the ditch system and numerous burials were stratigraphically related to each other. Most of the bodies were buried in a crouched position: ten were left-crouched, five were right-crouched and two or three individuals were buried in a supine position. The orientation of the burials varied between NE-SW and SE-NW with a predominance of NE-SW position. The forms of the grave pits vary between oval and rectangular. However, it was not possible to reconstruct the original pit form in all cases. Four individuals were buried in rectangular pits (graves 217, 432, 475, and 476). Compared to the previous LBK period

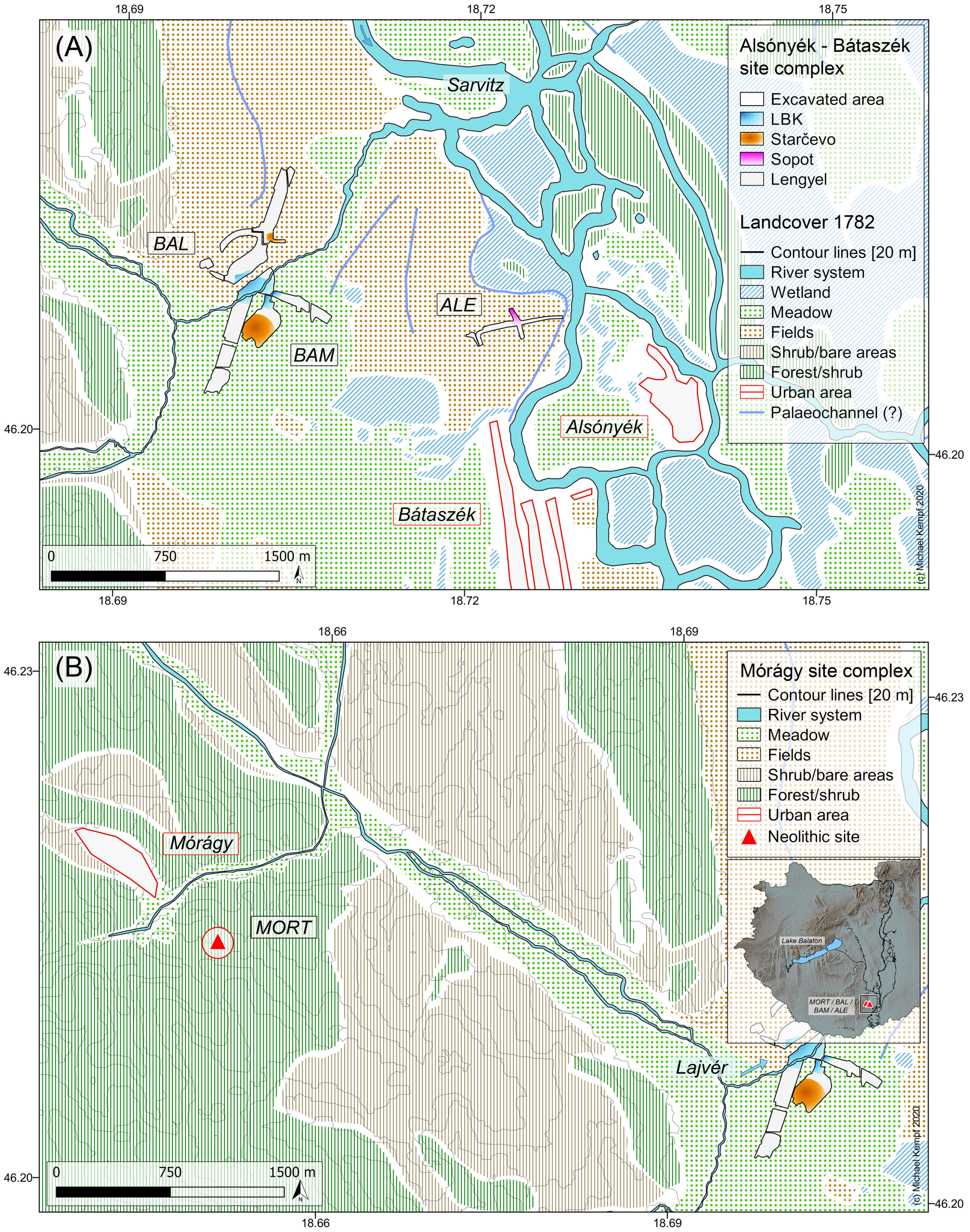

Fig. 1. (A) Historical landcover from 1782 and excavation plan at Alsónyék (the abbreviations BAM, BAL, ALE indicate the location of the sampled subsites within the site-complex). The excavated area shows Starčevo, LBK (*Linearbandkeramik*), Sopot, and a large-scale Lengyel period occupation. The latter covers almost the total excavated area. (B) Historical landcover from 1782 and the location of the site at Mórágy (samples from this site are abbreviated as MORT) (see Osztás et al., 2012, 380, Fig. 2 for the excavation plan and the subsites).

in Transdanubia, the number and the variety of grave goods increased considerably: among others, particularly the graves 464, 470, and 476 were richly furnished. Different types of ceramic vessels occurred to be the most frequent grave goods. However, also Spondylus and red deer canine teeth ornaments as well as chipped and polished stone artefacts were found. Samples marked with ALE in this paper originated from this subsite.

2.1.4. *The Lengyel period*

Alsónyék reached its greatest extent during the Late Neolithic Lengyel period (Fig. 1A). Nearly 9000 of the almost 15,000 excavated features can be associated with the Lengyel phase - including approximately 2300 burials, numerous pits and pit complexes, and 122 post-framed houses (Osztás, 2019; Osztás et al., 2016b). The traces of the Lengyel occupation cover the entire excavated area. It has been estimated that the site could have been covering up to 80 ha in its maximum extent (Osztás et al., 2016a). Ditch sections that were uncovered in the northern, eastern, and southern margins of the excavations may indicate the actual boundaries of the settlement. The western part is most likely limited by the margins of the adjacent hills.

A large part of the burials was found in spatially discrete groups, sometimes compact and clearly separated, with clusters of 25–35

Table 1
Number of individuals from each site and each archaeological culture sampled for strontium and/or oxygen isotope analyses. The radiocarbon dating of the Lengyel occupation at Mórágy is based on relative chronology and ceramic seriations.

Site	Abbr.	Archaeological culture	Absolute chronology (based on radiocarbon dating)		Number of individuals sampled for isotope analyses		References
			Begin of the occupation	End of the occupation	strontium	oxygen	
Bátaszék-Mérnökségi Telep	BAM	Starčevo	5800–5730 cal BC (2 σ) or 5775–5740 cal BC (1 σ)	5575–5505 cal BC (2 σ) or 5560–5525 cal BC (1 σ)	16	18	Oross et al. (2016a)
Bátaszék, Lajvérpuszta	BAL	LBK	5365–5230 cal BC (2 σ) or 5335–5280 cal BC (1 σ)	5040–4860 cal BC (2 σ) or 5010–4915 cal BC (1 σ)	1	0	Oross et al. (2016b)
Alsónyék, Hosszú dűlő	ALE	Sopot	5200–5005 cal BC (2 σ) or 5095–5020 cal BC (1 σ)	4850–4680 cal BC (2 σ) or 4825–4750 cal BC (1 σ)	13	15	Oross et al. (2016c)
Bátaszék, Lajvérpuszta	BAL	Lengyel	early 48th century cal BC	end of the 44th century cal BC	23	20	Osztás et al., 2016b
Mórágy-Tűzkődomb B1	MORT	Lengyel	4715–4660 cal BC	4180–4050 cal BC	20	19	Zalai-Gaál et al. (2014)

burials to clusters of about 100 burials. But in general, they were rather diffuse and overlap or merge spatially. Several scattered graves were also uncovered, some of which were buried into the pits or in the locale of former houses. Most of the graves faced in E–W direction and the body was deposited in a crouched position. The grave pits were mostly oval-shaped. Furthermore, a new type of construction, which corresponds to a rectangular pit with postholes in the four corners was discovered at Alsónyék. These graves were particularly frequent in the northern part of subsite 10B and featured rich grave good assemblages. Compared to other types of burials, these graves contained large amounts of polished and chipped stone tools, copper, and imported shell ornaments (*Spondylus* and *Dentalium*). The pottery types found in the graves varied greatly in shape and size and did not show significant differences from pottery of other south-eastern Transdanubian burials dating to the same period.

In this study, the 27 human individuals sampled for strontium and oxygen isotope analyses originated from the subsite 46 (Bátaszék, Lajvérpuszta, marked as BAL), which was excavated in 2009 by the National Heritage Protection Centre of the Hungarian National Museum. The samples were taken from a roughly compact grave group in the south-eastern part of the subsite where it connects to the south-western part of subsite 10B. From the 55 Lengyel burials, 36 individuals were lying on their left side, nine on their right side, one laid in supine position, and the position of the other individuals could not be observed. The most typical orientation ranged between NE-SW and E-W. Roughly one-fifth of the burials did not contain grave goods and the most common were pots, animal bones, and to a lesser extent chipped and polished stone tools.

2.2. *The Mórágy-Tűzkődomb site*

The site of Mórágy lies in south-eastern Transdanubia (Fig. 1B) and was investigated during a small-scale, but long-lasting excavation project between 1978 and 1990 led by István Zalai-Gaál (Zalai-Gaál, 2001b, 2002). This was the first systematic research excavation in southern Transdanubia after the 1930′s-1940′s excavations of Lengyel sites in the Baranya county (Dombay, 1939, 1958, 1959, 1960). The excavation of almost 2200 m^2 brought to light a variety of Lengyel features, including 109 Lengyel graves (Zalai-Gaál, 2001b). Two main areas were investigated through several trenches and two grave groups were unearthed, of which 86 graves formed the grave group B1 (Zalai-Gaál, 2002). However, due to erosion processes, ploughing activity, and the extent of the excavation, it is probable that it was not recorded entirely (Zoffmann, 2004). A part of a second grave group was excavated, which was recorded and interpreted as a different group (grave group B2) (Zalai-Gaál, 2001b). At Mórágy the bodies were crouched and over half of the burials were oriented in W–E direction (heads facing the west, bodies lying on their right sides) (Zalai-Gaál, 2010). Only a few (about 5%) graves were not furnished, more than 85% of the graves contained pots or pottery fragments (Zalai-Gaál, 2010). In grave group B1, the low number of male burials and of burials with polished stone tools are remarkable compared to other Lengyel burial sites (Zalai-Gaál, 2010). Furthermore, a remarkably large number of burials (n = 21) contain artefacts such as *Spondylus*, *Dentalium* and copper (Zalai-Gaál, 2010). The analysis of over 650 burials from southern Transdanubia led to the establishment of a relative chronological Lengyel development and to important socio-archaeological studies using quantitative attributes (Zalai-Gaál, 2001a, 2010). These analyses have contributed greatly to the understanding of the period's social organisation and relative chronology of the Lengyel culture. In this study, the 20 sampled individuals belong to the north-eastern part of the grave group B1. In this paper, the sampled material from Mórágy is labelled MORT.

3. Geographical settings

In this section, the environmental details of the site complexes are described and the differences in location parameters, sedimentological properties, and soil composition are presented. Important features of the potential agriculturally utilised areas are compared to flooding vulnerability and historical landcover change in Transdanubia (Bánffy, forthcoming; Kempf, submitted). In this context, the analysis of historical maps in terms of landcover and land-use change as well as premodern landscape dynamics are useful tools to come closer to an understanding of prehistoric surface conditions (Kempf, 2020). However, it must be pointed out that these analyses have methodological limitations and do not necessarily allow for the reconstruction of past landscapes and in particular potential agricultural conditions of prehistoric societies.

3.1. The Alsónyék site

The site is situated on the right bank of the river Danube in close direction to the western hilly margins of southern Transdanubia (Osztás et al., 2012). The sites are located outside the Holocene floodplain of the river Danube but closely connected to a tributary fluvial system that drains the gentle slopes. According to military observations and historical literature from the early 19th century (Bright, 1818; Kienreich, 1839), the north-south running system of the river Sárvíz (river Sarvitz/Sarwitz/Sarwiz) that drained the Lake Balaton (Johnston, 1850), produced a broad interconnected floodplain with several island-like plateaus and extensive wetlands, swamps, and morasses, which were “not only useless, but pestiferous” (Fig. 2) (Kimball, 1850). The floodplain further controlled the distribution of arable land prior to extensive regulations and channelisation activities in the 19th and 20th centuries (Ujházy and Biró, 2018). Due to a high flooding vulnerability and periodical inundation of the low-lying areas between the islands, the area could have been considered susceptible to waterlogged soils and a high natural ground-water level. Crop-cultivation would have therefore been at high risk of harvest loss. The historical landcover from the second half of the 18th century shows distinct boundaries between the broad floodplain to the east and the agriculturally utilised areas in between the western slopes and the terraces of the river Sárvíz (Fig. 1). In particular, the location of the Sopot site is characterised by close connection to fresh water along a potential palaeochannel of the Danube tributary Sárvíz. The former riverbed has accumulated fine-grained material due to low run-off velocity, which is visible in the oxbow-shaped wetland north of the site.

The site complex at BAM/BAL is situated west of the floodplain and outside the extensive flooding area. However, the complex is located at a secondary tributary (river Lajvér) that drains the hills to the west. The historical map clearly indicates the shifting flow-regime of the river, which cuts the excavation area in half. The disturbances in the middle of the excavation are caused by the canalisation of the Lajvér riverbed during the 19th/20th century. A meandering flow-regime and periodically shifting accumulation properties of the hydrological system prior to the canalisation, have covered the Neolithic settlement with considerable sediment deposits originating from the western hills. Geological conditions are dominated by continuous sedimentation processes characterised by periodical flooding events, the accumulation of fine-grained material (mostly clayey deposits and silty material), and relocation processes of loess deposits from the adjacent loess plateaus (Molnár et al., 2019). The accumulation regime shows gradual differentiation of material deposition with significant transition towards the elevated hillslopes. Sandy and coarse-grained material deposits are covered with recent alluvial sediments from the tributaries. That indicates multifold sedimentation processes: an eastern, Danube-dominated sedimentation regime caused by the anastomosing character of the river in the early Holocene, a secondary, more recent fine-grained filling of the palaeochannels and levees through the small-scale tributary system draining the hills, and an interspersed aeolian cover that has not experienced recent fluvial relocation (Kempf, submitted).

The soil composition represents mixed meadow soils; however, the fluvial deposits of the river show distinct sedimentological stratification in contrast to the surrounding, mostly wind-blown deposits of the transition zone between floodplain and elevated area. Isotopic signals and soil texture and conditions at BAM/BAL would rather be comparable to the original geological basis around the Mórágy site complex (MORT).

3.2. The Mórágy-Tűzkődomb site

The site at Mórágy (MORT) is characterised by Pliocene, Miocene, and Quaternary sediments covering a complex geological basement of various granite bodies, migmatites, and Jurassic and Cretaceous outcrops (Kercsmár et al., 2015; Márton, 1980). The uppermost 50 m of the granitoid body are strongly weathered and the sediment coverage thins towards the incised valleys (Tóth, 2018). According to the pedological map (Fig. 2b), soil composition and texture are entirely different at Mórágy compared to the lowlands. Skeletal and Brown Forest soils are mostly abundant (Laborczi et al., 2016; Pásztor et al., 2018). Towards the valleys, relocated material forms meadow soils and mixed signals. As pointed out for Alsónyék, the material relocation could affect the sedimentological stratification in close distance to the lower foothills. In this context, silty material from the Quaternary coverage at Mórágy would be relocated and accumulated in considerable thickness at Alsónyék. Furthermore, the satellite imagery (Fig. 2c) reveals significant difference in land-use opportunities between MORT and the adjacent floodplain. This is ultimately tied to soil properties and a potentially low-lying aquifer of the hilly margins (low and moderately productive porous aquifers (EGDI, 2020)).

The comprehensive geographical landcover evaluation and the historical data analysis provide the basis for the interpretation of the isotopic data comprised in this paper. Agricultural strategies and local human activity ranges will be considered to determine site-specific and micro-regional isotopic signals. In the following sections, the multivariate surface model will be described, followed by the results of the palaeolandscape and the isotopic analysis.

4. Material and methods

A variety of environmental datasets were used to display the heterogeneous geological, pedological, and hydrological conditions in the study area (Kempf, in preparation; Kempf, submitted). The data was processed with ©QGIS 2.8.9 and ©GRASS 7.4; ©QGIS 3.6.0 and ©GRASS 7.6.0. Statistical modelling and isotope analysis were performed using R software (©R 3.5.1). Satellite data was manipulated in ©multispec (Purdue University) and finally visualised in QGIS. Moreover, no statistical significance tests are carried out in this study because it was considered inappropriate regarding the small sample size per cultural group.

4.1. Environmental data

A 25 m grid cell digital elevation dataset was downloaded from the USGS (ASTER GDEM is a product of METI and NASA, https://earthexplorer.usgs.gov/, last accessed 24th of July 2019). Multispectral satellite imagery is available free of charge from the USGS and the ESA (Copernicus open access hub: USGS: https://earthexplorer.usgs.gov/, last accessed: 22nd of July 2019). Geological datasets (1:100 k) derived from MBFSZ as WMS layer (https://map.mbfsz.gov.hu/, last accessed 24th of July 2019) and the EGDI datasets (European Geological Data Infrastructure; http://www.europe-geology.eu/about-egdi/, last accessed 24th of July 2019 (EGDI, 2020)). Digital soil units, textures and excess water hazard maps were kindly provided by László Pásztor and his team from the Hungarian Institute for Soil Science and

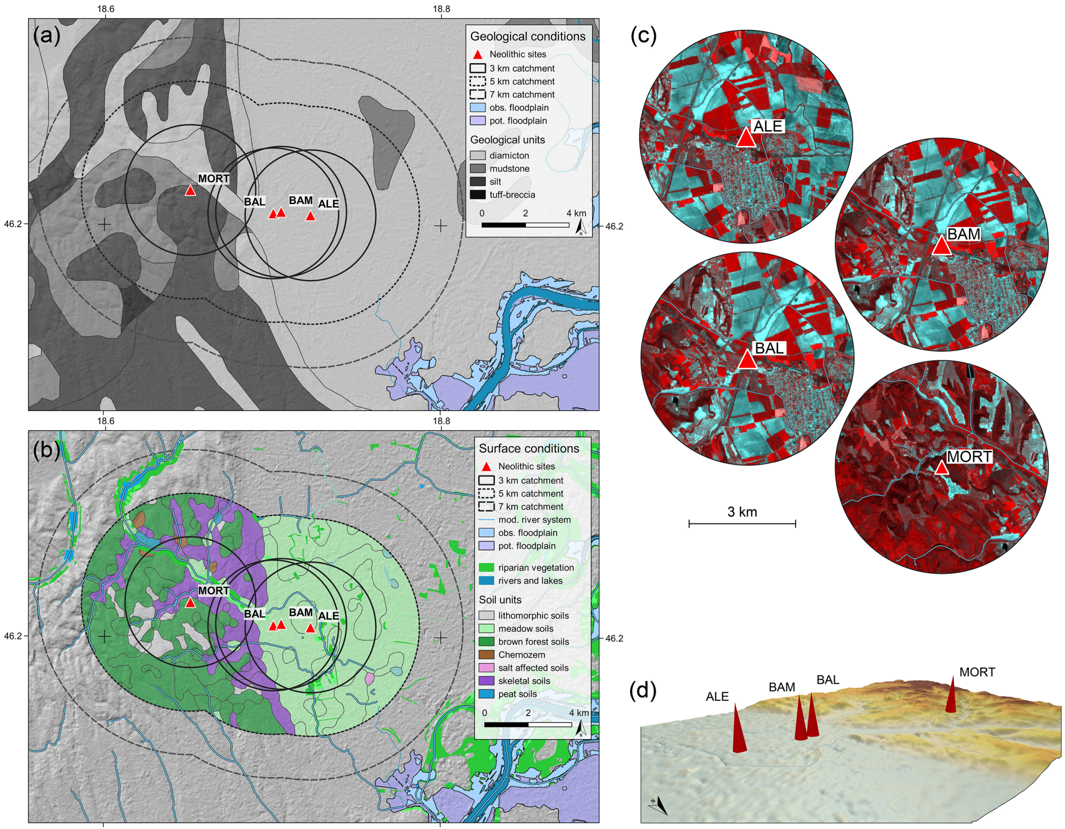

Fig. 2. Geological, pedological and hydrological map of the MORT, BAM, BAL, ALE complex on the right bank of the Danube. The surface lithology in the study area consists of unsorted or poorly sorted, clastic sediments with a wide range of particle sizes, including a muddy matrix. According to the geological units, BAM, BAL, and ALE cannot be distinguished. The MORT site is located on silty material that can clearly be distinguished (a). All sites lie outside the potential floodplain of the Danube and the larger tributaries. The whole complex is heavily affected by 19th century drainage activity and canalisations which is indicated by the various coupled historical river systems and the broad meadow patches in the Holocene floodplain of the Danube (light green signature) (b). A false color satellite image (channel combination NIR, R, R) from Sentinel-2B MSIL1C 26th December 2017 further visualises bare and poorly vegetated areas that appear blue, areas covered with intact vegetation/ strong agricultural exploitation appear red. The modern residential areas and the cropland extent align with the margins of the potential flooding area. The Neolithic sites are located outside the floodplain along a tributary river system that drains the gentle hills to the west.

Agricultural Chemistry at the Hungarian Academy of Sciences, Budapest, Hungary (Laborczi et al., 2016; Laborczi et al., 2019; Pásztor et al., 2018; Pásztor et al., 2015a,b). Historical maps from the 18th century CE were extracted from mapire.eu (last accessed 06th of April 2020), georeferenced and finally analysed to estimate historical landcover and particularly the hydrological system prior to the massive canalisation processes during the 19th and 20th centuries.

4.2. Isotope data and analyses

In this study, a total of 79 individuals from two Neolithic sites of present-day Hungary were sampled for strontium and oxygen isotope analyses. Three individuals among them were only sampled for strontium and three others only for oxygen isotope analyses (Tables 1 and 2). As far as possible, at least two teeth were analysed to gain insights into different steps of an individual's childhood and the related mobility patterns. In general, each site provided approximately the same number of males and females, and the last third of the sample comprised subadult individuals (infants and juveniles) that were not sex-determined. The morphological sex was determined by the method introduced by Éry et al. (1963). The anthropologists recorded metric and morphological characteristics, which are showing the sexual dimorphisms. These included eight skull, four jaw, and eleven postcranial characteristics (Éry et al., 1963). At Bátaszék-Mérnökségi telep (BAM), the sample represented the Starčevo culture. The sample from Alsónyék, Hosszú dűlő (ALE) corresponded to the Sopot culture, one sample from Bátaszék Lajvérpuszta (BAL) was dated to the LBK, and the Lengyel culture was represented at two sites: Bátaszék, Lajvérpuszta (BAL) and Mórágy–Tűzkődomb B1 (MORT) (Fig. 1). Furthermore, 15 human bones, 14 faunal dental enamel and 4 modern shells were sampled at these sites to determine a strontium isotope baseline (Table 3). The secure dating of the sampled contexts partly based on radiocarbon dates or on the associated material composition of the findings (Regenye, 2002). The radiocarbon measurements were mostly conducted at the Curt-Engelhorn-Zentrum Archäometrie in Mannheim, Germany (lab code: MAMS).

Strontium isotope analyses were led on the above-mentioned material following the methods described by Knipper in 2012 (Knipper et al., 2012) to investigate human mobility patterns at two different sites from the Sárköz region. The composition of the locally bioavailable strontium, which is introduced in the food chain though the vegetation, depends on bedrock properties and geological settings (Bentley, 2006; Montgomery, 2010; Price et al., 2012). The strontium isotope composition of food is furthermore transferred to human dental enamel and bone apatite after the consumption (Bentley, 2006; Montgomery, 2010; Price et al., 2002), which means that the $^{87}Sr/^{86}Sr$ ratios measured in human dental enamel bear information on an individual's location at the moment of the mineralisation of its sampled tooth (Knipper, 2017). The determination of the strontium isotope baseline in a study area enables interpreting these data in terms of mobility patterns: if the $^{87}Sr/^{86}Sr$ ratio of an individual's dental enamel does not match the $^{87}Sr/^{86}Sr$ ratio that is expected at the site, this

Table 2
Human dental enamel sampled of strontium and oxygen isotope analyses and related results.

Grave/Feature No.	Sample	Sex	Age categorie	Age (years)	Tooth	$^{87}Sr/^{86}Sr$	2σ	$\delta^{18}O_P$	1σ
Alsónyék, Hosszú dűlő (Sopot)									
210	ALE1	male	adult	35–45	M1 (?)	0.71083	0.00003	16.12	0.2
214.B	ALE2	female	adult	25–30	M3 (28)	_	_	15.35	0.3
214.B	ALE2	female	adult	25–30	M1 (26)	_	_	16.56	0.2
214.B	ALE2	female	adult	25–30	no data	0.70948	0.00004	_	_
220.B	ALE3	female	juvenile	16–18	M1 (36)	_	_	18.30	0.2
220.B	ALE3	female	juvenile	16–18	M2 (37)	0.70929	0.00004	_	_
220.A	ALE4	male	adult	35–45	M2 (37)	0.70898	0.00003	_	_
220.A	ALE4	male	adult	35–45	C (23)	0.70905	0.00001	_	_
240	ALE5	male	adult	25–35	M1 (46)	_	_	15.99	0.1
240	ALE5	male	adult	25–35	M3 (48)	0.70928	0.00005	16.94	0.0
282	ALE7	undet.	infant	13–14	M1 (46)	_	_	17.34	0.2
283	ALE8	female	adult	30–40	M1 (16)	0.70903	0.00002	16.78	0.1
283	ALE8	female	adult	30–40	M3 (18)	_	_	15.45	0.3
372	ALE9	female	juvenile	18–20	M1 (46)	_	_	18.20	0.1
372	ALE9	female	juvenile	18–20	M3 (38)	_	_	17.24	0.0
373	ALE10	female	adult	25–35	M1 (46)	0.70944	0.00005	17.21	0.3
373	ALE10	female	adult	25–35	M3 (48)	0.70948	0.00003	16.23	0.0
396	ALE11	undet.	infant	ca. 7	M1 (16)	_	_	17.44	0.2
396	ALE11	undet.	infant	ca. 7	M2 (17)	0.70934	0.00003	_	_
432	ALE12	female	adult	25–35	M1 (36)	_	_	17.38	0.1
432	ALE12	female	adult	25–35	M3 (38)	_	_	16.12	0.2
432	ALE12	female	adult	25–35	no data	_	_	17.40	0.0
463	ALE14	male (genetic.)	infant	ca.6	m1 (84)	0.70930	0.00001	_	_
464	ALE15	male	mature	40–45	M3 (38)	0.70897	0.00002	15.25	0.2
470	ALE16	male	adult	35–45	M3 (38)	_	_	16.37	0.2
470	ALE16	male	adult	35–45	M1 (36)	0.70900	0.00001	16.31	0.2
471	ALE17	undet.	infant	ca. 13	M1 (26)	_	_	16.54	0.1
471	ALE17	undet.	infant	ca. 13	M3 (38)	0.70999	0.00002	_	_
475	ALE18	undet.	infant	14–15	M2 (47)	0.70926	0.00003	16.40	0.1
476	ALE19	undet.	juvenile	18–20	M1 (36)	_	_	17.65	0.2
Bátaszék, Lajvérpuszta (Lengyel)									
26	BAL1	female	adult	20–25	M1 (36)	0.70987	0.00004	16.33	0.3
26	BAL1	female	adult	20–25	P2 (35)	0.70983	0.00006	16.49	0.4
27	BAL2	female?	adult	35–45	M1 (46)	0.71023	0.00006	16.93	0.1
35	BAL3	male	mature	40–59	M1 (46)	0.71004	0.00001	16.39	0.3
35	BAL3	male	mature	40–59	M2 (47)	0.70999	0.00002	_	_
36	BAL4	female?	juvenile	18–20	M1 (46)	0.70970	0.00004	17.03	0.1
36	BAL4	female?	juvenile	18–20	M3 (48)	0.70961	0.00006	16.07	0.2
38	BAL5	male	adult	30–40	M1 (46)	0.70964	0.00004	16.87	0.3
38	BAL5	male	adult	30–40	M3 (48)	0.70958	0.00005	15.91	0.2
39	BAL6	male?	adult	35–45	M1 (46)	0.70977	0.00003	16.95	0.1
39	BAL6	male?	adult	35–45	M2 (47)	0.70986	0.00003	_	_
40	BAL7	male	adult	25–30	M1 (36)	0.70997	0.00002	17.84	0.1
40	BAL7	male	adult	25–30	M3 (38)	0.70986	0.00005	16.51	0.0
49	BAL8	undet.	infant	6–7	m2 (85)	0.70999	0.00003	17.04	0.1
49	BAL8	undet.	infant	6–7	M1 (46)	0.70990	0.00003	_	_
65	BAL9	male	mature	40–59	M1 (36)	0.70968	0.00001	16.55	0.0
66	BAL10	male	adult	25–35	M1 (36)	0.70994	0.00004	16.07	0.1
66	BAL10	male	adult	25–35	M2 (37)	0.70983	0.00003	_	_
68	BAL11	undet.	juvenile	17–18	M1 (36)	0.70990	0.00004	16.85	0.0
68	BAL11	undet.	juvenile	17–18	M2 (37)	0.70997	0.00004	_	_
69	BAL12	male	adult	30–40	M1 (46)	0.71008	0.00005	16.53	0.2
69	BAL12	male	adult	30–40	M3 (48)	0.71012	0.00001	_	_
71	BAL13	male?	adult	25–35	C (?)	0.70997	0.00002	_	_
72	BAL14	female	adult	30–40	M1 (46)	0.71001	0.00002	16.51	0.2
72	BAL14	female	adult	30–40	M3 (48)	0.70942	0.00005	17.67	0.1
76	BAL15	undet.	adult	35–45	M1 (46)	0.70972	0.00006	16.45	0.3
76	BAL15	undet.	adult	35–45	M2 (47)	0.70993	0.00001	_	_
89	BAL16	female	adult	25–35	M1 (46)	0.70957	0.00005	16.67	0.3
89	BAL16	female	adult	25–35	M3 (48)	0.70948	0.00003	16.75	0.0
34	BAL18	male?	adult	25–35	M2/3 (47/48)	0.71002	0.00005	16.99	0.2
41	BAL19	male?	mature	40–59	M1 (36)	0.70955	0.00005	16.29	0.1
50	BAL21	female?	adult	35–45	M1 (16)	0.70990	0.00001	17.08	0.0
50	BAL21	female?	adult	35–45	M3 (18)	0.70980	0.00003	16.13	0.1
51	BAL22	female	adult	30–40	M1 (26)	0.70969	0.00001	16.57	0.4
51	BAL22	female	adult	30–40	M3 (?)	0.70969	0.00001	_	_
52	BAL23	undet.	adult	30–50	M?	0.70970	0.00002	_	_
70	BAL24	female	adult	35–45	M1 (26)	0.70956	0.00001	16.31	0.1
70	BAL24	female	adult	35–45	M3 (38)	0.70964	0.00003	16.07	0.3
Bátaszék, Lajvérpuszta (LBK)									
93	BAL25	male	mature	45–55	M? (?)	0.70931	0.00003	_	_
Bátaszék-Mérnökségi Telep (Starčevo)									
688	BAM1	female	adult	23–27	M1 (16)	_	_	14.83	0.5

(*continued on next page*)

Table 2 (*continued*)

Grave/Feature No.	Sample	Sex	Age categorie	Age (years)	Tooth	$^{87}Sr/^{86}Sr$	2σ	$\delta^{18}O_P$	1σ
721	BAM2	female	adult	30–40	M3 (18)	0.70938	0.00003	16.05	0.3
721	BAM2	female	adult	30–40	M1 (46)	_	_	17.10	0.2
745	BAM4	male (genetic.)	adult	35–45	M1 (36)	0.70955	0.00002	16.59	0.2
745	BAM4	male (genetic.)	adult	35–45	M3 (38)	0.70989	0.00004	15.56	0.0
746	BAM5	undet.	infant	9–11	M1 (36)	0.70924	0.00006	16.75	0.0
775	BAM6	undet.	infant	8–10	M2 (27)	_	_	16.13	0.2
797	BAM8	female	adult	35–45	M1 (36)	0.71072	0.00004	_	_
797	BAM8	female	adult	35–45	M2/3 (17/18)	0.71067	0.00003	14.64	0.2
1362	BAM10	female	adult	30–40	M1 (46)	0.71059	0.00004	15.65	0.5
1362	BAM10	female	adult	30–40	M2 (47)	0.71049	0.00002	14.41	0.2
1372	BAM11	male	adult	35–45	M1 (46)	0.70991	0.00001	15.72	0.3
1372	BAM11	male	adult	35–45	M3 (48)	0.70960	0.00008	16.56	0.2
1435	BAM13	undet.	infant	8–9	M1 (16)	0.70960	0.00004	17.27	0.3
1449	BAM15	female?	juvenile	17–18	M1 (46)	0.70978	0.00006	17.51	0.1
1449	BAM15	female?	juvenile	17–18	M2 (47)	_	_	16.72	0.3
1449	BAM15	female?	juvenile	17–18	M3 (28)	_	_	17.45	0.1
1461	BAM16	male	mature	45–55	M1/2	0.70928	0.00004	15.72	0.1
1461	BAM16	male	mature	45–55	M3 (28)	0.70960	0.00008	13.33	0.3
1483	BAM17	male (genetic.)	infant	7–8	M1 (36)	0.70931	0.00004	16.99	0.2
1495	BAM18	female	adult	23–30	M1 (36)	0.70967	0.00006	16.08	0.0
1495	BAM18	female	adult	23–30	M3 (38)	_	_	15.36	0.2
1513	BAM19	undet.	infant	10–12	M1 (26)	0.70952	0.00004	15.86	0.2
1513	BAM19	undet.	infant	10–12	M2 (37)	_	_	15.36	0.2
1516	BAM20	female	adult	23–27	M1 (46)	0.70955	0.00006	15.22	0.2
1516	BAM20	female	adult	23–27	M3 (48)	0.70961	0.0001	13.71	0.2
1531	BAM24	female	mature	40–50	M3 (48)	0.70907	0.00003	15.54	0.3
1532	BAM25	male (genetic.)	adult	20–30	M1 (46)	0.70946	0.00005	_	_
1532	BAM25	male (genetic.)	adult	20–30	M3 (48)	0.70902	0.00001	15.59	0.2
1533	BAM26	male	adult	35–45	M3 (48)	0.70909	0.00005	16.28	0.2
Mórágy-Tűzkődomb B1 (Lengyel)									
15	MORT1	female	senil	62–75	C (13)	0.71196	0.00005	15.60	0.4
16	MORT2	female	mature	41–45	M2 (27)	0.70936	0.00004	16.38	0.2
16	MORT2	female	mature	41–45	M3 (28)	0.70962	0.00005	16.72	0.2
43	MORT4	undet.	infant	9–11	M1 (26)	0.70983	0.00004	16.89	0.1
43	MORT4	undet.	infant	9–11	M3 (?)	0.70985	0.00005	16.59	0.1
46	MORT6	undet.	infant	9–11	m2 (75)	0.71015	0.00003	18.03	0.3
46	MORT6	undet.	infant	9–11	M1 (36)	0.70981	0.00005	16.92	0.1
46	MORT6	undet.	infant	9–11	M1 (?)	_	_	17.18	0.3
47	MORT7	undet.	infant	13–15	M1 (46)	0.70973	0.00005	16.28	0.0
47	MORT7	undet.	infant	13–15	M3 (48)	0.70930	0.00005	15.88	0.1
48	MORT8	female	juvenile	21–28	M1 (36)	0.71000	0.00001	18.05	0.1
48	MORT8	female	juvenile	21–28	M2 (37)	0.70984	0.00002	_	_
51	MORT9	female	infant	65–75	m2 (65)	0.70943	0.00001	16.94	0.1
52	MORT10	undet.	infant	2–3	m1 (54)	0.70934	0.00005	17.23	0.2
52	MORT10	undet.	infant	2–3	i1 (51)	0.7096	0.00005	16.92	0.2
55	MORT11	male	adult	22–28	M1 (46)	0.70965	0.00001	16.47	0.1
56	MORT12	female	mature	41–45	M1 (46)	0.70973	0.00002	16.63	0.1
56	MORT12	female	mature	41–45	M2 (47)	0.70983	0.00006	_	_
57	MORT13	male	mature	54–58	M2 (37)	0.70977	0.00003	15.86	0.1
57	MORT13	male	mature	54–58	M3 (38)	0.70957	0.00001	16.22	0.0
59	MORT15	female	juvenile	19–21	M1 (36)	0.70958	0.00004	15.96	0.2
59	MORT15	female	juvenile	19–21	M3 (18)	0.70979	0.00004	17.00	0.3
60	MORT16	undet.	infant	5–6	m2 (55)	0.70986	0.00005	16.73	0.2
60	MORT16	undet.	infant	5–6	M1 (?)	0.70998	0.00004	16.20	0.2
63	MORT18	undet.	infant	9–11	m2 (75)	0.70949	0.00005	18.48	0.2
63	MORT18	undet.	infant	9–11	M1 (36)	0.70934	0.00002	18.67	0.0
65	MORT19	female	mature	47–63	M1 (36)	0.70955	0.00003	_	_
65	MORT19	female	mature	47–63	M2 (37)	0.70997	0.00003	_	_
66	MORT20	male	adult	37–43	M1 (36)	0.71004	0.00003	15.98	0.4
66	MORT20	male	adult	37–43	M3 (18)	0.70974	0.00002	15.62	0.2
67	MORT21	female	adult	30–36	M1 (36)	0.70978	0.00003	16.98	0.2
67	MORT21	female	adult	30–36	M2 (37)	0.70989	0.00001	_	_
67	MORT21	female	adult	30–36	M2 (37)	_	_	17.00	0.2
74	MORT22	female	mature	40–46	M1 (46)	0.70958	0.00002	17.09	0.1
74	MORT22	female	mature	40–46	M3 (48)	0.70967	0.00004	16.75	0.2
77	MORT24	male	mature	41–47	M1 (16)	0.70987	0.00003	16.80	0.1
77	MORT24	male	mature	41–47	M3 (28)	0.70968	0.00002	_	_
81	MORT25	undet.	infant	9–11	M1 (36)	0.70927	0.00003	16.91	0.0
81	MORT25	undet.	infant	9–11	M3 (?)	0.70969	0.00003	16.90	0.2

individual was probably mobile or changed its dietary habits during its life (Bentley, 2006; Brönnimann et al., 2018; Maurer et al., 2012). Baseline samples originated directly from the sites and were not collected from the surroundings. The environmental settings of each site were not necessarily comparable, hence a site-specific and a micro-regional baseline, which included the baseline samples of different sites with different settings, were suggested for each site, following the methods presented in Kempf and Depaermentier *et al.* (in preparation).

Table 3
Human bone, faunal dental enamel, and shell samples for the determination of strontium isotope baseline.

Sample	Sample category	Sample type	Grave/Feature No.	$^{87}Sr/^{86}Sr$	2 σ
Alsónyék, Hosszú dűlő (Sopot)					
ALEM	shell	Bivalvia	1176/222	0.70925	0.00002
ALEO	faunal dental enamel	Ovis / Capra	1096/0189	0.70932	0.00001
ALES1	faunal dental enamel	Sus domesticus	1189/0190	0.70976	0.00001
ALES2	faunal dental enamel	Sus domesticus	1189/0190	0.70928	0.00001
ALES3	faunal dental enamel	Sus domesticus	1176/0222	0.70900	0.00006
Bátaszék, Lajvérpuszta (Lengyel)					
BAL9	human bone	Femur right	65	0.71009	0.00003
BAL13	human bone	Tibia left	71	0.71002	0.00004
BAL19	human bone	Femur left	41	0.71007	0.00002
BAL21	human bone	Femur	50	0.70997	0.00005
BAL25	human bone	Femur right	93	0.71001	0.00002
BAL26	human bone	Femur left	94	0.70993	0.00004
BAL27	human bone	Femur right	97	0.70999	0.00005
BALC	faunal dental enamel	Cervus elaphus	3338/252	0.70981	0.00001
BALS	faunal dental enamel	Sus domesticus	7223/416	0.70983	0.00002
Bátaszék-Mérnökségi Telep (Starčevo)					
BAMM1	shell	Bivalvia	708/584	0.70933	0.00006
BAMM2	shell	Bivalvia	800/2537	0.70945	0.00006
BAMS1	faunal dental enamel	Sus domesticus	1024/3411	0.70967	0.00001
BAMS2	faunal dental enamel	Sus domesticus	1460/2357	0.70929	0.00001
BAMS3	faunal dental enamel	Sus domesticus	276	0.70965	0.00001
BAMS4	faunal dental enamel	Sus domesticus	800/2537	0.70980	0.00001
Mórágy-Tűzkődomb B1 (Lengyel)					
MORT1	human bone	Femur	15	0.70975	0.00005
MORT2	human bone	Femur	16	0.70972	0.00001
MORT4	human bone	Femur	43	0.7097	0.00005
MORT6	human bone	Femur	46	0.71000	0.00004
MORT7	human bone	Femur	47	0.70989	0.00007
MORT12	human bone	Femur	56	0.70990	0.00003
MORT16	human bone	Femur	60	0.71013	0.00005
MORT18	human bone	Femur	63	0.70964	0.00003
MORTM	shell	Bivalvia	1986.VI.26B/IX	0.70882	0.00005
MORTS1	faunal dental enamel	Sus domesticus	1983.VII.28B/VIII	0.70960	0.00001
MORTS2	faunal dental enamel	Sus domesticus	46	0.70927	0.00002
MORTS3	faunal dental enamel	Sus domesticus	1984.VI.26B/IX	0.70910	0.00002
MORTS4	faunal dental enamel	Sus domesticus	no data	0.70947	0.00002

The identification of site-specific, mobile, micro-regional, and non-local individuals was enabled by the application of the methods described in Depaermentier *et al.* (in preparation).

Oxygen isotope analyses provided further information on Neolithic mobility patterns at the studied sites. The oxygen isotope composition of environmental water is related to hydrological processes and environmental settings such as temperature, altitude, latitude, seasonality, the distance to the sea, and climatic conditions (Fricke and O'Neil, 1999; Kohn and Welker, 2005; Luz et al., 1984). By drinking water, the locally available oxygen isotopes are incorporated into teeth and bones of an individual. The $\delta^{18}O$ value of human dental enamel can therefore provide information about human geographic origin (Chenery et al., 2012; D'Angela and Longinelli, 1990; Luz et al., 1984). However, further cultural factors such as food preparation (Brettell et al., 2012; Daux et al., 2008; Wright and Schwarcz, 1998) or breastfeeding (Britton et al., 2015) can also influence the $\delta^{18}O$ value of human dental enamel and should be considered in the interpretation of the data. In this study, local oxygen isotope data were calculated with the long-term annual average $\delta^{18}O$ value of modern precipitation data (generated by the Online Isotopes in Precipitation Calculator, (Bowen, 2010; Bowen, 2017; Bowen and Revenaugh, 2002; Bowen et al., 2005; Bowen and Wilkinson, 2002) accessible at http://wateriso.utah.edu/waterisotopes/pages/data_access/oipc.html) ± 1‰, which is the most usual span known from the literature for a local oxygen isotope baseline (Chenery et al., 2010; Gerling, 2015; Hemer et al., 2014; Knipper et al., 2018; Vohberger, 2011; Wilson and Standish, 2016). The 'Superset' linear regression equation (Pollard et al., 2011) was used to convert the $\delta^{18}O$ data measured in phosphate into data comparable to modern precipitation data. As far as possible, the standard samples were analysed three times. The $\delta^{18}O$ value for the standard NBS 120c was 22,2 ± 0,3‰ (n = 20 excluding the three outliers), the $\delta^{18}O$ value for the in-house standards of synthetic hydroxyapatite (HAP) was 17,12 ± 0,2‰ (n = 24) and the $\delta^{18}O$ value for Roman pig bones from the site of Dangstetten (SUS-DAN) was 14,19 ± 0,2‰ (n = 22). The results correspond to the expected values of these standards using the TC/EA methods (Chenery et al., 2010; Knipper et al., 2018; Pellegrini et al., 2016).

5. Results

Prior to the interpretation of the isotope baseline and the results of the strontium and stable oxygen isotope values of the sampled individuals, the potential landcover and Holocene landscape development needs to be considered. This chapter not only covers the results of the bioarchaeological data, but also a brief overview of the palaeoenvironmental considerations that derived from the digital multivariate modelling. The analysis reveals potential land-use patterns and thus enables the interpretation of site-specific common or distinct local human-landscape interaction, subsistence, and mobility patterns.

5.1. *Palaeolandscape and potential agricultural strategies*

Potential agricultural strategies within a 3 km distance around the sites have been estimated using multi-layered environmental data in a GIS (Fig. 3 A–D). The soil texture and units at Alsónyék are mostly characterised by meadow soils and relocated alluvial and colluvial deposits from the rivers Sárvíz and Lajvér, which produced a rather mixed material composition. Due to immediate water availability, the

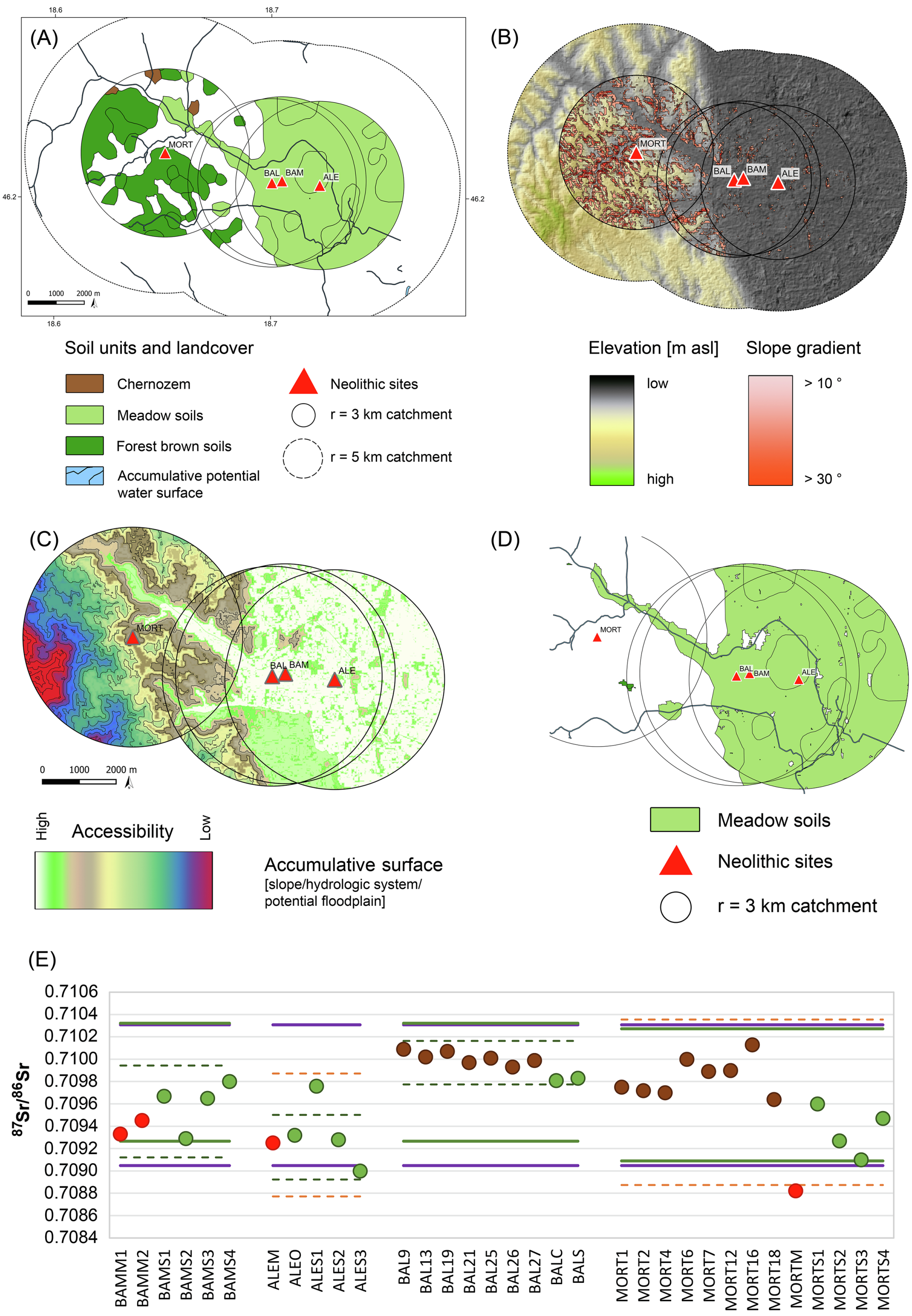

Fig. 3. (A) Favorable soil units in a 3 km buffer around the Neolithic site complex at ALE, BAM, BAL, and MORT (A). Terrain model and slope gradients within a 3 km and 5 km buffer around the sites. The classifications follow an inductive land-use model based on the distribution of 49 Neolithic sites in Hungary (Kempf, submitted). (C) Landscape permeability and accessibility at ALE, BAM, BAL, and MORT based on slope gradient, hydrologic system, palaeochannels, and the potential floodplain of the river Danube and its tributaries. (D) The combination of the calculated accumulative surface (A) and the soil classification highlights the most suitable soil patches in close vicinity to the sites. In the floodplain, meadow soils prevail that are rapidly accessible due to low terrain roughness and low flooding vulnerability around the BAM, BAL, ALE site complex. MORT shows no easily accessible soil patches because of the high slope gradients close to the site. (E) $^{87}Sr/^{86}Sr$ ratios of human bones (brown dots), animal dental enamel (green dots), and shells (red dots) from the sites at BAM, ALE, BAL, and MORT. The green lines represent the site-specific strontium isotope baseline range at the corresponding sites. The dashed green lines represent the range built by each sub-site sample from Alsónyék taken separately, excluding the outlier samples. The dashed orange lines represent the ranges at MORT and ALE that include these outlier samples. The violet lines represent the micro-regional strontium isotope baseline of this study area.

sites can be considered a high agricultural potential. However, the poor run-off velocity of the river Danube tributaries and the continuous flooding of the palaeochannels and abandoned riverbeds could have constantly triggered a high vulnerability to harvest-loss. Considering the historical topography, the manifold drainage ditches, and the extent of the hydrologic system, the location of the sites BAM, BAL, and ALE can be considered at the eastern margins of the potential cropland. In this context, the site at ALE is situated at a very site-specific location in direct vicinity to the interchanging hydrologic system of the river Sárvíz, which would furthermore influence the agricultural crop production and the livestock breeding opportunities. At Mórágy, the potential cropland cannot be identified with absolute certainty. The Forest brown soil provides suitable cropland, but the topographic heterogeneity does not allow to determine the exact location of the potential agricultural zones. Here, the local scale and possible fragmentation of the field system could have been important location parameters as well as water availability or scarcity.

The various environmental compositions would create diverse bioavailable strontium compositions: a rather Danube/tributary-influenced signal towards the floodplain, dominated by the Danube aquifer and the north-south draining river Sárvíz at ALE, a second signal towards the slopes that is rather influenced by the geological composition of the hilly margins and the erosive/accumulative character of the river Lajvér, which deposited relocated material from the loess-covered hills at BAM and BAL. A third isotope value would represent the loess-cover on the uneroded granite formations of the hills. The site at MORT would thus be characterised by a mixture of the loess-signal of the hilltops (arable land) and the access to fresh water in the valleys (alluvial sediments from the slopes), which would have further provided an important location factor for animal husbandry.

5.2. Strontium and oxygen isotope baseline ranges

The strontium ratios of each site baseline sample are represented in the Fig. 3E. It illustrates that at ALE, BAL, BAM and MORT, human bone samples show slightly higher $^{87}Sr/^{86}Sr$ ratios compared to shell and faunal dental enamel samples. The human bone samples, which are influenced by the filling material of the grave-pit, are not necessarily representative for the bioavailable strontium of a whole catchment area (Brönnimann et al., 2018; Kempf, in preparation). The faunal samples mostly correspond to *Sus domesticus*, which might have been kept within a small-scale spatial distance around the Neolithic sites or in the wetlands of the river Sárvíz – at least in the case of ALE. The human bone and faunal tooth enamel samples are therefore assumed to provide complementary data regarding strontium isotope baselines (Bentley, 2006; Brönnimann et al., 2018; Depaermentier, in preparation; Slovak and Paytan, 2011). When considered separately, BAL shows a very different site-specific baseline compared to BAM (see Fig. 3E). Nevertheless, both subsites are located in approximately 300 m distance to each other and, as shown by multivariate environmental analyses, they share a small and rather homogeneous geological, pedological, and hydrological landscape composition. Therefore, the site-specific baseline at BAM and BAL (0.70927–0.71032) was calculated by combining both site's baseline samples.

Regarding ALE, the multivariate environmental analysis has shown that the catchment area could be divided into two parts, with cropland in the western and pasture in the eastern part of the site, which corresponds to the wetlands of the river Sárvíz. It is therefore possible that the strontium isotope signal measured in faunal dental enamel at ALE would not represent the cropland signal that has been observed at BAL and BAM, but rather the signal of the meadow soil and vegetation composition. However, the strontium isotope composition of human dental enamel is mostly influenced by the plant component of the diet and faunal products (e.g. meat, milk) have a negligible impact on human strontium isotope values (Montgomery 2010). In this case, the sampled faunal dental enamel would not be representative for the site-specific baseline range at ALE. The small size of the dataset does not allow for evaluating this hypothesis and the sampled animals could also have grazed in the western part of the site. Consequently, two scenarios were suggested that propose two potential site-specific strontium isotope baselines at ALE: the first considers that livestock at ALE grazed also in areas with similar settings as the croplands and would thus have recorded similar strontium isotope values as humans. This scenario corresponds to the range built by the green dashed lines in Fig. 3E and Fig. 4. The second considers that livestock at ALE was only or mostly depending on meadows in the eastern part of ALE and would thus not be representative for the site-specific human dietary signal at ALE. In this scenario, ALE's site-specific strontium isotope baseline equals the range at BAM and BAL (green lines in Fig. 3E and Fig. 4) because the cropland of the three subsites represents similar environmental settings according to the multivariate analyses.

The site-specific strontium isotope baseline at MORT (0.70887–0.71036) integrates both faunal dental enamel and human bone samples but excludes the outlier *Bivalvia* sample MORTM. Individuals moving within the entire study area and consuming food from different fields would show $^{87}Sr/^{86}Sr$ ratios corresponding to the micro-regional strontium isotope baseline (0.7090–0.7103) of this area, which is calculated by combining every baseline samples from BAL, BAM, ALE and MORT (Fig. 3E). The similarity between MORT's and BAL-BAM's strontium isotope baseline ranges despite their distinct environmental settings is worth noting. This could be explained by the situation of BAL and BAM close to the river Lajvér, which runs from MORT to BAL-BAM and hence deposits a comparable sediment composition at both sites.

Oxygen isotope baseline ranges, on the other hand, were calculated by adding ± 1‰ to the annual average $\delta^{18}O$ value of modern precipitation data that were generated by the OIPC (WaterIsotopes.org; (Bowen, 2010; Bowen and Revenaugh, 2002; Bowen, Wasenaar and Hobson, 2005; Bowen and Wilkinson, 2002)), which are listed in Table 4.

5.3. Human strontium and oxygen isotope values

In this study, the $^{87}Sr/^{86}Sr$ ratios of human dental enamel span between 0.70897 and 0.71196, with an average value of 0.7097. The lowest value was found in the third molar of the matures male ALE15. The highest value was found in the canine tooth of the senile female MORT1. ALE individuals show generally lower $^{87}Sr/^{86}Sr$ ratios compared to the individuals at BAM, BAL, and MORT (Table 2; Fig. 4). Regardless the site-outliers, subadults, male and, female data show generally comparable spectra. However, at ALE females exhibit distinct strontium isotope ranges compared to males and subadults. At BAM, at least two females with particularly high $^{87}Sr/^{86}Sr$ ratios (BAM10 and BAM8) can be considered site outliers (Fig. 4). One further female (BAM24) and two males (BAM25 and BAM26) have site-outlier $^{87}Sr/^{86}Sr$ ratios in their third molar, which however still match the micro-regional baseline range. In addition, the first molar of male BAM25 exhibits a site-specific $^{87}Sr/^{86}Sr$ ratio. At ALE, one male (ALE1) exhibits a clear outlier strontium isotope composition. One infant (ALE17) also shows an outlier $^{87}Sr/^{86}Sr$ ratio in its second molar compared to the rest of the group, which still matches the micro-regional baseline range. Depending on the site-specific baseline range that is considered here, three males (ALE4, ALE15, ALE16) and one infant (ALE8) could be interpreted as local (first scenario) or non-local (second scenario). At BAL, human dental enamel strontium isotope ratios are scattered over the site-specific range and are generally higher than the ratios exhibited by the BAM individuals. At MORT, only one female (MORT1) exhibits a clear site-outlier strontium isotope composition, and subadults show a larger data spectrum compared to males and females.

The $\delta^{18}O$ ratios of human dental enamel span between 13.33 and 18.67‰, with an average value of 16.52‰ (Table 2, Fig. 5). The lowest value was found in the third molar of a mature male (BAM16). The highest value was found in the first molar of an infant (MORT18). The oxygen isotope data at BAM are very scattered and many data are outside the local baseline range. Four females (BAM1, BAM8, BAM10, BAM20) and two males (BAM16 and BAM25) have teeth with a clear outlier oxygen isotope composition. Two further females (BAM18, BAM24), one male (BAM4), and one juvenile individual (BAM19) exhibit oxygen isotope data that are right under the limit of the local range. Five individuals provided unreliable samples that are marked with a cross in Fig. 5. At ALE, five individuals show outlier oxygen isotope data. Two of them (the first molars of juvenile individuals ALE3 and ALE9) are probably reflecting the breastfeeding effect (see Britton et al., 2015) and can therefore not be considered as site-outliers. The other three (third molars of females ALE2 and ALE8, and of male ALE15) are under the limit of the local baseline range and might be considered site-outliers. In BAL and MORT, human dental enamel oxygen data show narrower spectra compared to BAM and ALE. The site-outlier signals found in the first molars of male BAL7 and juvenile individual MORT8, and in the deciduous tooth of infant MORT6 are probably related to the breastfeeding effect and cannot be considered site-outliers. However, the first molar of infant MORT18, the third molar of female BAL14, and the undetermined teeth of male MORT13 and juvenile individual MORT15 have probable site-outlier signatures. Moreover, BAM11, ALE5, BAL14, MORT13 and MORT15 show a higher value in their first molars compared to their third molars, which stands in contradiction to the expectations related to the breastfeeding effect

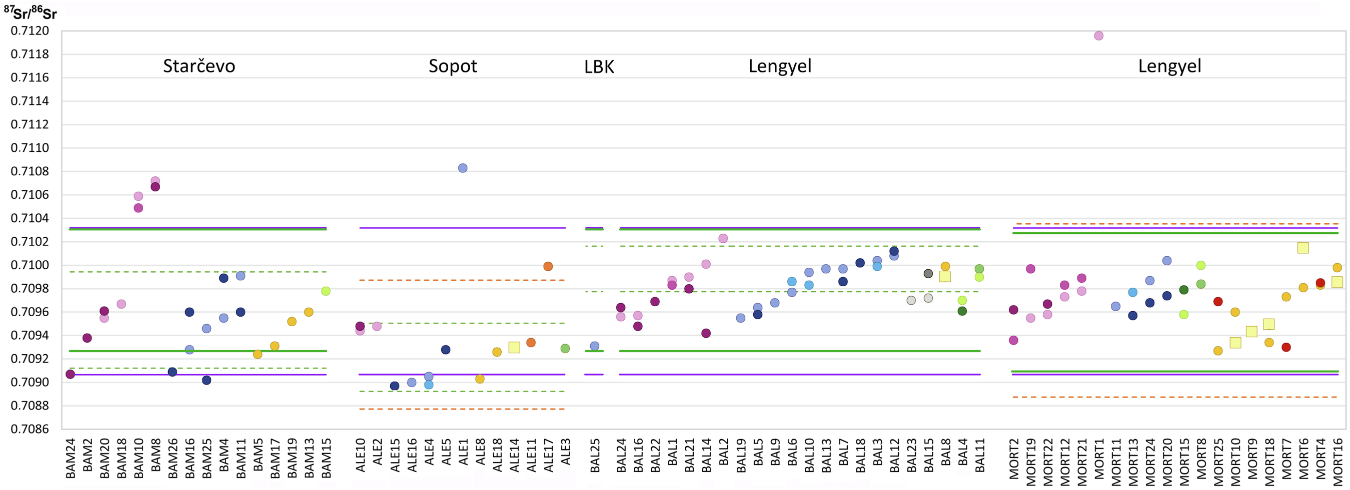

Fig. 4. ^{87}Sr/^{86}Sr ratios of human dental enamel per site, per sex and per age category at BAM, ALE, BAL, and MORT. Pink: females, blue: males, grey: undefined adults, yellow: infants; green: juveniles. Square: deciduous tooth; light color: M1/C/I; medium color: M2/PM; dark color: M3. The green lines represent the site-specific strontium isotope baseline range at the corresponding sites. The dashed green lines represent the range built by each subsite sample from Alsónyék taken separately and excluding the outlier samples. The dashed orange lines represent the ranges at MORT and ALE that include these outlier samples. The violet lines represent the micro-regional strontium isotope baseline of this study area.

Table 4
Long-term annual average δ^{18}O value of modern precipitation data calculated with the OIPC (WaterIsotopes.org; Bowen and Wilkinson, 2002; Bowen and Revenaugh, 2002; Bowen et al., 2005; Bowen, 2010).

Site/Abbr.	Lat.	Lon.	Altitude (m a.s.l.)	OIPC		Source	Converted baseline range
				δ^{18}O (‰)	1σ		(using the 'Superset' equation from Pollard et al., 2011)
ALE	46.20	18.72	87	−7.8	0.4	OIPC (WaterIsotopes.org, last accessed: 21.10.2019)	15.64–17.64
BAL	46.20	18.70	89	−7.7	0.3	OIPC (WaterIsotopes.org, last accessed: 21.10.2019)	15.64–17.64
BAM	46.20	18.70	91	−7.7	0.3	OIPC (WaterIsotopes.org, last accessed: 21.10.2019)	15.64–17.64
MORT	46.21	18.65	153	−7.8	0.3	OIPC (WaterIsotopes.org, last accessed: 21.10.2019)	15.57–17.57
River Danube (HU)			_	−10.56	0.4	Rank et al., 2014 (see GNIR, IAEA/WISER)	14.79

and would indicate that these individuals were at least mobile.

Plotting strontium isotope against oxygen isotope data (Fig. 6A) demonstrates that the isotope data from ALE, BAL, BAM, and MORT show overlapping and rather narrow values with some clear outliers that are labelled in Fig. 6A. Another way to identify mobile individuals consisted in comparing the difference between the ^{87}Sr/^{86}Sr ratios (Fig. 6B) or δ^{18}O value (Fig. 6C) of one individual's teeth to the normal variation in strontium (Fig. 6B) and oxygen (Fig. 6C) isotope composition within a site. This was calculated by adding two standard deviations to the average value of the difference between both deciduous teeth, between the deciduous tooth and the first molar, and between both first molars (see Knipper et al., 2018). Mobile individuals, whose teeth show an offset that exceeds the expected range for the normal variation within a site, are labelled in Fig. 6B and C.

6. Discussion

In order to interpret human dental enamel strontium and oxygen isotope values in terms of mobility patterns, a range of expected local isotope values needs to be determined. The spatial proximity of BAL, BAM, and ALE would usually have led to the consideration of a shared local strontium isotope baseline. However, this would not take into consideration the small-scale environmental disparities between ALE and BAL-BAM. ALE is located only 1.5 km away from BAL and BAM but

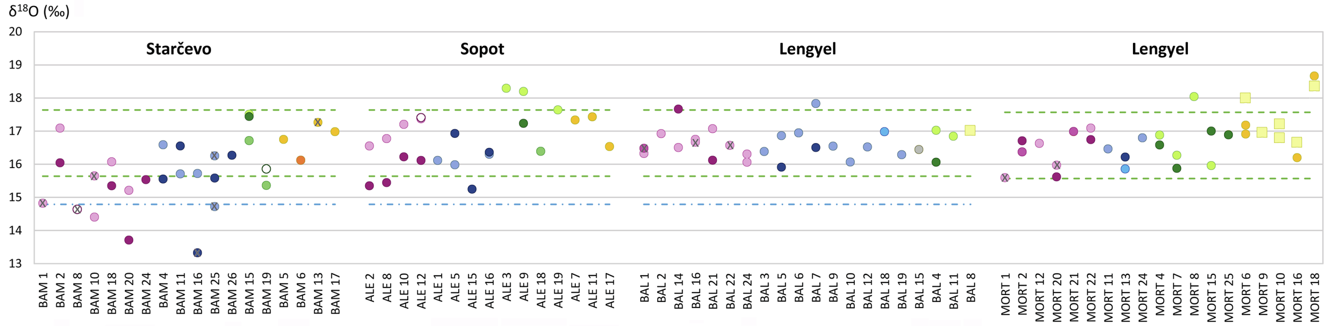

Fig. 5. δ^{18}O ratios of human dental enamel per site, per sex and per age category at BAM, ALE, BAL, and MORT. Pink: females, blue: males, grey: undefined adults, yellow: infants; green: juveniles. Square: deciduous tooth; light color: M1/C/I; medium color: M2/PM; dark color: M3; open circle: no data. The green dashed lines represent the approximate local oxygen isotope range calculated with modern precipitation data (OIPC, WaterIsotopes.org). The blue dashed line represents the mean δ^{18}O ratios of the Danube River in Hungary (Rank et al., 2014)).

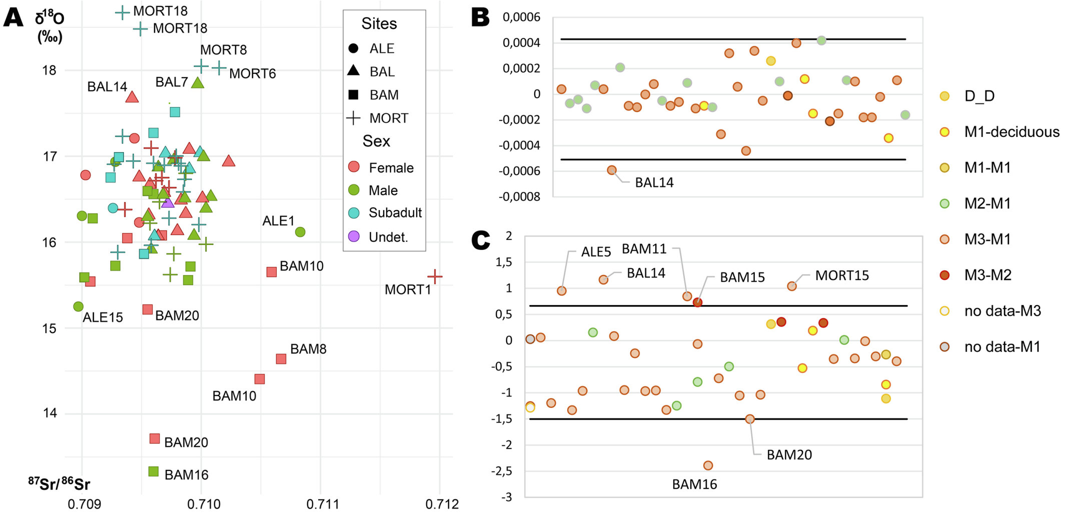

Fig. 6. A) $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ ratios of human dental enamel per site at ALE, BAL, BAM, and MORT. Each site's outlier sample is labelled. B) Differences of the $^{87}Sr/^{86}Sr$ of teeth from the same individual. C) Differences of the $\delta^{18}O$ of teeth from the same individual. The range built by the black lines in B) and C) show two standard deviations over the average difference between the $^{87}Sr/^{86}Sr$ ratios (B) or the $\delta^{18}O$ value (C) of two deciduous teeth, of the deciduous tooth and the first molar, and of two first molars of the same individual. The labelled individuals show an offset that could be related to mobility or to a significant shift in dietary habits during the teeth mineralising period.

shows distinct hydrological settings, which means that ALE's site-specific baseline might not be comparable to the baseline at BAL and BAM. However, this assumption depends on Neolithic land-use management, which could have been organised differently. One possibility considers that livestock was dependent on both pasture and cropland, which would have produced a similar signal in faunal and human dental enamel if the livestock were mostly grazing on cropland. This is supported by the assumption that livestock breeding also manures the field (Bayliss et al., 2016). Another possibility suggests a strict differentiation of ALE's catchment area into cropland in the west and pasture in the east, which is tied to the waterlogged humid meadows along the river Sárvíz. In this paper, it is assumed that livestock could indeed have been fed by products from the cropland, but only to a minor degree compared to the grazing activity on pasture. The local human diet would therefore most probably correspond to the cropland signal as calculated at BAL-BAM, making the second scenario more probable. Nevertheless, the small baseline sample at ALE does not allow for the evaluation of these hypothesis and consequently both are discussed in this chapter. Furthermore, the lack of baseline samples and comparative data in the region did not allow for a more precise oxygen stable isotope baseline range than presented above. But considering the various baseline ranges determined for each site and applying the above-mentioned methods, it was possible to retrace the evolution of mobility patterns from the Starčevo to the Lengyel period on different spatial scales.

The Starčevo sample at BAM is characterised by a large number and proportion of site-outlier individuals (exceeding one third of the sample, see Fig. 7A). This could confirm the acknowledged paradigm regarding the arrival of Balkanic Starčevo groups in Transdanubia, which introduced agriculture into present-day Hungary during the Early Neolithic (Anders and Siklósi, 2012; Bánffy, 2004; Raczky, 2010). This hypothesis was recently confirmed by aDNA analyses (Szécsényi-Nagy et al., 2015). However, based on the archaeozoological investigations, the two most frequent domesticated species were sheep/goat and cattle (Biller, forthcoming; Nyerges and Biller, 2015), and according to the morphometric characteristics of the domesticated and the wild species, the transitional forms were missing from the studied fragments. Therefore, and because the wild ancestors of the domesticated animals were not abundant in the Carpathian Basin, it is possible that the earliest settlers introduced their own livestock to Alsónyék (Nyerges and Biller, 2015). This means that the baseline range might be biased if the faunal dental enamel sampled for strontium isotope analyses belonged to this first generation of livestock. However, this hypothesis was not confirmed so far. In the current state of research, the strontium isotope baseline ranges determined for BAM are considered the most likely.

Moreover, a noticeable amount of locally born individuals show either considerable differences in the strontium and/or oxygen isotope composition among their teeth or have a site-outlier signal in their late-formed tooth, so that they can be considered mobile (Fig. 7A). This again highlights the significant mobility dynamic within this Starčevo community, which is also characterised by different mobility patterns depending on sex and age. The Starčevo outliers at BAM are almost only females (Fig. 7B), which suggests that this community had a patrilocal organisation, as already presumed by aDNA analyses (Szécsényi-Nagy et al., 2015). Furthermore, because it is not possible to identify the difference between initial settlers and later generations in the sample, the interpretation of the non-local people in terms of large-scale migration and Neolithisation processes cannot be tracked with absolute certainty. The high proportion of non-local people – and in particular females – could also be related to extensive marriage networks. It is noticeable that most BAM's locally born males were also mobile, while the sampled Starčevo subadults were born locally and part of them show evidences of mobility during their life. This is not surprising if we consider that the children who died young are likely to be buried at (or not far away from) the place where they were born. It further supports the hypothesis that the sampled individuals did not necessarily belong to the first generation of settlers. Identifying different settler generations would allow to distinguish between the role of large-scale exogamy patterns and the arrival of the first Neolithic settlers during the Starčevo period. When comparing the strontium and oxygen stable isotope data to the Starčevo burial context of the sampled individuals, it is furthermore not possible to notice clear tendencies regarding the correlation between isotopic foreigners and specific burial forms or grave goods. Indeed, three of the five individuals buried inside ovens were sampled for isotope analyses, which revealed that the two females (BAM10 and BAM24) were non-local or at least micro-regional, and that the subadult (BAM15) was mobile. But no data were available for the two other individuals buried in ovens, nor for the only individual buried with grave goods (grave 727). The other non-local, micro-regional, and mobile Starčevo individuals showed no deviating burial practices. Furthermore, further Starčevo individuals were sampled in

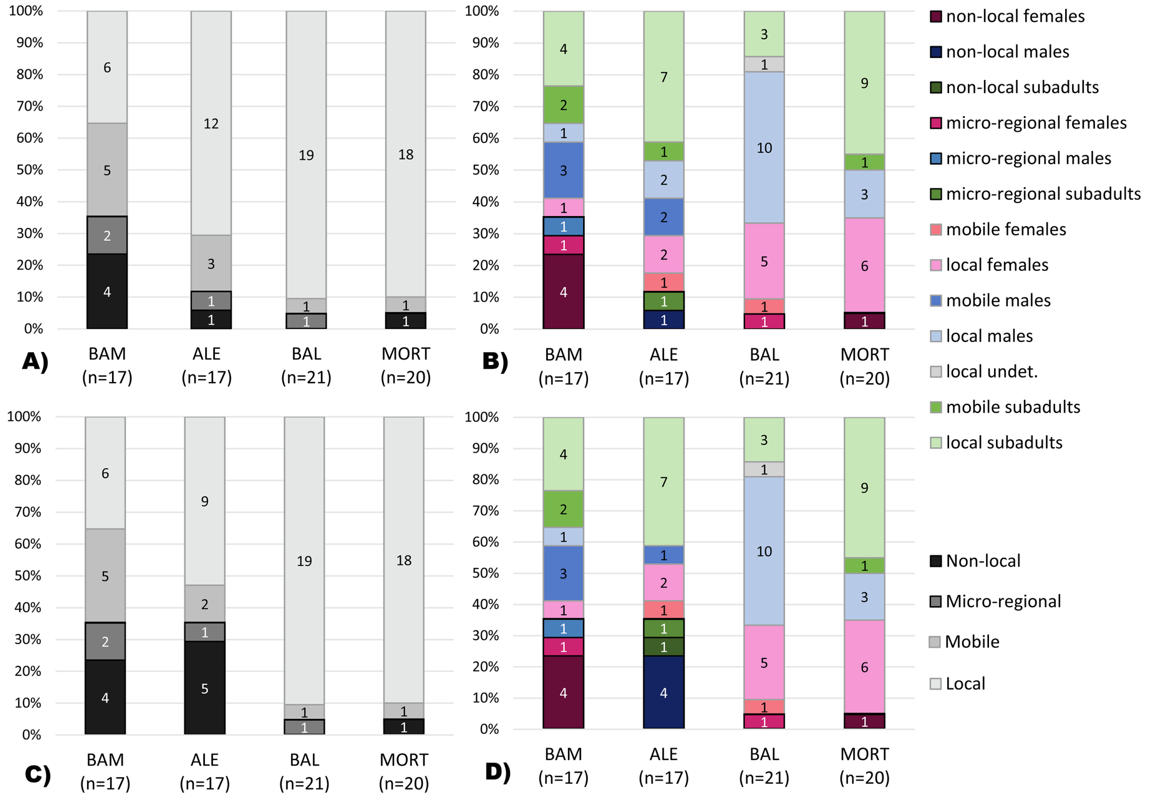

Fig. 7. Interpretation of strontium and oxygen isotope data in terms of mobility patterns. A) represents the total number and proportion of local, mobile, micro-regional, and non-local individuals at each site, when considering the first scenario. B) represents the number and proportion of local, mobile, micro-regional, and non-local individuals by sex and age category at each site when considering the first scenario. C) represents the total number and proportion of local, mobile, micro-regional, and non-local individuals at each site, when considering the second scenario. D) represents the number and proportion of local, mobile, micro-regional, and non-local individuals by sex and age category at each site when considering the second scenario.

Transdanubia and showed similar patterns as in BAM, thought the usually very small sample size does not allow for more relevant comparisons (see Depaermentier, in preparation). This nevertheless suggests that the Starčevo people were highly mobile and that isotopic site-outliers were not necessarily perceived as foreigners. However, the analysis of the other individuals buried in ovens would foster the understanding of this specific burial practice.

The LBK period is only represented by one sample (BAL25) and cannot be further discussed in this paper regarding mobility patterns. It is also not possible to draw a conclusion about the burial position of this male or the fact that he was buried without grave goods and the micro-regional signal measured in his tooth.

The interpretation of the Sopot sample at ALE depends on the considered site-specific baseline (Fig. 3E). The first, less probable scenario suggests a decreased proportion of site-outliers (two individuals: slightly more than 10%), which corresponds to non-local and micro-regional mobility patterns (Fig. 7A). This might contradict the expectations from the archaeological (Jakucs et al., 2016) and the aDNA data (Szécsényi-Nagy, 2015), according to which the Sopot individuals in the Sárköz region should represent the influx of groups from the direction of present-day Croatia, if the sampled individuals belonged to the first settler generation of the Sopot group. The second and more probable scenario suggests a larger proportion of site-outliers, equaling the rate of the Starčevo sample (nearly 40%), which mostly corresponds to non-local individuals (Fig. 7C). The disparities between both scenarios are related to the difficulty to determine a site-specific strontium isotope baseline at ALE with a small sample size. Furthermore, the dynamic of social, agricultural, economic strategies, and the spatial and temporal variability of environmental factors complicate the identification of a clear-cut ‘local’ isotopic range (Faure and Powell, 1972; Montgomery, 2010; Willmes et al., 2018). It is therefore a dilemma for both the archaeology and isotope analyses to clearly differentiate local and non-local people (Eckardt et al., 2015; Hingley et al., 2018; Knipper et al., 2018).

The noteworthy generally lower strontium isotope values of human dental enamel at ALE compared to the data at BAM and BAL could therefore be interpreted in different ways. In the first scenario, it could be explained by the different environmental settings that could lead to a slightly different composition of the bioavailable strontium, but also by a shift in subsistence strategies or dietary habits at this time. The zooarchaeological investigation shows significant changes in comparison to the Starčevo assemblage, with an increasing significance of hunting along to the importance of the domesticated livestock (Biller, forthcoming; Nyerges and Biller, 2015). Though the carnal and dairy part of human diet does not significantly influence the strontium signal measured in human teeth (Montgomery, 2010)). In the second scenario, it would rather be related to the arrival of new people during the Sopot period, which also fits the expectations regarding the Sopot migration history attested by archaeological and aDNA records (Szécsényi-Nagy, 2015). The additional amount of mobile individuals among the locally born people also increases the mobility rate of this Sopot sample (Fig. 7A and C).

Furthermore, the adult outliers at ALE are only males (Fig. 7B and 7D), especially when considering the second scenario (Fig. 7D), and the females sampled at ALE show local isotope values. This implies that there were probably matrilocal partnership rules within this Sopot community. This pattern was also attested by aDNA analyses (Szécsényi-Nagy et al., 2015). As for the Starčevo sample, this may indicate that the non-local males identified at ALE rather reflect large-scale exogamy relationships. It is also noticeable that the strontium isotope values of males ALE4, ALE15 and ALE16 are very close to the values of the three Sopot individuals sampled at Fajsz, the next easily accessible Sopot site of the region. This could highlight cultural group internal mobility patterns that may be related to socio-political or economic networks. However, a larger sample size and the identification of settler generations within the sample are required to confirm or revise the presented hypotheses and to explore site-specific land-use patterns.

Moreover, if considering the second scenario, the Sopot sample (ALE) provides no particular tendencies regarding the relation between burial practices and mobility pattern. Three of four individuals buried in a rectangular-shaped grave, which differs from the other grave shape at the site, were analysed and showed local signals (female ALE12 and subadults ALE18 and ALE19). The other locally born individuals were buried in the usual way. On the other hand, both males buried with particularly rich grave good assemblages (ALE15 and ALE16) and a deviating position (the strongly disturbed ALE16 possibly laid on his back and was E-W oriented) showed a non-local signal, while the other non-local individuals were not buried in a specific way. The micro-regional Sopot individual (infant ALE17) was buried without any object, even though most graves contain at least one vessel. Nevertheless, the sample size is probably too small to be representative.

The very small proportions of site-outliers (under 10%) at MORT and BAL (Fig. 7A) show that the Lengyel communities were mostly local, with daily activities barely exceeding the micro-regional scale. For the above-mentioned reasons, the number of site-outliers might also be revised upwards, but this dataset does not provide enough material to prove this hypothesis. Moreover, the site-outlier at BAL originated probably from the micro-regional surroundings and almost no mobile individual is attested in both Lengyel samples (Fig. 7A), which again points towards a low mobility rate during this period. The amount of Lengyel site-outliers at BAL and MORT is too small to allow for observations regarding differentiating mobility patterns between sex or age categories. No significant patterns could be observed in the Lengyel samples from Mórágy (MORT) and Bátaszék, Lajvérpuszta (BAL) regarding burial practices and mobility patterns. At BAL, the micro-regional female (BAL2) and the mobile female (BAL14) had no specific burials or grave goods. At MORT, the only clearly non-local individual (female MORT1) was not buried in a special way compared to the other individuals. Among the uncommon burials, the subadult buried in prone position (MORT8) was local and the subadult lying on its left side (MORT15) was also locally born but mobile. A systematic sampling and comparison between the burials would enable to evaluate if the grave shape, the body position or the grave-good's quantity and quality could be markers for distinct social groups or distinct geographical origin.

Based on the number of the excavated features, the occupation intensified during the Lengyel period at Alsónyék and the increasing population size entailed the demand for additional arable land and more animal keeping and hunting. This assumption was partly proven by δ^{15}N isotopes (Bayliss et al., 2016) and by the archaeozoological data. The increasing significance of hunting that started during the Sopot period reached its peak during the Lengyel period according to the analysis of approximately 20.000 faunal remains, which showed that wild and domesticated animals were consumed in almost equal proportions (Biller, forthcoming; Nyerges and Biller, 2015). It is important to note that each species had different environmental demands. For example, wild boar or their domesticated variants are tolerant to humid conditions in floodplain forests, swamps, and reeds, which provided abundant nutrients. However, sheep prefers drier grazing and not waterlogged areas. Because the wetland is an unfavorable habitat for small ruminants and the surrounding pastures could soon be depleted by a larger livestock, keeping sheep increases the possibility or the need of transhumance. During the transhumance, natural pastures and several grazing zones could have been utilised in rotation (Biller, forthcoming). The use of varied and larger spatial areas for both animal husbandry and agriculture could explain the larger spectrum of human dental enamel strontium isotope values within the local range.

A current model, which integrated the total number of features of each settlement and radiocarbon dates, suggests a particular intensification of human activity during the Lengyel period (Bánffy et al., 2016). Starting from this model, one hypothesis suggests that Alsónyék could have been a kind of aggregation settlement which would explain its rapid growth through an increased pull factor (Bánffy et al., 2016). Among the archaeological findings, however, no imported ware, except for the *Spondylus* and copper items were found in the graves which could have also reached the settlement through an intensified exchange and trade system. However, a detailed evaluation of pottery assemblages and other artefacts is still lacking. The results of the strontium and oxygen stable isotope analyses do not support this assumption and would rather underline that the rapid population growth was caused by internal socio-cultural development. However, it is possible that mobility patterns remain unnoticed if they occurred in geographically distant or geologically homogeneous areas that have similar strontium and oxygen isotope values as Mórágy (Brettell et al., 2012; Kempf, in preparation; Montgomery, 2010; Willmes et al., 2018). The proportion of non-local individuals might therefore remain underestimated. Furthermore, the sample represent only a small part of a subsite, which might not be representative for the development of the whole Lengyel site. It is also worth noting that an appropriate demographic model requires the knowledge of the number of people living at the same time within one settlement. In this case, isotope analyses would suggest revising this model.

7. Conclusion

This study revealed new insights into the organisation of Neolithic communities, which occupied the sites at Alsónyék–Bátaszék and Mórágy-Tűzkődomb. First of all, the integration of multivariate environmental data showed that, despite the proximity of the subsite Alsónyék, Hosszú dűlő (5603/2), the small-scale variation of environmental settings led to differences in the composition of the site-specific bioavailable strontium compared to the other part of Alsónyék–Bátaszék, which would however only influence the livestock and not the human enamel strontium isotope values. On the contrary, the different environmental settings between Mórágy and Alsónyék led to similar strontium isotope baselines, which makes it difficult to identify mobility patterns between both contemporaneous sites. The determination of a micro-regional baseline, however allowed identifying individuals from the sample that did not originate from the micro-region. These observations attested for large-scale mobility patterns, which played a particularly important role in the Starčevo and the Sopot context. The results of strontium and oxygen stable isotope analyses might strengthen the Neolithisation paradigm, according to which the Starčevo people introduced agricultural crop production to Transdanubia.This sample would thus confirm the results of both archaeological and aDNA analyses that argued for a considerable migration process from the south during the Sopot period. However, the lack of data regarding the determination of a reliable site-specific baseline might bias the results. Furthermore, this paper highlighted diverse aspects of the social organisation of the Neolithic communities in the study area. Building on aDNA analyses, the patrilocal signal of the Starčevo group and the matrilocal signal of the Sopot group could be confirmed. The large proportion of non-local Starčevo females and Sopot males could rather reflect large-scale marriage and economic networks throughout both periods than Neolithisation processes. Identifying the different settler generations in the sample would allow to evaluate both hypotheses. The isotope analyses further revealed that the studied Lengyel communities were organised on the local scale and that the strong population development might rather result from an internal process. Nevertheless, the similarity between the strontium isotope baselines at both Lengyel sites did not allow for identifying mobility patterns within this area and small-scale mobility probably remained unnoticed. Compared to the previous period, the larger spectrum of human dental enamel strontium isotope values suggested the spatial diversification of agricultural cropland and pasture, which also confirmed the results of nitrogen and carbon oxygen analyses led in the same research area (Bayliss et al., 2016). However, the dataset did not allow for recognising specific exogamy patterns in the Lengyel communities. Generally, the shift in strontium isotope values between the different cultural groups are linked to various mobility patterns and diverse subsistence strategies involving different agricultural areas. The comparison of the isotope data and the archaeological context demonstrated that differentiation in the burial practices cannot be linked to different mobility habits or origin. Bioarchaeological data would therefore highlight socio-cultural integration as well as high mobility rates within cultural groups in Neolithic communities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

MLCD and MK designed the methodical approach of the paper.
MLCD modelled the isotope data.
MLCD, AO, and MK wrote the paper.
EB and KWA provided the isotope data and organised the fundraising.

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