Journal of World Prehistory
https://doi.org/10.1007/s10963-024-09181-1

Patrilocality at the Beginning of Farming? An Isotopic Approach from SE Moravia

Berta Morell-Rovira[1] · Zdeněk Tvrdý[2] · Marta Díaz-Zorita Bonilla[3] · Penny Bickle[4] · Peter Tóth[5] · Michal Přichystal[6] · Alžběta Bedáňová[7] · Alba Masclans[8]

Accepted: 20 March 2024

Abstract

This research combines Strontium ($^{87}Sr/^{86}Sr$) and Oxygen ($\delta^{18}O$) isotope analysis to challenge the prevailing interpretation of patrilocal exogamic practices among eastern European Early Neolithic *Linearbandkeramik* (LBK) communities. Patrilocality has been considered the key factor influencing the mobility patterns of central Europe's first farmers (c. 5500–4900 cal. BC), especially in the south-eastern Moravian region (Czech Republic). Focusing our attention on both male and female tooth enamel samples from cemeteries, settlement graves and small clusters of graves, this paper reassesses the correlation between mobility, biological sex, and funerary practices. This task is accomplished by establishing a new isotopic footprint using new $^{87}Sr/^{86}Sr$ data, as well as significantly increasing the number of sampled individuals for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$. The outcome of this research contributes to a better understanding of the mobility patterns among early farmers in central Europe, challenging existing theories and providing new insights into their social and cultural dynamics.

Keywords Neolithic · *Linearbandkeramik* · LBK · Mobility patterns · $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ · Funerary contexts

Introduction

Patrilocality, suggested by both strontium isotope ($^{87}Sr/^{86}Sr$) analysis (Bentley et al., 2003, 2012) and aDNA studies (Rasteiro & Chikhi, 2013; Rasteiro et al., 2012), has become the accepted and dominant kinship model for the Early Neolithic in Central Europe (Linearbandkeramik – hereafter LBK: c. 5500–4900 cal BC). Such exogamic practices are often implicitly linked to strongly gender-differentiated demographic and dietary patterns (Bickle & Whittle, 2013; Masclans et al., 2021a; Oelze

Berta Morell-Rovira and Alba Masclans have equally contributed to the work.

Extended author information available on the last page of the article

Published online: 20 April 2024

et al., 2011), sexual division of labour (Masclans et al., 2021a) and interpersonal violence (Hedges et al., 2013), leading to assumptions about female status and male dominance (Jeunesse, 1997; Augereau, 2018).

The western Carpathian Basin is home to some of the most studied Early Neolithic cemeteries, such as Vedrovice (Czech Republic) and Nitra (Slovakia). They have been included in several research projects involving Early Neolithic male and female mobility patterns through $^{87}Sr/^{86}Sr$ isotopic analysis (Smrčka, 2005; Richards et al., 2008; Bickle & Whittle, 2013). These studies suggest that, while most male individuals remained within the same area all their lives, female mobility was more variable, which has been interpreted in terms of exogamic patrilocal practices. Polygyny has also been recently suggested, given the demographic skew towards females at the two cemeteries (Hrnčíř et al., 2020a, b). However, alternative interpretations of the same data proposed that bilocality and bilateral descent patterns were present at Vedrovice, and local marriages with groups with redundant resources occurred at Nitra (Ensor, 2021). Kinship need not explain all mobility data and Hofmann (2020) hypothesised migration was a social strategy to improve individual status.

Indeed, females from Vedrovice displayed greater variability in the $^{87}Sr/^{86}Sr$ isotopic values of their second molar (M2, mineralised between 1 and 8 years), than in their first (M1, mineralized during the last month of gestation up to 2 years) and third molar (M3, mineralised between 7 and 17 years) (Bickle & Whittle, 2013; Masclans et al., 2020), which implies further complexity.

A possible correlation between the mobility patterns, the $\delta^{15}N$ values and the grave-good characterization among cemetery individuals (*Vedrovice-Široká u Lesa*) have been suggested. Whittle et al. (2013) and Bentley et al. (2012) found that males buried with adzes were consistently related to local loess areas, while Masclans et al., (2021a, 2021b) pointed out that local skeletons had higher $\delta^{15}N$ values than the non-local individuals (related either to a diet richer in protein, or to the consumption of animals that grazed on fields with different degrees of fertilisation), and that the non-locals (who were predominantly females) were less probably related with stone and bone tools and most likely buried with pottery vessels and *Spondylus* ornaments.

These mobility patterns have been predominantly observed in cemeteries, which account for the largest percentage of known LBK burials in the area. However, other kinds of funerary contexts in south-eastern Moravia have also been studied for $^{87}Sr/^{86}Sr$ analysis, including burials alongside houses, settlement burials (*Vedrovice-Sidliště, Brno-Starý Lískovec* and some of the *Těšetice-Kyjovice* graves) and small burial clusters within settlements (including *Vedrovice-Za Dvorem* and some of the *Těšetice-Kyjovice* burials) (Bickle et al., 2014; Whittle et al., 2013). These contexts generally contain graves similar to those found at cemeteries—oval pits with individual inhumations—but present more variability in body positions and orientations, suggesting that individuals buried in cemeteries more closely followed a normative LBK burial rite than those buried outside them (Bickle et al., 2014; Hofmann, 2009). Furthermore, it has been suggested that settlements and cemeteries generally present different demographic patterns, with females and non-adults generally found in higher numbers

in settlements and considered to have low status because of their lower number of grave goods (as summarised by Hofmann & Orschiedt, 2015). However, recent reanalysis suggests that the belief that more females than males were buried at settlements may have been overemphasised (Bickle, 2020).

As for $^{87}Sr/^{86}Sr$ analysis, settlement graves and small clusters of burials have been considered to fall within isotopic local ranges, while a greater value variability has been observed in cemeteries (Bickle et al., 2014; Whittle et al., 2013). Until very recently, the settlement funerary contexts were not dated through radiocarbon dating, preventing rigorous comparisons with cemetery data. Recent studies have provided a robust knowledge of the temporality of the contexts included in this research, confirming that they overlapped in time (Masclans et al., in preparation). Specifically, Bayesian modelling determined that all the dated burials were continuous in time and distributed in three overlapping phases (Masclans et al., in preparation; Fig. 1, see Online Resource SI 2: Table 1), indicating that the funerary practices are contemporaneous in time. This fact implies that any differences in the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopic data can be considered as arising in different concurrent lifeways, rather than representing change over time, raising new and interesting interpretative possibilities.

This data has had an impact on our knowledge and understanding of LBK communities and their lifeways. However, the empirical evidence to support this hypothesis is presently constrained for five main reasons. Firstly, there is an over-representation of samples from cemeteries over settlement burials. A total of 68 $^{87}Sr/^{86}Sr$ samples from 63 individuals are available in the cemetery of *Vedrovice-Široká u Lesa* (72.41% of the inhumed sampled), while just 28 samples on 26 individuals were performed in the settlement burials of *Vedrovice-Sidliště*, *Brno-Starý Lískovec* and *Těšetice-Kyjovice*, and the *Vedrovice-Za Dvorem* small cluster of burials (54.16% of the inhumed sampled). This fact may exaggerate the variability of cemeteries, suggesting that they represent a more heterogeneous population in their isotopic values than the settlements. The different demographics of settlements and cemeteries may also add to these challenges, as the greater presence of certain sex and age ranges can influence isotopic variability. Secondly, most of the available samples were taken from M1 (54.41% of the samples) and M2 (58.82%) molars, while M3 is underrepresented (30.88%), which makes it difficult to evaluate whether indeed age played a determining role in the mobility patterns of these communities.

The characterisation of the local isotopic $^{87}Sr/^{86}Sr$ footprint is also necessary. Previous works estimated the local isotopic footprint by means of human femur samples (Smrčka et al., 2005), calculating averages within the isotopic ranges of human enamel, or by using the range of values for children and juveniles, assuming that children were more likely to be local because they had less time to migrate than adults in their lifetime (Bickle & Whittle, 2013; Hrnčíř & Laffoon, 2019; Masclans, et al., 2021a). However, a more accurate review of the different geological areas surrounding the site's isotopic values is essential to test the population's mobility patterns. Considering the limitations of $^{87}Sr/^{86}Sr$ analysis for the exploration mobility within large areas displaying the same isotopic ratio (Montgomery, 2010; Price et al., 2002), it can be useful to compare strontium data with other mobility proxies, such as $\delta^{18}O$ isotopic ratios (Bentley & Knipper, 2005a, 2005b). This

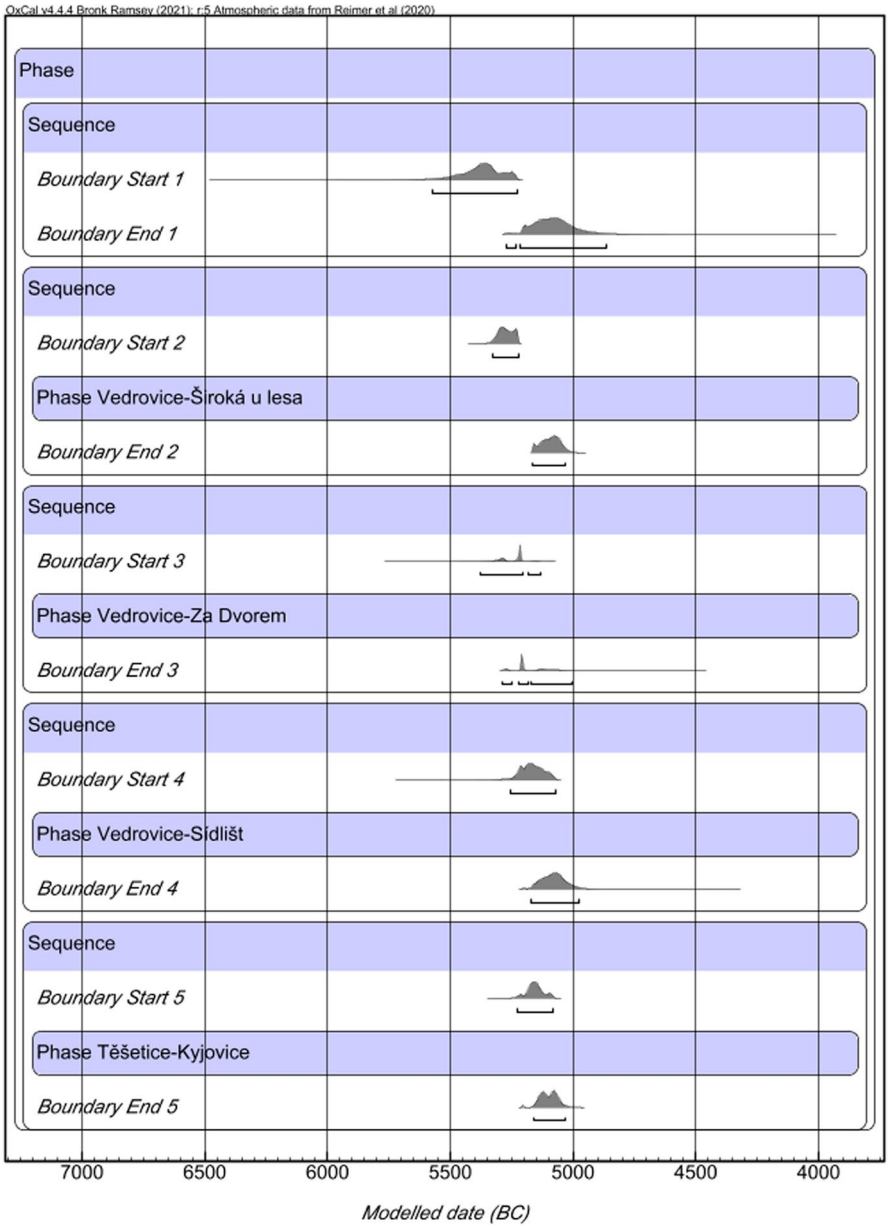

Fig. 1 Overlapping phases Bayesian modelling (*Amodel* 108.5 and *Aoverall* 107.8) of the analysed sites using OxCal v.4.4 software (Bronk Ramsey, 2009) and the IntCal20 calibration curve (Reimer et al., 2020)

complementary approach would make it possible to determine whether or not these movements took place in areas with different precipitation indices or water resources (Pederzani & Britton, 2019).

Finally, the abovementioned models do not fully take account of the implications of the biased demographic pyramid, in both cemeteries and settlement sites, when interpreting mobility patterns. This is especially the case in the male sample, which presents clear age gaps between sites. A thorough review of all the published anthropological data is still necessary to reinterpret the consistency of the sex and age ratios in each of the different kinds of funerary contexts.

Following the different gaps that limit the explanation and interpretation of the mobility patterns of these communities, the goals of this paper are as follows: (1) to contribute to the characterisation of the south-eastern Moravian $^{87}Sr/^{86}Sr$ isotopic footprint; (2) to re-evaluate the implications of the population demography in each of the analysed sites for mobility by reviewing all the published anthropological data of the analysed sites; (3) to determine the individual's mobility sequence through their lives; (4) to assess whether the mobility sequences changed according to the type of funerary pattern (cemeteries/settlement graves); (5) to correlate $^{87}Sr/^{86}Sr$ mobility data with $\delta^{18}O$ values in order to test whether the two mobility indicators match; and (6) to re-evaluate the correlation between the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopic values, the variability in the inhumed person's grave goods, and diet ($\delta^{15}N$ and $\delta^{13}C$) in the light of the new data.

Materials and Methods

To achieve our goals, a total of 5 funerary contexts have been analysed, namely *Brno-Starý Lískovec*, *Těšetice-Kyjovice, Vedrovice-Sidliště*, *Vedrovice-Široká u Lesa,* and *Vedrovice-Za Dvorem*. *Vedrovice* (Znojmo District, Fig. 2) is located in Southern Moravia at the base of the Bohemian Massif, between the rivers Dyje (south) and Jihlava (north). It comprises three different burial areas: the settlement (*Sidliště*), a cemetery (*Široká u Lesa*) and a small grave cluster (*Za Dvorem*). On the basis of site documentation and osteological analyses (Podborský, 2002; Ondruš, 1972; Smrčka et al., 2005; Dočkalová & Čižmář, 2007, 2008), and discarding non-reliable grave contexts, 86 individuals distributed in 84 graves were counted at *Široká u Lesa*, 10 burials at *Sidliště*, and 13 at *Za Dvorem*, making a total of 109 individuals (SI 1, Table 2).

Brno-Starý Lískovec (Brno District) is situated on the Bohunice plateau, on the southern outskirts of the city of Brno. It is an enclosed multi-phase settlement with a total of 12 settlement graves (Berkovec, 2004; Přichystal, 2008; Dočkalová & Čižmář, 2007, 2008) (Online Resource SI 1: Table 2). Finally, *Těšetice-Kyjovice* (Znojmo District) corresponds to a settlement area with a small cluster of 8 graves in its north-eastern part (including one double burial) and 4 burials spread among the dwellings (Online Resource SI 1: Table 2) (Dočkalová, 2006; Dočkalová & Čižmář, 2007, 2008). The site is located between the Bohemian Massif and the Carpathian area, on the eastern edge of the Krumlovian Forest.

A total of 35 new samples were performed for $^{87}Sr/^{86}Sr$ and $\delta^{18}O$, including both human (26 samples from 13 individuals) and faunal (9 samples from *Bos*, *Ovis* and *Sus*) enamel (Table 1, see Online Resource SI 1: Table 1 for details). Eight samples came from *Brno-Starý Lískovec*, 10 from *Těšetice-Kyjovice,* 2 from

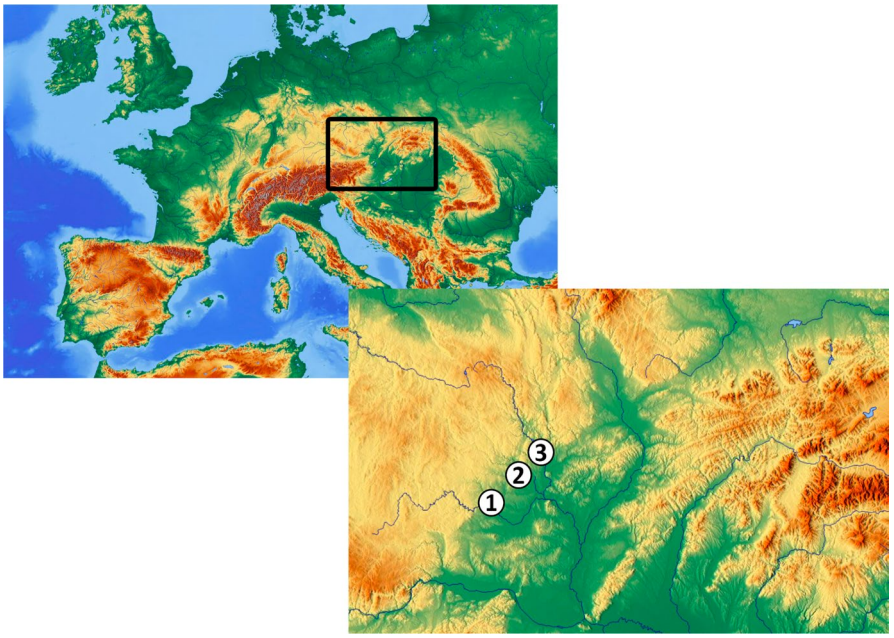

Fig. 2 Map displaying the sites included in the analysis: *Těšetice-Kyjovice* (1), *Vedrovice Široká u Lesa*, *Sidliště* and *Za Dvorem* (2) and *Brno-Starý Lískovec* (3). Map source: OpenStreetMap (Open Database License)

Table 1 Sex classification of individuals (after Dočkalová & Čižmář 2007, 2008; Lillie, 2008) according to the different sites and the number of individuals sampled for $^{87}Sr/^{86}Sr$ analysis

Site	Total /sampled males	Total /sampled females	Total/sampled non-adults	Total/sampled non-determined adults
Vedrovice-Široká u Lesa	21/18	41/32	20/12	4/1
Vedrovice-Za Dvorem	2/1	7/6	4/0	0/0
Vedrovice-Sidliště	2/2	0/0	8/5	0/0
Brno-Starý Lískovec	6/5	0/0	5/0	1/0
Těšetice-Kyjovice	3/3	4/3	6/2	0/0

Vedrovice-Sidliště, 14 from *Vedrovice-Za Dvorem* and 1 from *Vedrovice-Siroká u Lesa*.

Previous $^{87}Sr/^{86}Sr$ performed by Richards et al. (2008), Bickle and Whittle (2013) and Smrčka et al. (2005) were considered during the sample selection, prioritising individuals that had already been sampled with the aim of comparing values between different teeth. Since each molar mineralizes at different times in the first years of life (from childhood to early adolescence), analysing more than one molar per individual allowed us to determine at what age individuals moved.

A total of 119 human enamel samples (including existing and new measurements) from a total of 90 individuals have been used in this study (41 females, 29 males, 1 non-determined adult and 19 non-adults; see Table 1, and SI 1: Table 2 for details – new values are marked in bold). This corresponds to a total of 41 M1, 48 M2, 29 M3 and 1 PM.

The 24 available $^{87}Sr/^{86}Sr$ values on femur samples from *Vedrovice-Sídliste* (6), *Vedrovice-Za Dvorem* (1) and *Vedrovice-Siroká u Lesa* (1) (Smrčka et al., 2005) were used to characterises the local isotopic footprint (Lacroix, 1971; Price et al., 2002), together with 9 values on fauna samples performed in the framework of this project (Online Resource SI 1: Table 2). Furthermore, a database including $^{87}Sr/^{86}Sr$ values from Moravian human, geological and animal samples was performed (see Online Resource SI 1: Table 3) and grouped according to the geographical and geological formations where the samples were taken (excluding those coming from migratory animals) (Fig. 3) (see Online Resource SI 1: Table 4). These formations included the Tertiary and Quaternary soils from the Carpathian Foredeep, the *Ždánický les* mountains (corresponding to the beginning of the Carpathians), the Quaternary soils east of the *Ždánický les*, the Bohemian Massif Paleozoic and the Bohemian Massif Proterozoic (Chytrý, 2012). To work with as much accuracy as possible, only the values from geological samples, snails and *Sus Scrofa* (the domestic animal more likely to be less mobile) were ultimately considered (see Online Resource SI 2: Fig. 1).

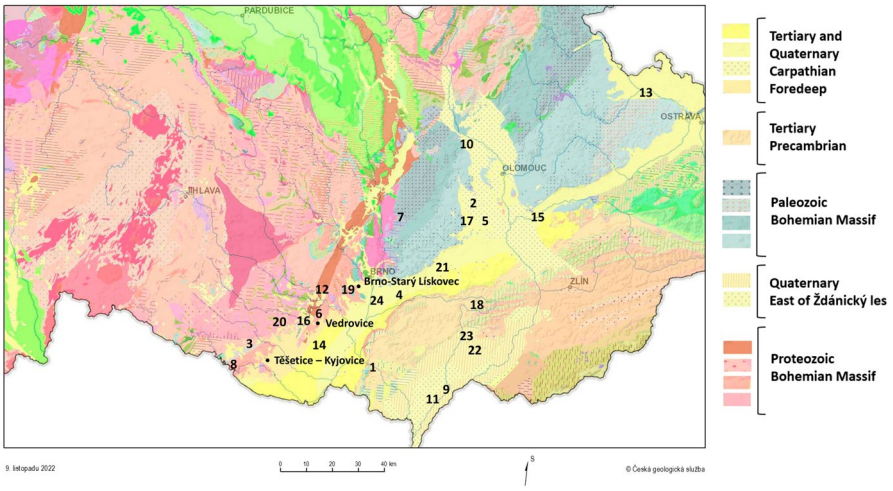

Fig. 3 Available local isotopic signatures of the studied area, based on geological and archaeological/anthropological fauna and malacofauna samples published so far from the following sites: (1) Dolní Vestonice, (2) Držovice, (3) Hluboké Mašůvky, (4) Holubice, (5) Kralice na Hané, (6) Krumlovský les, (7) Kůlna Cave, (8) Mašovice u Znojma, (9) Mikulčice-Valy, (10) Mladeč Cave, (11) Moravská Nová Ves, (12) Nová Ves u Oslavan, (13) Opava, (14) Pohořelice-Šumice, (15) Předmostí-Dluhonice, 16) Rybníky, (17) Seloutky, (18) Slatinky, Močílky, (19) Střelice, (20) Trstěnice, (21) Vyškov, (22) Žadovice, (23) Želešice u Brna and (24) Cezavy u Blučiny. To check the isotopic signatures for each of the sites see: SI 1: Table 3. Map source: Česká geologická služba

The chemical pre-treatment of the $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopic samples was conducted at the isotope laboratory of the biogeology group at the Department of Geosciences of the University of Tübingen in accordance with established procedures (Müller-Sohnius, 2007, Bocherens et al. 2016) (for details see Online Resource SI 3). The isotopic measurements were carried out at the Curt-Engelhorn-Zentrum Archäometrie gGmbH in Mannheim, Germany.

The statistical analysis has been performed using R software (version 4.0.1; R Core Team, 2013) in the case of the Multiple Correspondence Analysis, together with the R packages FactoMineR and factoextra (Hervé et al., 2010; Husson et al., 2017) and ggplot2 (Wickham, 2016). χ^2, F, T, Kolmogorov–Smirnov, and Shapiro Wilk tests were also used by means of PAST (version 3.0; Hammer et al., 2001).

In all the sampled sites the graves are those characteristic of LBK burial practices: generally oval, and dug directly in the ground, where the bodies were inhumed individually. The grave goods generally consist of ornaments (*Spondylus* beads, pendants and medallions, snail shells, marble beads and animal teeth), stone adzes, flint blades and fragments, pottery vessels, pebbles possibly used as utensils, bone tools, antler items, ochre blocks, ochre powder, as well as a group of objects generally referred to as 'grinding tools', whose precise use is yet to be determined (Podborský, 2002, see Online Resource SI 1: Table 2).

Results

The Anthropological Record

The revision of the anthropological record (Dočkalová & Čižmář, 2007, 2008; Lillie, 2008) found that female-sexed skeletons outnumber males at both the *Vedrovice-Široká u Lesa* cemetery and *Vedrovice-Za Dvorem* cluster, while the situation is reversed at the settlement graves, where males and non-adults dominate (Table 1).

If the age of individuals at death is considered (Table 2), opposite trends can also be observed between sites, especially among males. For instance, at *Vedrovice-Široká u Lesa* a smaller number of adult mature males (5 individuals) are found in contrast to mature adult females (14 individuals). At *Vedrovice-Sidliště*, the only

Table 2 Total number of individuals per site according to sex and age. Adult individuals whose sex was not determined were not recorded in this table (for more detailed information see SI 1, Table 2). Age classification criteria follow White et al. (2011) and Schaefer et al. (2009)

Site	Adult mature male/female	Advanced age male/female	Young Adult male/female	Juvenile male/female	Non-adult
Vedrovice-Široká u Lesa	5/14	2/7	11/12	1/3	20
Vedrovice-Za Dvorem	0/1	0/2	2/1	0/3	4
Vedrovice-Sidliště	2/0	0/0	0/0	0/0	8
Brno-Starý Lískovec	2/0	1/0	1/0	1/0	5
Těšetice-Kyjovice	0/1	0/0	1/2	2/0	6

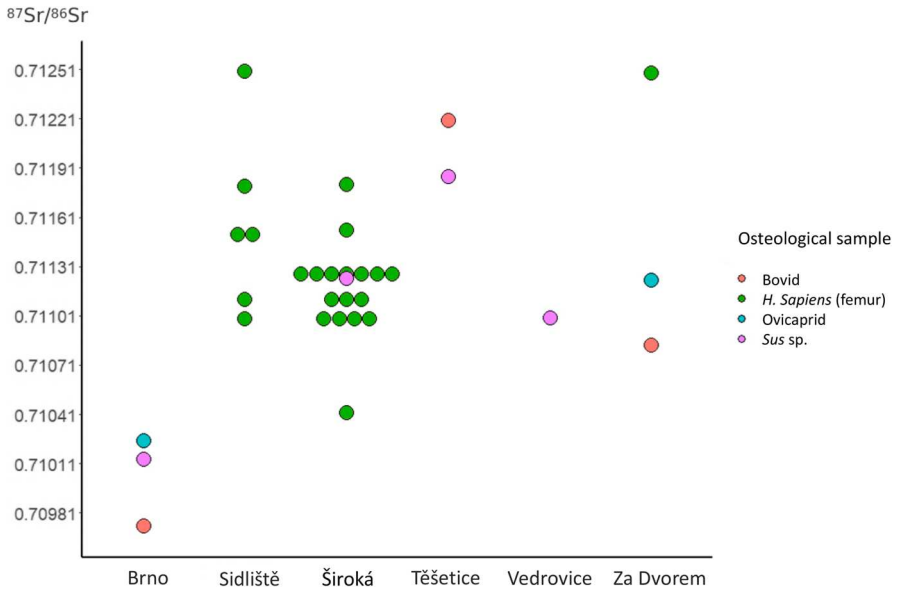

Fig. 4 Local isotopic signature based on available human femurs' $^{87}Sr/^{86}Sr$ data and new faunal samples. Abbreviations of the sites are as follows: Těšetice = Těšetice-Kyjovice; Brno = Brno-Starý Lískovec; Za Dvorem = Vedrovice-Za Dvorem; Siroká = Vedrovice-Široká u Lesa; Sídliště = Vedrovice-Sídliště. The *Sus* sample from Vedrovice was published by Smrčka (2019) without specifying to which sector it belonged. Graph produced by *Ggplot2* software

Table 3 Regional $^{87}Sr/^{86}Sr$ isotopic signatures of the analysed sites

Site	$^{87}Sr/^{86}Sr$ isotopic range	$^{87}Sr/^{86}Sr$ isotopic mean
Těšetice-Kyjovice & Vedrovice	0.71042–0.71249	0.71128 ± 0.00119
Brno-Starý Lískovec	0.70973–0.71025	0.71004 ± 0.00023

buried adults are mature males (2 individuals), at *Vedrovice-Za Dvorem* males are only young adults (2 individuals) and at *Těšetice-Kyjovice* just one juvenile and two young adults (3 individuals). The only burial place with an equal mixture of male ages is *Brno-Starý Lískovec*, where 2 adult matures, 2 juveniles, 1 young adult and 1 advanced age adult were documented.

Local $^{87}Sr/^{86}Sr$ Isotopic Footprint

The $^{87}Sr/^{86}Sr$ from both new fauna enamel samples and available human femurs (Fig. 4, Table 3; for complete database and references see Online Resource SI 1: Table 1 and 2; SI 2: Fig. 1) indicate that the local isotopic range at *Těšetice-Kyjovice* and *Vedrovice* presents similar strontium values (0.71042–0.71249) (excluding an

Ovis/Aries outlier from *Těšetice-Kyjovice* with higher radiogenic values = 0.71651, which could be the result of transhumance or of being a trade item), as they both lie on the border between the Carpathian basin and the Bohemian Massif. The values from *Brno-Starý Lískovec,* situated on the Bohunice plateau, are slightly lower (0.70973–0.71014) (see complete database and references in SI 1: Table 1 & 2), probably because the loess in this area derives from late Weichselian interpleniglacial soil complex with varied underlying geology defined by a wide range of granitoids (Starkel, 1977; Mateiciucová, 2008). Accordingly, while the Moravian groups settled on loess soils, as was common among the LBK communities (Bentley & Knipper, 2005a; Bentley et al., 2006; Price et al., 2002, 2004), the higher $^{87}Sr/^{86}Sr$ ranges obtained in this area in comparison with the regular loess $^{87}Sr/^{86}Sr$ ratios (0.70860–0.71030) suggests that there is a greater contribution from Precambrian and Proterozoic rocks to the loess in the vicinity of the sites, which may reflect their position on the edge of the Bohemian–Moravian Highlands, where the strontium values are higher.

$^{87}Sr/^{86}Sr$ from south-eastern Moravian human, geological and animal samples (see Online Resource SI 1: Table 3) were combined to produce strontium isotopic baselines for each of the geological formations in the region. The observed ranges are as follows (Table 4): for Tertiary and Quaternary soils from the Carpathian Foredeep (TQCF), the isotopic range is approximately 0.71054–0.71056 when considering geological samples alone. However, when incorporating measurements from the primary human cluster, the range expands to 0.71018–0.71080. The Paleozoic formations in the Bohemian Massif (Paleo BM) exhibit a range of 0.70946–0.71059. In the Quaternary soils behind *Ždánický les* mountains (Quat BPZ), the range is 0.70941–0.71038, and for *Ždánický les* itself (Tertiary Z) it is 0.70891–0.70979. The Proterozoic from the Bohemian Massif (Prot BM) baseline was built on the basis of the local isotopic range from *Těšetice-Kyjovice* and *Vedrovice,* measured on human femurs and domestic fauna (0.71042–0.71249) and matching the data with the human long bones and *Sus scrofa* samples from the sites of *Krumlovský les* and *Trstěnice* (Fig. 5).

$^{87}Sr/^{86}Sr$, Sex and Age

Considering the $^{87}Sr/^{86}Sr$ values, in all the sampled sites except *Brno-Starý Lískovec*, the non-local values are predominantly found in female individuals and the local ones in males and non-adults (Fig. 6). Most of the *Vedrovice-Široká u Lesa*, *Vedrovice-Za Dvorem*, *Vedrovice-Sídliště* and *Těšetice-Kyjovice* local individuals' $^{87}Sr/^{86}Sr$ values fall within the isotopic footprint of the Proterozoic Bohemian Massif, where the sites are located.

At *Vedrovice-Sídliste*, where only males and non-adults were recorded, all strontium values matched the local baseline. At *Vedrovice-Za Dvorem*, *Vedrovice-Široká u Lesa* and *Těšetice-Kyjovice*, females displayed a greater isotopic variability than males. Only 2 male individuals were classified as non-local in the whole sample, both buried at *Vedrovice-Siroká u Lesa* (11% of the total sampled males). This contrasts with 2 non-local females at *Těšetice-Kyjovice* (66% of the sampled females), 3

Table 4 $^{87}Sr/^{86}Sr$ local isotopic footprint from south-eastern Moravia

Region	$^{87}Sr/^{86}Sr$ isotopic range	$^{87}Sr/^{86}Sr$ isotopic mean
Tertiary and Quaternary soils from the Carpathian Foredeep (TQCF)	0.71054–0.71056	0.71055 ± 0.000001
Paleozoic formations from the Bohemian Massif (Paleo BM)	0.70946–0.71059	0.709994 ± 0.000462
Proterozoic formations from the Bohemian Massif (Proto BM)	0.71042–0.71249	0.71128 ± 0.00119
Quaternary soils behind *Ždánický les* mountains (Quat BPZ)	0.70941–0.71038	0.71013 ± 0.00042
Ždánický les mountains (Tertiary Z)	0.70891–0.70979	0.70935 ± 0.00044

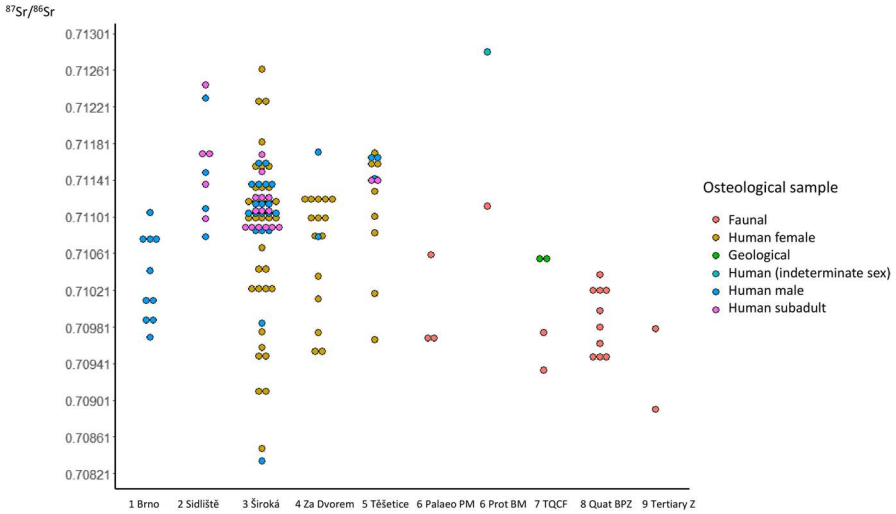

Fig. 5 Strontium isotopic values ($^{87}Sr/^{86}Sr$) from Moravian human, geological and animal samples, including those from the studied archaeological sites. Paleo BM = Paleozoic from the Bohemian Massif; Prot BM = Proterozoic from the Bohemian Massif: TQCF = Tertiary and Quaternary soils from the Carpathian Foredeep; Quat BPZ = Quaternary soils behind Ždánický les mountains; Z = Ždánický les mountains (Carpathians); m = males; f = females. See SI-2: Fig. 1 to check the animal species, and SI-2: Fig. 3 to check the isotopic values for the humans. Graph produced by *Ggplot2* software

at *Vedrovice-Za Dvorem* (50% of the sampled females) and 13 at *Vedrovice-Siroká u Lesa* (41% of the sampled females) (Fig. 6). Thus, a strong statistical relationship between biological sex and mobility is observed from the aggregated data (see χ^2 test results in Online Resource SI 2: Table 2).

In the case of *Brno-Starý Lískovec*, where only males and non-adults were buried, two males presented local values (burials 805 and 806), whereas three displayed ranges outside the local (burials 800, 801 and 803). In this case, the sampled molars corresponded to M1 and M2, indicating that these individuals probably moved during infancy.

The different $^{87}Sr/^{86}Sr$ ratios from the three molars (M1, M2 and M3) were compared by sex in the cases of *Vedrovice-Široká u Lesa*, *Vedrovice-Za Dvorem*, *Vedrovice-Sídliště* and *Těšetice-Kyjovice*. As a result, only in the case of M3 (mineralized between 7 and 17 years) was the relationship between sex and mobility statistically significant (see Online Resource SI 2: Table 2). In the cases of M1 (mineralized during the last month of gestation up to 2 years) and M2 (mineralised between 1 and 8 years), no statistically significant sex-related patterns were observed (see Online Resource SI 2: Table 2), even though there were more non-local females (4 M1, 8 M2, 8 M3) than males (0 M1, 1 M2 and 2 M3). This means that mobility patterns for males and females were especially divergent at the point the M3 was forming (7–17 years), potentially linking greater female mobility to the beginnings of puberty and early adolescence.

A closer analysis of the non-local $^{87}Sr/^{86}Sr$ values indicates the presence of potentially different mobility groups. Most of the non-local individual signatures

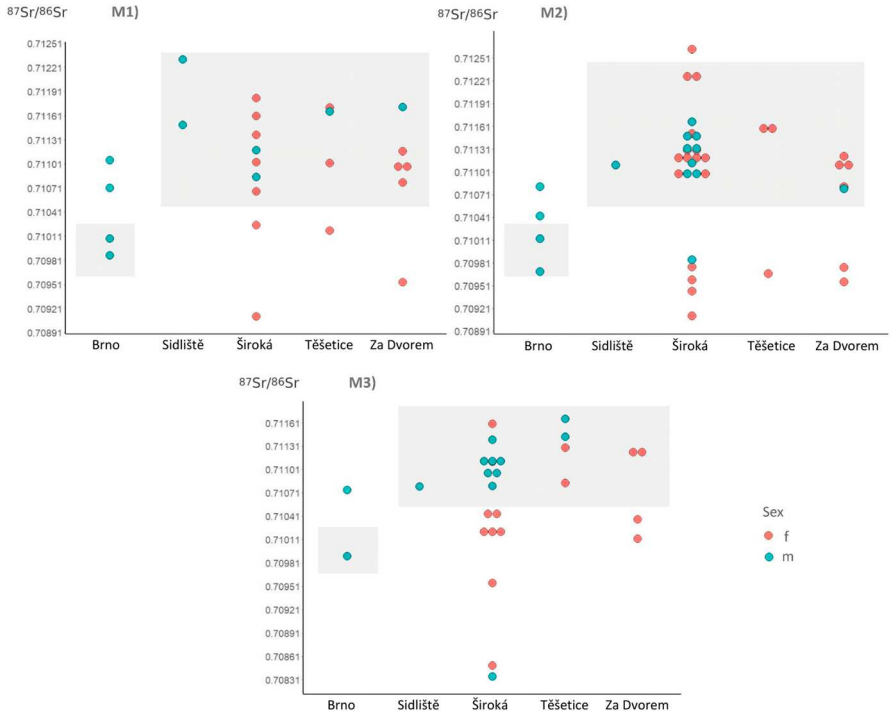

Fig. 6 Dot plot including the different sites' $^{87}Sr/^{86}Sr$ distribution according to males' and females' molars M1, M2 and M3 (excluding the male outlier from grave 69/78 from *Vedrovice-Siroká u Lesa*). The grey shading indicates the local isotopic footprint. Graph produced by *Ggplot2* software

do not differ much from the isotopic footprint of the other geological areas nearby: the *Vedrovice* (including the three sectors) and *Těšetice-Kyjovice* non-local females present $^{87}Sr/^{86}Sr$ values between 0.71228 and 0.71048, which match the Bohemian Massif Palaeozoic baseline as well as the Quaternary and Tertiary sediments from the Carpathian Foredeep, the *Ždánický les* mountains (corresponding to the beginning of the Carpathians), and, especially, the Quaternary soils east of the *Ždánický les*. Even though the $^{87}Sr/^{86}Sr$ analysis interpretative limits do not allow us to assess where exactly these females were moving, the similarities with the nearby geological deposits of the region suggest that they could be involved in short-distance movements within this area (nearby areas located less than 50 km away). Yet, a male and female individual from *Vedrovice-Siroká u Lesa* (graves 99/81 and 29/76) are exceptions with extreme non-local values that do not match any of the baselines in south-eastern Moravia and must have arisen in movement from more distant regions.

In the case of the three non-local males from *Brno-Starý Lískovec*, isotopic values match the footprint defined for the *Vedrovice* complex, being clearly beyond the Bohemian Massif palaeozoic baseline and within the Bohemian Massif palaeozoic range (Figs. 5 and 6), and suggesting that this could have been the area through which they were moving.

The $^{87}Sr/^{86}Sr$ values of *Vedrovice* and *Těšetice-Kyjovice* fall within the Proterozoic isotopic footprint and within the Paleozoic at *Brno-Starý Lískovec*; thus, the so-called 'locals' could either have moved westwards within the Bohemian Massif or not moved at all from their settlements located at the border between the Carpathian basin and the Bohemian Massif.

$\delta^{18}O$ and $^{87}Sr/^{86}Sr$

The correlation between $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ isotopic data contributed interesting results (Fig. 7), compensating for the interpretative limitations of $^{87}Sr/^{86}Sr$ analysis. In the case of samples which have local $^{87}Sr/^{86}Sr$ determinations and $\delta^{18}O$ data (see Online Resource SI 1: Table 1), the isotope local/non-local attributions agree. *Brno-Starý Lískovec* samples are considered local though $^{87}Sr/^{86}Sr$ analysis presented slightly different $\delta^{18}O$ values (−7.15/-7.45) from *Vedrovice*'s (including the three sectors) and *Těšetice-Kyjovice*'s (−6.3/−7.45), probably because of the consumption of water from different *Svratka* river tributaries (see Online Resource SI 2: Fig. 3).

In the case of the individuals for whom we have non-local $^{87}Sr/^{86}Sr$ determinations and $\delta^{18}O$ data (4 in total), grave 11 from *Těšetice-Kyjovice,* and 10/89 and 7/88 from *Vedrovice-Za Dvorem* presented $\delta^{18}O$ values similar to those belonging to *Brno-Starý Lískovec*, which suggests this area as their probable place of origin. At the same time, the individual from *Brno-Starý Lískovec* considered as non-local on the basis of $^{87}Sr/^{86}Sr$ (burial 803), also presents $\delta^{18}O$ ranges similar to those determined at *Vedrovice* and *Těšetice-Kyjovice* (Fig. 7b). This probably indicates short-distance movements between the two areas, which are geologically different (and hence have distinct $^{87}Sr/^{86}Sr$ footprint), but with similar water resources (and similar $\delta^{18}O$ values).

In the case of the fauna samples used in $^{87}Sr/^{86}Sr$ analysis to identify the local signature, they present clearly different $\delta^{18}O$ values from those which can be considered local in all sites (Fig. 7a: see Online Resource SI 1: Table 1). At *Těšetice-Kyjovice*, *Sus* and a *Bos* have relatively high values (between -8 and -9), at *Vedrovice-Za Dvorem*, *Ovis* presented very low values (-5.3) and *Bos* high ones (-8) and, finally, at *Brno-Starý Lískovec*, *Bos* presented very low values (-5.8) and *Ovis* high ones (-8). This last data has been interpreted bearing in mind that $\delta^{18}O$ composition of tooth enamel is species dependent and so the measured values of the various species cannot be compared directly.

Mobility, Diet and Grave Goods

Multiple ribs and long bone samples have been analysed for dietary isotopes ($\delta^{15}N$ and $\delta^{13}C$) in the framework of other projects, confirming an essentially terrestrial diet based on C_3 cereal in all sites (Whittle et al., 2013). Bearing that in mind, the available $\delta^{15}N$ data variation (see raw data at Online Resource SI 1: Table 2) was used to chart diversity in protein consumption. The $\delta^{15}N$ values were statistically different between male and female individuals considering all

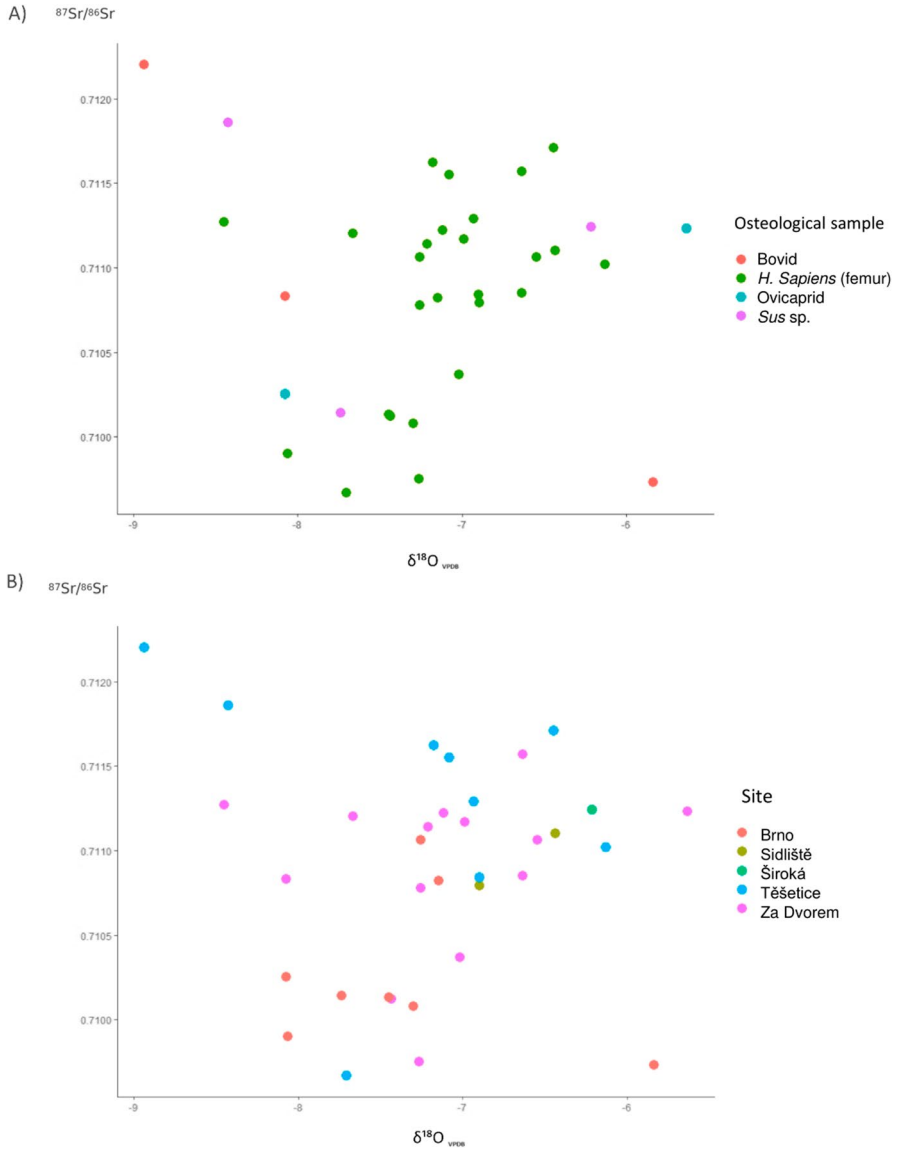

Fig. 7 Biplot indicating the relationship between the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data from the analysed sites according to the sites **A** and the sampled individuals' sex and animal species **B** (excluding the *Ovis/Aries* outlier from Těšetice-Kyjovice with higher radiogenic values). Graph produced by *Ggplot2* software

sites together (T Test 0.0005462, F Test 0.23844 for normal distributions after checking with Shapiro Wilk: see details at Online Resource SI 2: Table 3), with females' values clearly lower than those of males (Fig. 8). These results could be an indicator of different rates of protein consumption, with males eating more protein than females, or due to the consumption of animals from other areas with

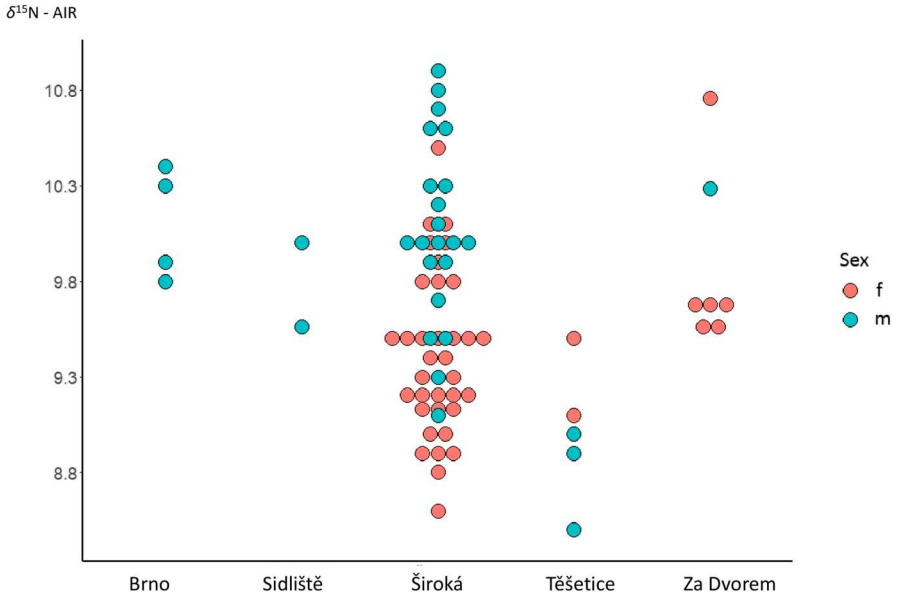

Fig. 8 Dot plot including δ^{15}N values according to sex and site. Abbreviations: f = females, m = males. Graph produced by *Ggplot2* software

different manuring systems or no field manuring at all (as suggested by Richards et al. (2008) and Masclans et al. (2021a, 2021b) for *Vedrovice-Široká u Lesa*).

Two δ^{15}N clusters were identified using K-means (see Online Resource SI 2: Fig. 4), including 'high' (9.8–10.8, including 19 males, 11 females) and 'low' (8.5–9.7, including 8 males, 29 females) δ^{15}N values, and used in the MCA analysis.

According to χ^2 test, there is not a significant variation in the presence of furnished or unfurnished graves between males and females (χ^2 test = 0.006835; df 1; p no assoc = 0.93411), nor between the different funerary sites (χ^2 test = 3.341; df 4; p no assoc = 0.50246, in this case including also the non-adult individuals).

To examine whether sex and mobility (^{87}Sr/^{86}Sr & δ^{18}O) of the buried individuals co-varied with the grave goods distribution and the available isotopic dietary values (δ^{15}N), a correlation between these factors was explored through Multiple Correspondence Analysis (MCA). The MCA results indicate a relationship between the sex of the buried individuals, the grave goods assemblages, diet and mobility (see Online Resource SI 2, Figs. 4 & 5 for full statistics, and SI 4 for the database) (Fig. 9). Males with higher δ^{15}N dietary values were more likely to be buried with more stone and bone tools, as well as pottery vessels, whereas males with lower δ^{15}N dietary determinations were correlated with a lesser presence of grave goods.

In contrast, female individuals do not present statistical associations with any particular kind of grave good. In this case, non-local females were less likely to receive grave goods (26% local unfurnished, 41% non-local unfurnished), although no differences were identified in terms of the variability of the objects. Non-local females

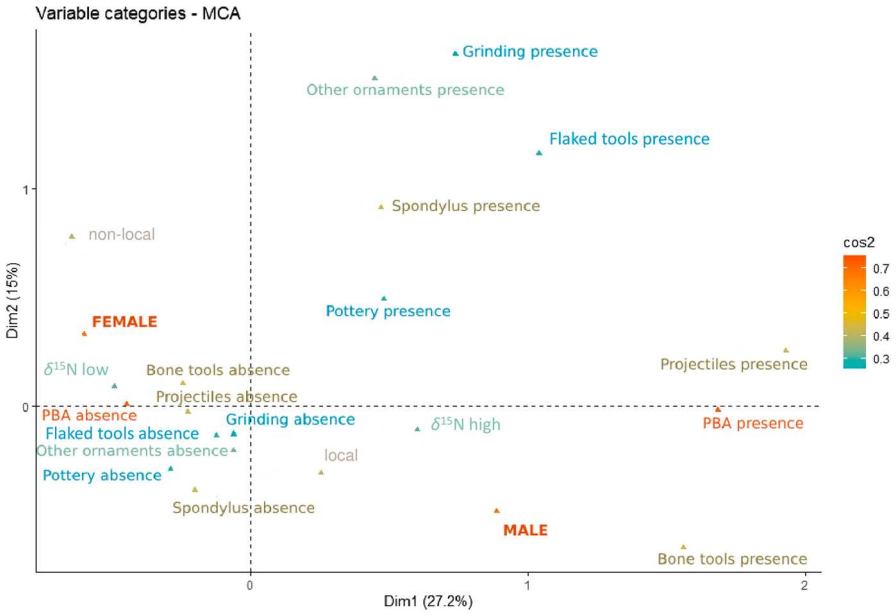

Fig. 9 Multiple Correspondence Analysis of the buried individuals' sex, mobility ($^{87}Sr/^{86}Sr$), diet ($\delta^{15}N$) and grave good distribution. Graph produced by *Ggplot2* software

presented generally less $\delta^{15}N$ variability than local ones (values between 9 and 10), with statistically different value distributions (Kolmogorov–Smirnov 0.0064).

Discussion and Conclusions

The results of this study confirm that sex and age played a key role in the mobility patterns of the LBK Moravian communities: not only were females more mobile than males, but their mobility increased progressively with age. The M3 are statistically more likely to show a non-local strontium isotope among females than males. As the mineralisation of the third molar occurs at roughly the same time as puberty, we can suggest that female mobility significantly increased from puberty and early adolescence.

We also observed that the mobility patterns do not differ between the various funerary contexts (settlements and cemeteries), suggesting that what determines the presence of non-local individuals is not the funerary pattern but the proportion of females versus males in each of the sites.

At least four possible mobility realities coexisted at the studied sites. The first one corresponds to 'local' males, females and non-adults. Considering that the 'local' $^{87}Sr/^{86}Sr$ baseline falls within the Proterozoic isotopic footprint at *Vedrovice* and *Těšetice-Kyjovice* and within the Paleozoic at *Brno-Starý Lískovec*, they could either have been moving westwards within the Bohemian Massif or not moving at all from their settlements located at the border between the Carpathian basin and the

Bohemian Massif. However, the hypothesis that they did not move at all from their place of settlement becomes less plausible in the light of $\delta^{18}O$ data, which supports the idea of short-distance movements by 'local' individuals consuming water from the same *Svratka* river tributary.

In contrast, the non-local females were possibly moving eastward at distances of less than 100 km (from the Carpathian Foredeep, the Carpathian *Ždánický les* mountains or the Quaternary soils east of the *Ždánický les*) and/or from the north (Paleozoic of the Bohemian Massif). Despite the similarity of most of the non-local values with the nearby areas, the hypothesis that they moved to eastward regions with similar $^{86}Sr/^{87}Sr$ isotopic determinations cannot be ruled out.

This could also have been the case with some non-local females from *Vedrovice-Široká u Lesa* and *Vedrovice-Za Dvorem*, whose values coincide with the local isotopic footprint of the contemporary Slovak cemetery of *Nitra* (between 0.70932 and 0.70964) (Masclans et al., 2021b), with an isotopic footprint close to the Carpathian Mountains and at a distance of about 180 km. However, the $\delta^{18}O$ isotopic data, though still very sparse, points towards the first hypothesis (that is, eastward movements at distances under 100 km), as both individual 11 from *Těšetice-Kyjovice* and 10/89 from *Vedrovice-Za Dvorem*, considered as non-local based on Strontium values, present $\delta^{18}O$ values similar to those belonging to *Brno-Starý Lískovec,* located at the border of the Paleozoic of the Bohemian Massif, indicating short-distance movements between geological areas with different Strontium isotopic baselines but similar water resources.

Finally, only in two cases are there extreme non-local values that do not match any of the baselines in south-eastern Moravia: one female and one male, from *Vedrovice-Siroká u Lesa*. This kind of mobility thus seems to be not sex-related and is clearly rare.

The anthropological record shows an unequal distribution of males/females according to the funerary record (female-sexed skeletons outnumber males at cemeteries and burial clusters, and the situation is reversed at the settlement graves), indicating selection based on sex in burial practices. This selection is seen in the age of buried individuals, especially among males. The unbalanced presence of buried men in the funerary contexts could be explained by the presence of differential access to certain funerary practices defined by sex and age, but it could also indicate some kind of age-based mobility pattern among men.

Traditionally, female migration, patrilocality and community exogamy have been considered as a factor explaining the higher proportion of females than males in burial contexts, as well as a more plausible explanation for higher variability of $^{87}Sr/^{86}Sr$ ratio in females than males (Chamberlain, 2006; Hrnčíř et al., 2020a; Whittle et al., 2013). Our results, however, challenge this idea and lead to new hypotheses no longer focused on whether or not females moved for reasons of exogamy, but rather why there is a more mobile group of females and what differentiates them from the rest of their community.

These results challenge the dichotomy between 'locals' and 'non-locals', which was previously questioned by Bickle and Hofmann (2007) and Snoeck et al. (2016); for further discussion about the problems related to what can be considered 'local' or 'non-local' in prehistory see Cavazzuti et al. (2019). Instead of 'local' versus

'non-local', we suggest here that it may be more accurate to speak about mobile versus non-mobile individuals. It makes sense to interpret those non-local females as simply more mobile than the rest of their community, bearing in mind that this mobility was short-distance in nature.

As the strontium isotope record of LBK funerary contexts has grown, it has demonstrated a heterogeneous patchwork of mobility patterns, raising questions as to the existence of a single predominant LBK patrilocal model. In south-western Germany, for example, isotopic data suggested differences between male and female individuals, pointing to major mobility among males, which has been interpreted as the result of the integration of marginal landscapes (uplands) for animal husbandry (Bentley & Knipper, 2005b; Knipper, 2009). In settlements like Stuttgart-Mühlhausen (Baden-Württemberg, Germany) different mobility patterns were identified among the cemetery sectors, as well as between the sexes according to their ages (Knipper, 2011). A different situation was also found at the settlement of Nieder-Mörlen (Hessen, Germany), where the individuals who died as juveniles presented non-local values, while those who died as adults had local ones (Montgomery et al., 2009).

This kind of data re-interpretation agrees with the latest aDNA studies on two LBK cemeteries, *Nitra* and *Derenburg-Meerenstieg II* (Childebayeva et al., 2022; Gelabert et al., 2023), where only about 60% (in *Nitra*) and 25% (in *Derenburg-Meerestieg II*) of the individuals had biological relatives buried at the same site. This low degree of kinship relationships at cemeteries suggests that it was not only the individuals determined as non-local by $^{87}Sr/^{86}Sr$ who moved from their places of origin, but also the local ones, both female and male, since they were not genetically related either. Together this data makes us rethink who is being buried in these contexts and what defines them as a group that belonged together in death. It opens the possibility of understanding burial groups no longer as a straightforward representation of a living community and its kinship structure, as has been implicitly assumed for previous models of patrilocality.

In order to create more data to better understand those questions, we explored the correlation between the $\delta^{15}N$ dietary values and the number of artefacts deposited as grave goods. As a result, we observed that the more mobile females were less likely to be buried with grave goods (or, at least, with non-perishable grave goods) and statistically more related to lower $\delta^{15}N$ values than non-mobile females, who, in turn, presented lower $\delta^{15}N$ values and lower grave-good variability than male individuals.

The lower $\delta^{15}N$ values associated with these more mobile females could either reflect different dietary practices involving lower animal protein ingestion rates, or the consumption of animals from other areas with different manuring systems or no field manuring at all. One possible explanation for this phenomenon may be related to economic practices involving seasonal movement between geological areas (as indicated by $^{87}Sr/^{86}S$ analysis), but at short distances with the same climatic conditions and very similar water resources (as suggested by oxygen analysis). The presence of transhumance activities within regions presenting similar strontium isotopic baselines could be an explanation for this variability.

Especially striking is the fact that the different samples of *Ovis and Bos* from the same sites present different $\delta^{18}O$ values. This variability could be related to the consumption of different hydric resources or because of differences in the animals' diet

(Pederzani & Britton, 2019). The presence of transhumant activities within regions presenting similar $^{87}Sr/^{86}S$ isotopic baselines could be an explanation for this $\delta^{18}O$ variability.

There may also be a division of labour by age and sex associated with mobility. The sexual division of labour has already been proposed in relation to the distribution of tools deposited as grave goods within cemeteries (Masclans et al., 2020, 2021a, 2021b), while osteological and physical examination of upper and lower limbs reveals musculoskeletal stress markers which strongly suggest sex-differentiated activity patterns and labour-related asymmetry between the sexes (Berner et al., 2018; Macintosh et al., 2014a, 2014b, 2017; Masclans et al., 2021b). We find it relevant that this more mobile form of life is directly associated with the onset of puberty, contradicting accepted models so far, which mostly related mobility to M2 (Bickle & Whittle, 2013; Masclans et al., 2020). That is, it would appear that, for females, the onset of a more mobile lifestyle corresponded with the transition to adulthood and the assumption of responsibilities within the community, and which involved a marked sexual division of labour. However, more evidence needs to be collected to confirm this hypothesis, especially data concerning animal husbandry and mobility practices related to transhumance, as well as more detailed research on osteology and musculoskeletal stress markers.

Although our results do not directly explain the mobility of this group of females, they do shed light on the wide range of possible reasons for it, as well as on the complexity of the social organisation of these communities. Our study shows that the female–male binary and patrilocal exogamic practices are not on their own sufficient as an analytical framework to interpret the mobility patterns of these central European first farmers.

Overall, we demonstrate that a sedentary lifestyle did not necessarily imply that the groups remained static; rather, they changed their mobility strategies as a result of population migrations, which expanded the new economic model in most of the European regions to smaller-scale mobility potentially related to kinship or labour.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10963-024-09181-1.

Author Contributions Berta Morell-Rovira: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; writing original draft. Zdeněk Tvrdý: Resources; writing review and editing. Marta Díaz-Zorita Bonilla: Supervision; writing review and editing. Penny Bickle: Writing review and editing. Peter Tóth: Resources; Writing review and editing. Michal Přichystal: Resources. Alžběta Bedáňová: Resources. Alba Masclans: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; writing original draft.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This project has been founded by Gerda Henkel Foundation (Germany). Research project grants AZ 20/V/20: 'Gender on the move: chronology and exogamic practices at the beginning of farming. The case of North Carpathian Basin', PI: Dr Masclans and Dr Morell-Rovira. The project was also supported by the Spanish Ministry of Science and Innovation (State Research Agency:*Juan de la Cierva Formación Program, Dr Masclans and Dr Morell-Rovira) and the Galician Innovation Agency (Axudas de apoio á etapa de formación posdoutoral. Modalidade Aprogram, Dr Morell-Rovira). Dr Tvrdý and A. Bedáňová were funded through the institutional support of long-term conceptual development of research institutions provided by the Ministry of Culture (ref. MK000094862). Dr Tóth was further funded through a Grant Agency of the Czech Republic (GA20-19542S) and Grant Agency of Masaryk University (MUNI/A/0998/2021).*

We would like to thank the Moravian Museum of Brno (Czech Republic) and the Isotope Laboratory of the Biogeology group at the University of Tübingen, especially Mauricio Marciales Daza and Valentina García-Huidobro, for their support during the laboratory work. Thanks to Corina Knipper at CEZA for measuring $^{87}Sr/^{86}Sr$. We are also grateful to the two anonymous reviewers for their feedback, which improved the paper.

Data Availability The datasets of this paper are available in the supplementary materials (Online Resources: SI 1, SI 2, SI 3 and SI 4).

References

Augereau, A. (2018). *La condition des femmes au Néolithique : Pour une approche du genre dans le Néolithique européen*. Paris: soutenance HDR. https://doi.org/10.4000/books.editionsmsh.39108

Bentley, R. (2006). Strontium isotopes from the earth to the archaeological skeleton: A review. *Journal of Archaeological Method and Theory, 13*(3), 135–187. https://doi.org/10.1007/s10816-006-9009-x

Bentley, R. A., Bickle, P., Fibiger, L., Nowell, G. M., Dale, C. W., Hedges, R. E., Hamilton, J., Wahl, J., Francken, M., Grupe, G., Lenneis, E., Teschler-Nicola, M., Arbogast, R. M., Hofmann, D., & Whittle, A. (2012). Community differentiation and kinship among Europe's first farmers. *Proceedings of the National Academy of Sciences of the United States of America, 109*(24), 9326–9330. https://doi.org/10.1073/pnas.1113710109

Bentley, R. A., & Knipper, C. (2005a). Geographical patterns in biologically available strontium, carbon and oxygen isotope signatures in prehistoric SW Germany. *Archaeometry, 47*(3), 629–644. https://doi.org/10.1111/j.1475-4754.2005.00223.x

Bentley, R. A., & Knipper, C. (2005b). Transhumance at the early Neolithic settlement at Vaihingen (Germany). *Antiquity, 79*(306), 1–3.

Bentley, R. A., Krause, R., Price, T. D., & Kaufmann, B. (2003). Human mobility at the early Neolithic settlement of Vaihingen, Germany: Evidence from strontium isotope analysis. *Archaeometry, 45*(3), 471–486. https://doi.org/10.1111/1475-4754.00122

Berkovec, T. (2004). *Ohrazené areály kultury s lineární keramikou na Moravě (I). Brno-Nový Lískovec. Pod kamenným vrchem*. Archeologické centrum Olomouc Editions.

Berner, M., Sládek, V., Holt, B., Niskanen, M., & Ruff, C. B. (2018). Sexual dimorphism. In C. B. Ruff (Ed.), *Skeletal variation and adaptation in Europeans: Upper Paleolithic to the twentieth century* (pp. 133–161). John Wiley & Sons.

Bickle, P. (2020). Thinking gender differently: New approaches to identity difference in the Central European Neolithic. *Cambridge Archaeological Journal, 30*(2), 201–218. https://doi.org/10.1017/s0959774319000453

Bickle, P., Bentley, R. A., Dočkalová, M., Fibiger, L., Griffiths, S., Hamilton, J., Robert, H., Hofmann, D., Mateiciucová, I., & Whittle, A. (2014). Early Neolithic lifeways in Moravia and Western Slovakia: Comparing archaeological, osteological and isotopic data from cemetery and settlement burials of the Linearbandkeramik (LBK). *L'anthropologie, 52*(1), 35–72.

Bickle, P., & Hofmann, D. (2007). Moving on: The contribution of isotope studies to the early Neolithic of Central Europe. *Antiquity*, *81*(314), 1029–1041.

Bickle, P., & Whittle, A. (Eds.). (2013). *The first farmers of central Europe: Diversity in LBK lifeways*. Oxbow. https://doi.org/10.1080/00665983.2015.1040675

Bocherens, H., Koch, P. L., Mariotti, A., Geraads, D., & Jaeger, J. J. (1996). Isotopic biogeochemistry (^{13}C, ^{18}O) of mammalian enamel from African Pleistocene hominid sites. *Palaios, 11*(4), 306–318. https://doi.org/10.2307/3515241

Bronck Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. *Radiocarbon, 51*(1), 337–360. https://doi.org/10.1017/s0033822200033865

Cavazzuti, C., Skeates, R., Millard, A. R., Nowell, G., Peterkin, J., Bernabò Brea, M., Cardarelli, A., & Salzani, L. (2019). Flows of people in villages and large centres in Bronze Age Italy through strontium and oxygen isotopes. *PLoS One, 14*(1), e0209693. https://doi.org/10.1371/journal.pone.0209693

Chamberlain, A. T. (2006). *Demography in archaeology*. Cambridge University Press.

Childebayeva, A., Rohrlach, A. B., Barquera, R., Rivollat, M., Aron, F., Szolek, A., Kohlbacher, O., Nicklisch, N., Alt, K. W., Gronenborn, D., Meller, H., Friederich, S., Prüfer, K., Deguilloux, M. F., Krause, J., & Haak, W. (2022). population genetics and signatures of selection in Early Neolithic European farmers. *Molecular Biology and Evolution, 39*(6), msac108. https://doi.org/10.1093/molbev/msac108

Chytrý, M. (2012). Vegetation of the Czech Republic: Diversity, ecology, history and dynamics. *Preslia, 84*(3), 427–504.

Dočkalová, M. (2006). Two skeleton graves from Neolithic settlements in Moravia (Czech Republic). *L'anthropologie, 44*(2), 127–138.

Dočkalová, M., & Čižmár, Z. (2007). Neolithic children burials at Moravian settlements in the Czech Republic. *L'anthropologie, 45*(1), 31–60.

Dočkalová, M., & Čižmár, Z. (2008). Neolithic settlement burials of adult and juvenile individuals in Moravia, Czech Republic. *Anthropologie, 46*(1), 37–76.

Ensor, B. E. (2021). *The not very patrilocal European Neolithic: Strontium, aDNA, and archaeological kinship analyses*. Archaeopress.

Gelabert, P., Bickle, P., Hofmann, D., Teschler-Nicola, M., Anders, A., Huang, X., Olalde, I., Fournier, R., Ringbauer, H., Akbari, A., Cheronet, A., Lazaridis, I., Broomandkhoshbackt, N., Fernandes, D., Buttinger, K., Callan, K., Candilio, F., Bravo, G., Curtis, E., Reich, D. (2023). Social and genetic diversity among the first farmers of Central Europe. Biorxiv: The preprint server for biology. https://doi.org/10.1101/2023.07.07.548126

Hammer, Ø., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica, 4*(1), 9.

Hedges, R., Bentley, R. A., Bickle, P., Cullen, P., Dale, C., Fibiger, L., Hamilton, J., Hofmann, D., Nowell, G., & Whittle, A. (2013). The supra-regional perspective. In P. Bickle & A. Whittle (Eds.), *The first farmers of central Europe: Diversity in LBK lifeways* (pp. 343–384). Oxbow.

Hervé, A., & Williams, L. J. (2010). Principal component analysis. *WIREs Computational Statistics, 2*, 433–459.

Hofmann, D. (2009). Cemetery and settlement burials in the Lower Bavarian LBK. In D. Hofmann & P. Bickle (Eds.), *Creating communities: New advances in central European Neolithic* (pp. 220–234). Oxbow.

Hofmann, D. (2020). Not going anywhere? Migration as a social practice in the early Neolithic Linearbandkeramik. *Quaternary International*, *560*, 228–239.

Hofmann, D., & Orschiedt, J. (2015). Mortuary practices, bodies, and persons in Central Europe. In C. Fowler, J. Harding & D. Hofmann (Eds.), *The Oxford handbook of Neolithic Europe* (pp. 987–1004). Oxford Academic online.

Hrnčíř, V., Duda, P., Šaffa, G., Květina, P., & Zrzavý, J. (2020a). Identifying post-marital residence patterns in prehistory: A phylogenetic comparative analysis of dwelling size. *PLoS One, 15*(2), e0229363. https://doi.org/10.1371/journal.pone.0229363

Hrnčíř, V., & Laffoon, J. E. (2019). Childhood mobility revealed by strontium isotope analysis: A review of the multiple tooth sampling approach. *Archaeological Anthropological Science, 11*, 5301–5316. https://doi.org/10.1007/s12520-019-00868-7

Hrnčíř, V., Vondrovský, V., & Květina, P. (2020b). Post-marital residence patterns in LBK: Comparison of different models. *Journal of Anthropological Archaeology, 59*, 101190. https://doi.org/10.1016/j.jaa.2020.101190

Husson, F., Le, S., & Pagès, J. (2017). Exploratory multivariate analysis by example using R. *Boca Raton Press*. https://doi.org/10.1201/b10345

Jeunesse, C. (1997). *Pratiques funéraires en Néolithique ancien: Sépultures et nécropoles danubiennes (5500–4900 av. J.-C.)*. Paris: Collection des Hesperides, Editions errance.

Knipper, C. (2009). Mobility in a sedentary society: Insights from isotope analysis of LBK human and animal teeth. In P. Bickle & D. Hofman (Eds.), *Creating communities: New advances in Central European Neolithic research* (pp. 142–158). Oxbow.

Knipper, C. (2011). *Die räumliche Organisation der linearbandkeramischen Rinderhaltung Naturwissenschaftliche und archäologische Untersuchungen.* BAR S2305. Archaeopress. https://doi.org/10.30861/9781407308821

Lacroix, P. (1971). The internal remodeling of bones. In G. Bourne (Ed.), *The biochemistry and physiology of bone: Development and growth* (pp. 119–144). Academic Press.

Lillie, M. (2008). Vedrovice: Demography and palaeopathology in an early farming population. *Anthropologie (Brno), 46*(2–3), 135–215.

Macintosh, A., Pinhasi, R., & Stock, J. T. (2014a). Lower limb skeletal biomechanics track long-term decline in mobility across 6150 years of agriculture in Central Europe. *Journal of Archaeological Science, 52*, 376–390. https://doi.org/10.1016/j.jas.2014.09.001

Macintosh, A., Pinhasi, R., & Stock, J. T. (2014b). Femoral and tibial cross-sectional morphology reflects complex changes in sex roles, mobility, and division of labour across ~6200 years of agriculture in Central Europe. *Americal Journal of Physical Anthropology, 153*, 173–173.

Macintosh, A., Pinhasi, R., & Stock, J. T. (2017). Prehistoric women's manual labour exceeded that of athletes through the first 5500 years of farming in central Europe. *Science Advances, 3*, eaao3893. https://doi.org/10.1126/sciadv.aao3893

Masclans, A., Bickle, P., & Hamond, C. (2020). Gendered inequalities in the early Neolithic? Exploring gender relationships at the cemetery of Vedrovice using use-wear analysis, diet and mobility. *Journal of Archaeological Method and Theory, 28*(1), 232–273. https://doi.org/10.1007/s10816-020-09453-y

Masclans, A., Hamon, C., Jeunesse, C., & Bickle, P. (2021a). A sexual division of labour at the start of agriculture? A multi-proxy comparison through grave good stone tool technological and use-wear analysis. *PLoS One, 16*(4), e0249130. https://doi.org/10.1371/journal.pone.0249130

Masclans, A., Tvrdý, Z., Pavúk, J., Cheben, M., & Bickle, P. (2021b). Exploring sexual division of labour at 'Nitra Horné Krškany' cemetery using stone tool use-wear analysis, physical activity markers, diet and mobility as proxies. *Archaeological and Anthropological Sciences, 13*, 109. https://doi.org/10.1007/s12520-021-01318-z

Mateiciucová, I. (2008). The beginnings of the Neolithic in Central Europe in the light of research into the chipped stone industry of early farming (LBK) communities in Moravia and Lower Austria, 5700– 4900 BC. *Dissertationes Archaeologicae Brunenses/Pragensesque*, 4.

Montgomery, J. (2010). Passports from the past: Investigating human dispersals using strontium isotope analysis of tooth enamel. *Annals of Human Biology, 37*(3), 325–346. https://doi.org/10.3109/03014461003649297

Montgomery, J., Evans, J., Schade-Lindig, S., Pichler, S. L., Richards, M. P., & Alt, K. W. (2009). Mobility or migration: A case study from the Neolithic settlement of Nieder-Mörlen (Hessen, Germany). *Journal of Archaeological Science, 36*(8), 1791–1799. https://doi.org/10.1016/j.jas.2009.04.008

Müller-Sohnius, D. (2007). $^{87}Sr/^{86}Sr$ for Isotope standards of Eimer and Amend (E&A), Modern Seawater Strontium (MSS), and the Standard Reference Material (SRM) 987: Development of interlaboratory mean values, procedures of adjusting, and the comparability of results. *Geologica Bavarica, 110*, 1–56.

Oelze, V. M., Siebert, A., Nicklisch, N., Meller, H., Dresely, V., & Alt, K. W. (2011). Early Neolithic diet and animal husbandry: Stable isotope evidence from three Linearbandkeramik (LBK) sites in Central Germany. *Journal of Archaeological Science, 38*(2), 270–279. https://doi.org/10.1016/j.jas.2010.08.027

Ondruš, V. (1972). Dětské pohřby na neolitickém sídlišti ve Vedrovicích. *ČMMB,* LVII, 27–36.

Pederzani, S., & Britton, K. (2019). Oxygen isotopes in bioarchaeology: Principles and applications, challenges and opportunities. *Earth-Science Reviews*, *188*, 77–107.

Podborský, V. (2002). *Dvě pohřebiště Neolitického lidu s Lineární Keramikou ve Vedrovicích na Moravě*. Masarykovy University Philosophy Faculty Department of Archaeology & Museology.

Price, T. D., Burton, J. H., & Bentley, R. A. (2002). The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry, 44*(1), 117–135. https://doi.org/10.1111/1475-4754.00047

Price, T. D., Knipper, C., Grupe, G., & Smrcka, V. (2004). Strontium isotopes and prehistoric human migration: The Bell Beaker period in central Europe. *European Journal of Archaeology, 7*(1), 9–40. https://doi.org/10.1177/1461957104047992

Přichystal, M. (2008). Brno (k. ú. Bohunice, nový a Starý lískovec, okr. Brno-město). *Život a smrt v mladší době kamenné*, 50–59.

R Core Team (2013*). R: A language and environment for statistical computing*. R Foundation for Statistical Computing (Vienna, Austria, 2013). Retrieved June 26, 2026. https://www.R-project.org/

Rasteiro, R., Bouttier, P. A., Sousa, V. C., & Chikhi, L. (2012). Investigating sex-biased migration during the Neolithic transition in Europe, using an explicit spatial simulation framework. *Proceedings of the Royal Society B: Biological Sciences, 279*(1737), 2409–2416. https://doi.org/10.1098/rspb.2011.2323

Rasteiro, R., & Chikhi, L. (2013). Female and male perspectives on the Neolithic transition in Europe: Clues from ancient and modern genetic data. *PLoS One, 8*(4), e60944. https://doi.org/10.1371/journal.pone.0060944

Reimer, P. J., Austin, W. E., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., 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., & Talamo, S. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon, 62*(4), 725–757. https://doi.org/10.1017/RDC.2020.41

Richards, M. P., Montgomery, J., Nehlich, O., & Grimes, V. (2008). Isotopic analysis of humans and animals from Vedrovice. *L'anthropologie, 2*(3), 185–194.

Schaefer, M., Black, S., & Scheuer, L. (2009). *Juvenile osteology: A laboratory and field manual*. Academic Press.

Smrčka, V., Bůzek, F., Erban, V., Berkovec, T., Dočkalová, M., Neumanová, K., & Nývltová Fišáková, M. (2005). Carbon, nitrogen and strontium isotopes in the set of skeletons from the Neolithic settlement at Vedrovice (Czech Republic). *L'anthropologie, 43*(2/3), 315–324.

Snoeck, C., Pouncett, J., Ramsey, G., Meighan, I. G., Mattielli, N., Goderis, S., Lee-Thorp, J. A., & Schulting, R. J. (2016). Mobility during the Neolithic and Bronze Age in Northern Ireland explored using strontium isotope analysis of cremated human bone. *American Journal of Physical Anthropology, 160*(3), 397–413. https://doi.org/10.1002/ajpa.22977

Starkel, L. (1977). The palaeogeography of mid- and east Europe during the last cold stage, with west European comparisons. *Philosophical Transactions of the Royal Society of London. Biological Sciences, 280* (972), 351–372. https://doi.org/10.1098/rstb.1977.0114

White, T., Black, M., & Folkens, P. (2011). *Human osteology*. San Diego Academic press.

Whittle, A., Bentley, A., Bickle, P., Dockalová, M., Fibiger, L., Hamilton, J., Hedges, R., Mateiciucová, I., & Pavúk, J. (2013). Moravia and western Slovakia. In P. Bickle & A. Whittle (Eds.), *The first farmers of central Europe: Diversity in LBK lifeways* (pp. 101–158). Oxbow.

Wickham, H. (2016). *Ggplot2: Elegant graphics for data analysis*. Springer.

Authors and Affiliations

Berta Morell-Rovira[1] · Zdeněk Tvrdý[2] · Marta Díaz-Zorita Bonilla[3] · Penny Bickle[4] · Peter Tóth[5] · Michal Přichystal[6] · Alžběta Bedáňová[7] · Alba Masclans[8]

✉ Berta Morell-Rovira
bertamorell@imf.csic.es

[1] Department of Archaeology and Anthropology, Institució Milà i Fontanals - Consejo Superior de Investigaciones Científicas, Barcelona, Spain

[2] Moravian Museum, Anthropos Institute, Brno, Czech Republic

[3] Institut für Ur- und Frühgeschichte und Archäologie des Mittelalters, University of Tübingen, Tübingen, Germany

[4] Department of Archaeology, University of York, York, UK

[5] Department of Archaeology and Museology, Masaryk University, Brno, Czech Republic

[6] Institute for Archaeological Heritage, Brno, Czech Republic

[7] Moravian Museum, Institute of Archaeology, Brno, Czech Republic

[8] Girona, Spain