Charles University

Faculty of Arts

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Archaeology of Prehistory and Middle Ages

Ph.D. Thesis

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Mobility of individuals and populations in the prehistoric period. Confrontation of archaeological, ethnological and natural scientific methods.

Mobilita osob a populací v předhistorickém období. Konfrontace archeologických, etnologických a přírodovědných metod.

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2020

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In Prague on 21 March 2020

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Abstract

This thesis focuses on the use of natural scientific methods and cross-cultural research to study the mobility of individuals and populations in the prehistoric period and confronts these methods with the results of traditional archaeological approaches. In the first part, the advantages and limits of multiple-tooth strontium isotope analysis are critically assessed. Analysis of published strontium data of more than 1,000 individuals across the world reveals a high degree of variability in childhood mobility patterns between different regions and periods. In the second part, the association between post-marital residence and dwelling size is tested using phylogenetic comparative analysis methods and a global sample of 86 pre-industrial societies. The results confirm that large dwellings are associated with matrilocality (whereas smaller with patrilocality) and suggest that average dwelling size can be used as a material proxy for inferring post-marital residence rules in prehistoric societies. The last part of the thesis combines various types of evidence (archaeological, strontium and ethnographic) to determine post-marital residence patterns in the Early Neolithic of the Central European temperate zone. Two Linear Pottery Culture burial sites in Vedrovice (Czechia) and Nitra (Slovakia) serve as a case study. The thesis warns against one-sided interpretation of strontium isotope results and suggests that in addition to patrilocality, other residential rules were also possible, albeit less likely. A hypothetical model combining different post-marital rules on different social and geographical levels is proposed.

Keywords: Mobility, Strontium isotope, Cross-cultural research, Phylogenetics, Childhood, Linear Pottery Culture, Post-marital residence patterns, Dwellings

Abstrakt

Předkládaná práce se zaměřuje na využití přírodovědných metod a mezikulturního výzkumu pro studium mobility osob a populací v předhistorickém období a konfrontací těchto metod s výsledky tradičních archeologických přístupů. V první části jsou kriticky posouzeny možnosti a limity stronciové analýzy využívající vzorky ze dvou a více zubů stejného jedince. Analýza publikovaných dat více než 1000 jedinců z celého světa odhaluje odlišné vzorce dětské mobility napříč časem a prostorem. V druhé části je pomocí fylogenetické srovnávací analýzy a vzorku 86 předindustriálních společností zkoumána hypotéza o vztahu mezi velikostí domů a post-maritální rezidencí. Výsledky potvrzují, že velké domy jsou spojené s matrilokalitou (zatímco malé s patrilokalitou) a naznačují, že průměrná velikost domů může sloužit jako materiální indikátor post-maritálních pravidel v pravěkých společnostech. Poslední část práce kombinuje různé druhy dokladů (archeologické, stronciové a etnografické) ve snaze určit post-maritální rezidenci ve starším neolitu středoevropského mírného pásma. Jako případová studie slouží dvě pohřebiště kultury s lineární keramikou ve Vedrovicích (Česko) a Nitře (Slovensko). Práce varuje před jednostrannou interpretací stronciových dat a naznačuje, že kromě patrilokality byla možná i další rezidenční pravidla, i když méně pravděpodobná. Představen je hypotetický model, kombinující různá post-maritální pravidla na různých sociálních a geografických úrovních.

Klíčová slova: Mobilita, Stronciová analýza, Mezikulturní výzkum, Fylogenetika, Dětství, Kultura s lineární keramikou, Post-maritální rezidence, Obydlí

Acknowledgment

Special thanks go to my supervisor Petr Květina, who has been supervising me since I started working on my bachelor's thesis. I especially appreciate his support, advice and the fact that he enables me to pursue my own research interests. I am very grateful to Jason E. Laffoon for allowing me to visit him at the Department of Archaeological Science at Leiden University. He taught me a lot about strontium isotope analysis, and I like to remember the time spent in the Netherlands. A big thank you goes to Pavel Duda and Jan Zrzavý for inviting me to their project Ecological and geographical determinants of modern human diversification and for their help with the paper "Identifying post-marital residence patterns in prehistory". Thanks to Gabriel Šaffa for his contribution to the paper. Thanks to Václav Vondrovský for his contribution to the paper "Post-marital residence patterns in LBK". I would like to thank my family and fiancée Eliška for their support.

CONTENT

1. Introduction

1.1. Definitions: Mobility, motility, movement, migration

The term *mobility* has several different meanings. One can talk about spatial mobility, social mobility, virtual mobility, capital mobility, labor mobility and many others. Since mobility is the main topic of this paper, it is first necessary to provide its exact definition.

In general terms, *mobility* can be defined as an ability to move or to be moved or as a capacity to change place. In human geography, *mobility* has two basic meanings: 1) the movement of people, ideas and things across space (physical or horizontal mobility); and 2) a change in social status (social or vertical mobility) (Hanson 2009: 467). The term is used both for the actual movement (relocation from one place to another, social rise or fall) and for the potential and ability of such movement (Scheiner and Kasper 2003: 320). Kaufmann with colleagues (2004) attempted to incorporate all these aspects of mobility into a single term of *motility*, which they defined as “the capacity of entities (e.g. goods, information or persons) to be mobile in social and geographic space, or as the way in which entities access and appropriate the capacity for socio-spatial mobility according to their circumstances” (Kaufmann et al. 2004: 750).

This thesis focuses primarily on physical mobility, i.e. the spatial movement of people. Although social mobility is strongly connected to physical one, it would be difficult to examine both aspects at the same time since each requires a different methodological approach and the scope of this study is limited.

Mobility and *movement* are often used as synonyms, but some authors make differences between them. For example, Lelièvre and Marshall (2015) distinguish movement as an object of observation and mobility as an object of study. According to the authors, movement is “a simultaneous change in space and time that subjects or objects experience actively and/or passively, [while] mobility, as the analytical object of study, can only be approached by bringing into dialogue the practices, perceptions, and imagined conceptions of movement” (Lelièvre and Marshall 2015: 440). In practical terms, however, there is no significant difference between mobility and movement. Therefore, both terms will be used interchangeably throughout this thesis.

Migration is another concept closely linked to mobility and the movement of people. The term can be simply described as long-distance and relatively permanent resettlement of one or more persons (cf. Cabana and Clark 2011: 5; Hiebert 2009: 462; Kok 2010: 216). Since migration is only one of several forms of mobility, it will be described in more detail in Section 1.3., together with the concepts of colonization, diaspora etc.

1.2. Mobility and sedentism

Before discussing different types of mobility, let us briefly mention another closely related term – *sedentism*. Sedentism is not easy to define. Some authors describe sedentary groups as those "in which at least part of the population remains at the same location throughout the entire year" (Eder 1984: 844; Rice 1975: 97). For others, year-round occupation of one place is not a sufficient condition. Instead, the period of one human generation is considered a minimum time to indicate a sedentary community (Dow and Reed 2015: 57). Plog (1990: 180-181) emphasizes year-round "using" of structures and facilities within one village, as opposed to "residing", in his definition. As a result, sedentism is perceived in many ways, and what one author describes as a sedentary way of life is labeled as semi-sedentary or semi-nomadic by another (Kelly 1992: 49).

Many anthropologists and archaeologists think about mobility and sedentism in a typological sense. A classical division of societies is into four basic types: *fully nomadic*, *semi-nomadic*, *semi-sedentary* and *fully sedentary* (Murdock 1967). However, one can find also other categories, such as *free wandering*, *restricted wandering*, *central-based wandering*, *short-term sedentism*, *semi-permanent sedentary*, *deep* or *long-term sedentism*, *shifting sedentism*, *embedded sedentism* etc. (Beardsley et al. 1956; Varien 1999; Whittle 1997). A different approach is to perceive settlement strategies as a continuum ranging from mobile to sedentary (Kelly 1992: 44). However, Eder (1984: 848) pointed out that mobility and sedentariness are not "either-or", they are not two ends of one scale. He argues that sedentariness is primarily related to social groups, whereas mobility is a continuous variable best applicable at the level of individuals. This division is useful because it emphasizes that individuals can be mobile in any society, even in "sedentary" one. Nevertheless, perceiving mobility only from an individual perspective can also be misleading because people often move in groups. One possible solution to the problem is to accept the fact that all human societies are mobile and that this mobility is multidimensional (Varien 1999: 9-10). Similarly, Kelly claims that "No society is sedentary […] – people simply move in different ways" (Kelly 1992: 60).

1.3. Types of mobility

Mobility can be viewed from many different perspectives (Table 1.1.; for a different division cf. Cabana and Clark 2011; Ortman and Cameron 2011). The first one is the scale. Two general approaches can be distinguished: micro-level and macro-level (Cadwallader 1992). The former focuses on individuals or smaller groups and their decision-making processes, the latter on larger groups and the associated long-term manifestations of collective behavior. Both approaches are not mutually exclusive (Laffoon 2012: 23). Sometimes people behave as independent individuals, in other cases they make decisions and behave as a group (Whittle 2003: 13). Four sub-levels are distinguished in the following text: 1) individual, 2) small group, 3) community and 4) supra-community. Although the *community* can be defined in many ways, in this thesis it is defined as a group of people who create an economically self-sufficient and in some way politically independent unit, which at the same time resides in one defined place in geographical space (cf. Beardsley et al. 1956: 133). At its simplest, this is a band; at its most complex, a town, with settlements or villages of different sizes lying in between. The term *small group* refers to a part of a community that includes two or more individuals but not the whole community. A family or household usually belong to this category, but sometimes they may represent analytical units themselves. Supra-communities, such as tribes, nations or even the entire Homo sapiens species, are comprised of several localized communities.

The second perspective is the distance of movement. Mobility includes short movements over several meters (e.g. moving from one dwelling to another) as well as long-distance migrations that could span thousands of kilometers (e.g. migration during the California Gold Rush in the mid-19th century (Unruh 1979) or even longer journeys made possible by modern transportation). Although every division will be subjective and artificial, movements within the scope of a one-day trip (i.e. kilometers and lower tens of kilometers) can be considered as short-distance movements, whereas journeys taking several days (over 50 or 100 kilometers on foot) as long-distance movements.

Another important parameter is the duration of the movement. One extreme may be a few minutes long walk from point A to point B, while long-distance journeys can take months or years (e.g. Cook's exploratory voyages in the 18^{th} century (Beaglehole 1974)). However, mobility can be viewed also from a time perspective longer than a single journey or even a period of one human life. The example of the spread of modern humans across the planet suggests that mobility can be studied from the perspective of tens of thousands of years or even more. In such cases, however, we speak about the duration of the whole migratory process rather than of the individual movements.

In addition to duration, movements can be distinguished according to their frequency and regularity. Again, the range is very broad: one-off transfers, daily resource and food gathering, or long-term cycles of residential change where communities move from one place to another every few years. Repetitive movements can be regular or irregular.

Some researchers divide migrations into internal and external (Duff 1998: 32; Laffoon 2012: 23-24), which can also be applied to mobility in general. Internal mobility refers to movements within boundaries (cultural, social, political, environmental or geographical), while external mobility crosses these boundaries. Internal mobility tends to be more frequent and take place over shorter distances. External movements, on the other hand, are usually less frequent and long-distance. However, this relation is not absolute. In some cases, short-distance movements may be considered external, while long-distance movements may be internal, depending on the exact definition of the boundaries. External mobility is more visible archaeologically because it is more probably associated with major changes in material culture (Duff 1998: 32). Likewise, it is more detectable by isotope analyses because it often crosses different geological regions.

Another parameter is the permanency of residential change. The intention can be either to return to the starting place or to make a permanent or long-lasting change in residence (Zelinsky 1971: 225-226). The former is referred as *circulations* and include, for example, daily routine movements, seasonal movements, social visits, religious pilgrimages or travels for exchange, the latter as *migrations*. The conceptual boundary between the two is unclear, however, because there is no exact definition of permanency or temporality. Every migrant can return home and many frequently do so (Schachner 2012: 205).

Migration scholars further distinguish between *voluntary* and *forced* migrants (Koser 2007: 16-17). Once again, this division can be applied to all movements, not just migration. People who are forced to leave their homes do so because of conflicts, persecution or environmental threats such as drought or hunger. Forced mobility occurs at the level of both individuals and larger groups. Captives and slaves represent a specific type of forced migrants (Cameron 2016).

In the following paragraphs, I will briefly describe a few basic types of mobility divided according to the above-mentioned perspectives (Table 1.2).

Table 1.1. *Perspectives of mobility.*

	Mobility	
Scale	**Individual** < > **Community** < >	**Supra-community***
Distance / Duration	short - long	long
Boundaries	internal - external	external
Frequency (*regularity)*	one-time - repetitive (*regular / irregular*)	long-term process
Permanency	temporary - permanent	migration stream
Intention	voluntary - forced	

*tribes, nations, species.

Table 1.2. *Types of mobility from different perspectives.*

Mobility	**Scale**	**Distance *Duration***	**Boundary**	**Frequency *(regularity)***	**Permanency**	**Intention**
Everyday	I	S	I	R / I	T	V
Residential	I	S / L	I / E	O / I	P / T	V / F
Subsistence	SG / C	S / L	I / E	R / I	T	V
Travelling	I / SG	S / L	I / E	O / R / I	T	V
Raids and captive taking	SG / C	L	E	O / R / I	T (raiders), T / P (captives)	V (raiders), F (captives)
Fission and colonization	SG	L	E	O / I	P	V / F
Whole- community migration	C / SC	L	E	O	P	V / F

Legend: *Scale*: I = Individuals, SG = small groups, C = communities, SC = supra-communities. *Distance*: S = short, L = long; *Boundary*: E = external, I = Internal; *Frequency*: O = one-time; I = irregular repetitive, R = regular repetitive; *Permanency*: T = temporary, P = permanent; *Intention*: V = voluntary, F = forced.

1.3.1. Everyday mobility

The basic type of mobility is the daily movements of individuals. These movements take place over short distances, usually within a community boundary (social and geographical). They are usually repetitive (both regular and irregular), voluntary and always with an aim to return. Examples include trips to fields and gardens, social visits of neighbors, daily hunting and gathering trips and other routine movements within and around the community area.

This type of mobility is very difficult to study archaeologically because it takes a short time and is over a short distance. Therefore, primary sources for human everyday mobility in the past most frequently have the form of ethnographic and historical analogies.

1.3.2. Residential mobility of individuals

Residential mobility usually refers to a change of residence. It can take place over a short or long distance; within a community or between two communities. People can change residence once or several times during their lifetime and these changes are usually irregular and permanent, although temporary residential changes also occur. People change residence voluntarily or can be forced (by parents, spouse, community, etc.).

The typical form of residential mobility is post-marital residence change (Peoples and Bailey 2011: 183-186). Since husband and wife usually come from different households, at least one of them should leave home after marriage. In most societies, couples move to the house or community of the husband's parents (patrilocal residence). In others, they move to the wife's kin (matrilocal) or build a separate dwelling apart from both parents (neolocal). However, the variability of post-marital residence rules is much greater and represents one of the subjects of this thesis (Case Studies 2 and 3). Besides, people change residence also for other reasons, for instance when they are fostered during childhood, due to household/community disputes or after divorce.

Residential mobility in past societies can be relatively well studied archaeologically, for example, by isotope analyses, which can determine whether an individual grew up in a place different from the one he/she was buried (Bentley 2006).

1.3.3. Subsistence (seasonal, annual or supra-annual) mobility

Residential movements of hunter-gatherers, nomadic pastoralists or slash-and-burn cultivators can be classified as another type of mobility. Subsistence mobility differs from residential mobility of individuals in several aspects. First, it refers to a residential move of a group or a whole community. Second, it is primarily associated with food acquisition (e.g. moving to more abundant resources, a new pasture or a new forested area). Third, the movement is cyclical, i.e. regular or semi-regular. The distance can be short or long; for example, the average distance per move among hunter-gatherers range from 2 to 70 kilometers (Kelly 2013: Table 4-1). While subsistence mobility is usually within some boundaries (e.g. cultural, social and political), it can sometimes cross other types of spaces (e.g. geographical or environmental).

Although campsites and short-term settlements of mobile people are detectable archaeologically (e.g. Vencl et al. 2013), more detailed information on past human seasonal mobility (e.g. the length of settlement, the number of residential moves per year or the average distance per move) is difficult to deduce.

1.3.4. Traveling

In general, traveling for exchange, ceremony, social events etc. differs from daily mobility in that it is less frequent and usually over a longer distance. Individuals can travel alone or in groups, but the whole community travels rarely. Traveling is voluntary and individuals always plan to return. The journey can be one-time but also repetitive (regularly or irregularly). It can be within cultural and geographic boundaries, or external.

Like everyday mobility, traveling is very difficult to study archaeologically. Only when individuals cross cultural boundaries and leave the remains of "imported" artifacts behind can archaeologists get some clues of past trips and journeys.

1.3.5. Raids and captive taking

Warfare, raids, captive taking and kidnapping were common in prehistoric societies (Cameron 2011, 2016). Women, children and men could be captured and taken from their homes. The coercive nature of this movement is what distinguishes it from traveling. Furthermore, captivity can be permanent, and the captors and the captives came from different communities. Although captive taking usually took place among neighbors, long-distance raids were also common in many regions.

The captured individuals were often fully incorporated into the captor society, leaving little trace of their origin, which makes captivity difficult to discover archaeologically. In contrast to warfare, material evidence for captives is less obvious in the archaeological record. However, there are some lines of evidence suggesting the presence of captives. Those include isotopic and genetic analyses that detect nonlocal individuals, human remains with trauma, different burial practices or the lack of formal burial for certain members of society, artwork depicting war captives, evidence on depopulation or skewed sex-ratios in burial populations (Cameron 2016). Similar methods are used to identify slaves (Hrnčíř and Květina 2016).

1.3.6. Community fission and colonization

Residential mobility can take place either on the level of individuals (see section 1.3.2) or on the level of groups or whole communities. *Fission* refers to the situation when a part of a community splits and moves away (Cameron 2013: 222-223). The reasons for such decision include war, famine, depleted resources, disputes and competition among social factions or witchcraft accusation. Community fission is often a sudden event, although the tension may increase gradually. The migrating group can move to a close neighborhood or to a completely different cultural and geographical region, depending on the nature of the dispute. The migrants can join other settlements or establish a new one.

Colonization in the sense of "the departure of individuals from one community to establish a new community that replicates the home community" (Manning 2012: 5) is similar to community fission in many aspects. The main difference is that colonization process is perceived more positively, usually as territorial expansion. Colonists come from communities that are thriving and frequently maintain positive relationships with their homeland.

1.3.7. Whole-(supra-)community migration

One of the minimal definitions of *migration* is a "one-way residential relocation to a different 'environment' by at least one individual" (Cabana and Clark 2011: 5). Such a broad term includes several types of mobility presented above, such as residential change by individuals, subsistence mobility, fission and colonization. The last basic category of mobility is migration of a whole community or entire social group (e.g. tribe, nation) across a geographic, political or social boundary. My definition of *whole-community migration* is different from that provided by Manning (2012: 5) in that it includes only movements which are relatively permanent (i.e. one-way) and not cyclical. The reasons for whole-community migration can be negative (e.g. warfare, famine, environmental catastrophe) or positive (e.g. abundance of resources), sometimes referred to as the *push-pull model* (Anthony 1990). When negative factors prevail, the migrants are usually called *refugees*. *Diaspora* means migration to multiple destinations, while *return migration* refers to the movement back to the place of origin.

As both community fission (or colonization) and whole-community migration are frequently over a long distance and involve a significant segment of a population, they are relatively easily visible in the archaeological record. The material visibility of migrants in the new destination, nevertheless, depends on several factors: 1) how much the migrants' culture is distinct from the host culture; 2) how well the migrants integrate into the host population; 3) the availability of raw materials in the destination compared to the homeland; and 4) how much the migrants continue their homeland practices (Ortman and Cameron 2011: 243-244).

Next, I will briefly describe different approaches that archaeologists apply when studying mobility.

1.4. Archaeological methods for studying human mobility

Traditionally, archaeologists have studied prehistoric mobility through the spatial distribution of material culture. Such approach is problematic, however, because it is based on indirect evidence of movement. The mapping of certain cultural traits (e.g. house type, burial rite, ceramic style) provides no explanation in itself for the processes underlying the distribution (Burmeister 2016: 44). It does not evidence whether cultural traits spread via actual relocation of people, trade and exchange (short-term travels), the movement of ideas (diffusion), the imitation of behavior or were invented independently (Laffoon 2012: 3).

Closely associated with the examination of migrations is the problem of ethnicity (Burmeister 2000, 2016). On the one hand, it is uncertain whether specific cultural traits (e.g. costume elements) are tied to a specific ethnic (or social) group. On the other, immigrant groups do not always maintain their original identities, and their material culture changes because they assimilate or accommodate. Both aspects make the identification of migrations using material culture difficult, except for the cases of initial colonization and ultimate abandonment.

One of the approaches attempting to overcome the limitations is, for instance, the reconstruction of demographic trajectories (Duff 1998). Based on the settlement histories, researchers estimate changes in relative population density of neighboring regions (i.e., a population drop in one area coincident with a population rise in another). Patterns of migrations, aggregation and communal moves can be subsequently inferred from those long-term demographic trends.

A specific method using material remains as a proxy for individual movements in prehistory is stone artifact refitting (Close 2000). The approach uses the reassembling of stone debitage and cores to trace the distances and directions in which the artifacts were moved. From this, distances and directions traveled by the people carrying the artifacts are inferred. Nevertheless, the reconstructed movements are usually short-distance, reaching hundreds of meters at the most. Refits from a larger distance as well as analyses of lithic sourcing more likely reflect series of movement or mobility patterns rather than a single episode of movement by one person.

A different approach is to focus on the prehistoric people themselves, specifically on their skeletal remains. Before the development of DNA and isotope studies, bioarchaeologists used the method of biological distance analysis to study morphological variation in skeletal and dental traits (Stojanowski and Schillaci 2006). Besides inferring relationships between the analyzed individuals, the results of this method can contribute to the reconstruction of residential mobility or long-distance migrations. For example, analysis of sex-specific phenotypic variation allows to estimate which sex was more mobile (the one with the greater diversity) and thus indicate post-marital residence practices.

With more recent advances in scientific methods, the focus has moved to the study of the genetic structure of present-day and prehistoric populations, referred to as archaeogenetics (Černý et al. 2017; Reich 2018). Unlike cultural proxies, which allow for a wide range of causal explanations, genetic diversity and transformation is always the result of the geographic or chronological movement of human beings. Analyses of modern and ancient DNA are therefore able to identify past migratory movements, colonization, demographic growth or fission and fusion of originally isolated human populations. Genetic studies focus primarily on mobility at the macro-level, i.e. large-scale, long-distance movements of supra-communities, such as Near East farmers during the Neolithic (Lipson et al. 2017) or the Yamnaya steppe herders during the Early Bronze Age (Haak et al. 2015). However, sex-specific genetic variation has also been used to infer residential mobility. The assumptions are similar to morphometric data: the sex with the greater diversity should be the migrant sex (Oota et al. 2001). Nevertheless, even genetic studies are not free of problems. Modern DNA results are particularly problematic in determining the exact date and nature of past demographic processes. Contrarily, the main limitation of ancient DNA studies lies in the relatively small samples. In both cases, the correct interpretation within the context of cultural studies is necessary (Burmeister 2016).

Biogeochemical analyses based on the study of the isotope compositions of biological tissues represent another developing natural scientific method of investigating past human mobility (Brown and Brown 2011; Kristiansen 2014). Compared to DNA studies, isotope analyses of strontium, oxygen or lead focus rather on the mobility of specific individuals, i.e. the micro-level. The method can determine whether an individual moved from one place to another during his/her life and whether he/she moved more than once (Bentley 2006; Frei et al. 2017; Montgomery 2010; Slovak and Paytan 2011). There have also been attempts to use this method to identify the geographic origin of individuals (e.g. Laffoon et al. 2017), but this is a difficult goal to achieve (Pollard 2011). The use of the strontium isotope method to study mobility is one of the main subjects of this thesis (Case Studies 1 and 3).

As a complementary approach or if it is impossible to study the remains of human beings directly, genetic and isotope analyses of ancient domesticated animals have been used to indicate past human mobility. For example, genetic discontinuity in different turkey populations in 13th century US southwest has been used as evidence for large-scale migration of humans accompanied by their domestic animals (Kemp et al. 2017). The use of cattle or canine isotope data as proxies for inferring past human behaviors has also been discussed (Evans et al. 2019; Laffoon et al. 2019).

The above methodological overview is not exhaustive; many other approaches exist, especially concerning subsistence mobility (e.g. Eerkens 2003; Lepofsky and Lyons 2003; Ruff 2018), but they are beyond the scope of this thesis.

1.5. Aims and scope of the thesis

The mobility of individuals and populations in the prehistoric period can be studied from many different perspectives and using different methods, as has been indicated above. The present thesis is not, and cannot be, a comprehensive review of past human mobility. It is just an attempt to address selected problems.

In Case Study 1, we focused on multiple tooth strontium isotope analysis and its potential and limits in inferring past human mobility. In contrast to the analysis of a single tooth sample per individual, analyzing multiple teeth permits the detection of migrations occurring during childhood, more fine-grained temporal resolution of the age at which migration(s) occurred and even the identification of multiple migration episodes. Our study reviews the application of such approaches to a wide range of archaeological contexts worldwide. Specifically, we compiled and analyzed published strontium data for 1043 individuals from 122 sites across the world to explore the potential variability of childhood mobility patterns cross-culturally. The results demonstrate a high degree of variability in childhood mobility that differs significantly between different regions and periods. Potential interpretations of these variations include heterogeneity in the variance of regional strontium signal as well as variability in human mobility patterns such as residential change of the whole family, fosterage, herding activities, post-marital residence rules or forced migrations.

In Case Study 2, we attempted to verify the hypothesis that the average house floor area can be used as a material proxy for inferring post-marital residence patterns in prehistoric societies. Several cross-cultural studies have demonstrated that in agricultural societies, large dwellings are associated with matrilocality, whereas smaller dwellings with patrilocality. We tested this association using phylogenetic comparative analyses and a global sample of 86 pre-industrial societies, 22 of which were matrilocal. Our analysis confirmed that the association is valid. It applies to a broad range of post-marital residence patterns (not only to strictly matrilocal or patrilocal residence) and remains significant after controlling for other explanatory variables (agriculture, fixity of settlement and construction material) and phylogeny. The effect of agriculture on dwelling size seems to be a by-product of the effect of the fixity of settlement. The association between house size and post-marital residence is not absolute, however; specifically, societies with very large houses (over ca. 200 m^2) are not associated with any particular type of residence.

Case Study 3 discusses post-marital residence mobility in the society of the first farmers in the European temperate zone (Linear Pottery Culture, ca. 5500–4900 cal BC). We present several anthropological models, based on a review of ethnographic literature, and compare them with published strontium isotope results from two LBK cemeteries – Vedrovice (Czechia) and Nitra (Slovakia). Although strontium data appear to clearly indicate patrilocality and community exogamy, we argue that other post-marital residence rules such as ambilocality, avunculocality, shifting residence or predominant matrilocality were also possible for both sites. Arguments set in contradiction to a one-sided interpretation of strontium data include a possible practice of polygyny, abduction of young women and non-inhumation burials. We also draw attention to the facts that post-marital residence patterns are often complex, geographical and social space not necessarily overlapping and exogamous rules difficult to detect with strontium data.

2. CASE STUDY 1. Childhood mobility revealed by strontium isotope analysis: a review of the multiple tooth sampling approach[1]

2.1. Introduction

The topic of human mobility is not only popular in discussions of contemporary societies but owing to the rapid development of various scientific approaches, such as genetics and biogeochemical analyses, also in archaeological research. Traditional archaeological methods to explore past human mobility often relied upon indirect evidence such as the changing distributions of material culture in time and space. However, it has long been recognized that it is extremely difficult to distinguish between the actual movement of people and other processes such as diffusion (the movement of ideas), exchange and trade (the movement of objects and materials), independent innovation and evolution (the autochthonous development of similar ideas and cultural "traits"), or emulation (the copying of behaviors; Anthony 1990; Burmeister 2000, 2016; Hakenbeck 2008; Laffoon 2012).

In the last decades, there has been an exponential increase in archaeological research utilizing recent advances in scientific methods and techniques. The trend, sometimes called *The Third Science Revolution in Archaeology* (Kristiansen 2014) began with the study of genetic and phenotypic data (e.g., Ammerman and Cavalli-Sforza 1984) and increasingly the use of biogeochemical analyses based on the study of the isotope compositions (e.g. strontium, oxygen and lead) of biological tissues (Brown and Brown 2011; Laffoon et al. 2017; Slovak and Paytan 2011). These methods, unlike traditional archeological approaches, can provide direct evidence about the movement of populations and individuals from the analyses of their skeletal and non-skeletal remains.

To date, most such studies have focused on the analysis of a single tooth sample per individual to identify migration. The single tooth sampling approach is, however, limited to the identification of a single migration event occurring sometime after the formation of the sampled tooth (varying from roughly birth to mid-teens for permanent teeth, depending on the dental element). Increasingly, however, studies have analyzed multiple teeth from the same individual permitting the detection of migrations during childhood, more fine-grained temporal resolution

[1] This case study was published as **Hrnčíř V.**, Laffoon J.E. (2019). Childhood mobility revealed by strontium isotope analysis: a review of the multiple tooth sampling approach. Archaeological and Anthropological Sciences 11: 5301–5316. https://doi.org/10.1007/s12520-019-00868-7. Jason E. Laffoon has agreed to use the article as part of this Ph.D. thesis.

assessments of the age at which migration(s) occurred, and even multiple migration episodes (e.g., Buikstra et al. 2004; Eriksson et al. 2018; Evans et al. 2006; Fraser et al. 2018; Hadley and Hemer 2011; Hedman et al. 2018; Knipper 2009; Knipper et al. 2018; Schweissing and Grupe 2003; Weber and Goriunova 2013). This follows the current trend of increased interest in the topic of childhood in the past, which had been previously neglected (e.g., Crawford et al. 2018; Hadley and Hemer 2014; Murphy 2017).

The objective of the current study is to compile and analyze published $^{87}Sr/^{86}Sr$ data from sites across the world to explore the variability in childhood mobility cross-culturally. We also discuss potential outcomes and interpretations involved in multiple tooth $^{87}Sr/^{86}Sr$ analysis and highlight various issues concerning this approach and their implications for future research.

2.2. Background

2.2.1. Strontium isotopes from the ground to the human body

The principles, methods and applications of strontium isotope analysis in archaeological research have been described in detail elsewhere (e.g., Bentley 2006; Slovak and Paytan 2011). Here, we provide only a brief summary.

Strontium (Sr) is a chemical element that occurs in rocks, as well as in seawater, fresh water, soil, plants and animals, including humans. There are four naturally occurring isotopes (atoms that have the same number of protons, but different numbers of neutrons) of strontium – ^{84}Sr, ^{86}Sr, ^{87}Sr, and ^{88}Sr. Three of these are stable and non-radiogenic, while ^{87}Sr is radiogenic, being produced by the radioactive decay of ^{87}Rb, with a half-life of approximately 4.88×10^{10} years (Faure and Mensing 2005: 3).

From an archaeological point of view, the most important ratio is that of $^{87}Sr/^{86}Sr$ because it varies substantially in regions with different bedrock geology and thus serves as a "geochemical signature". In simple terms, very old rocks have higher $^{87}Sr/^{86}Sr$ ratios, while younger rocks have lower $^{87}Sr/^{86}Sr$ ratios (Bentley 2006: 139). Besides, there are additional, non-geological sources of strontium in the biosphere, such as seawater, groundwater, rivers or atmospheric aerosols that also influence the resulting $^{87}Sr/^{86}Sr$ signatures in biological tissues, although usually to a lesser extent (Bentley 2006).

Strontium passes from weathered bedrock through soil into the plants and then moves through the food chain into the human body, where it substitutes for calcium in the mineral portions of skeletal tissues. Because of strontium's relatively large atomic mass, $^{87}Sr/^{86}Sr$ ratios change very little as it moves through trophic levels. This means that the strontium ratio measured in human tissues reflects the composition of water, plants, and animals consumed, which in turn reflect the $^{87}Sr/^{86}Sr$ geochemical signatures in a given territory from which consumed food and water originates.

On this basis, it is possible to distinguish individuals who are local (i.e., have $^{87}Sr/^{86}Sr$ ratios in accordance with a local range) and those who are not. Therefore, characterizing the local range of $^{87}Sr/^{86}Sr$ variation is an essential component of such research (Price et al. 2002). Researchers have come up with several approaches to this problem, including using the average Sr ratio of human bones (Grupe et al. 1997; Price et al. 2001); a "normalized" sample of human tooth enamel ratios (Wright 2005); modern environmental samples (rocks, soil, water and plants) which were collected around a site (Evans et al. 2010; Hodell et al. 2004); or archaeological faunal samples such as rodents, land snails, and other small animals that presumably lived locally (Bentley 2006; Hedman et al. 2009; Price et al. 2002). The use of archaeological fauna to determine strontium isotope baselines is not possible for all regions due to the unavailability of appropriate samples, large investments in time and resources, or in cases of high proportions of marine foods in paleodiet (Slovak and Paytan 2011: 745-746), and the appropriatness of an exclusive focus on faunal isotopic data has been questioned (Grimstead et al. 2017).

Different tissues form at different time periods and remodel at varying rates (Eriksson 2013: 134-135). Tooth enamel and (primary) dentine form primarily during infancy and childhood, after which their chemical composition does not generally change, while bones remodel continuously. Hair and nails are metabolically inert once formed but grow progressively during the whole lifespan. Theoretically, analysis of different types of tissues from the same individual may indicate dietary changes over time, which in turn, may indicate residential change. Practically, however, most researchers focus exclusively on tooth enamel because archaeological bones are susceptible to diagenetic contamination (Bentley 2006: 163-169; Hoppe et al. 2003) and non-skeletal tissues are usually not preserved. Nevertheless, by analyzing two or more teeth per individual (e.g., first molars versus third molars) it is possible to demonstrate mobility during childhood and/or adolescence.

Nevertheless, it is worth stressing that the strontium isotope approach has multiple limitations, one of the most important of which is equifinality (Price et al. 2007). This means that it is not possible, at least with a single isotope proxy and in the absence of other evidence, to identify migrations that have occurred within an isotopically homogenous area nor those that occurred between two geographically distinct but isotopically similar locations. Consequently, the non-locals, identified by the strontium isotope method should be considered a minimal estimate of the actual number of non-locals within any given analyzed sample population. This limitation is not, however, specific to the multiple tooth sampling approach to strontium isotope analysis, as it is equally true of all single isotope proxy approaches.

2.2.2. Strontium isotopes as evidence for mobility during childhood

While strontium ratios in teeth reflect the places of residence during different childhood ages, the ratios in the bones, on the contrary, correspond to the last years, and in the case of nails and hair even the last months of life. For instance, comparison of the strontium ratios in different bones and teeth confirmed the high mobility of the famous Alpine Iceman "Ötzi" (Hoogewerff et al. 2001; Müller et al. 2003). Similarly, high temporal resolution reconstructions of mobility of extremely well-preserved individuals from Denmark were revealed through the combined analysis of their teeth, nails and hair (Frei et al. 2015a; Frei et al. 2015b; Frei et al. 2017).

Due to the low resistance to contamination in the case of bones, and the very rare preservation in the case of hair and nails, however, the most common analyzed material is dental enamel. One of these approaches is micro-sampling of a single tooth (or intra-tooth sequential sampling) at the resolution of its enamel growth layers by laser ablation or micro-drilling (Copeland et al. 2008; Lewis et al. 2014; Richards et al. 2008a). The advantages of this sampling method are the possibility to explore individual mobility at smaller temporal scales and the minimal destruction of precious archaeological materials. Unfortunately, it is still not clear whether this method is sufficiently reliable, and whether the mineralization of these layers occurs in a well-ordered linear sequential fashion in humans or rather in a non-linear multidirectional pattern (Montgomery and Evans 2006; Montgomery et al. 2010; Nowell and Horstwood 2009). For this reason, the most common method to explore human childhood mobility is currently through the isotopic analysis of different teeth from the same individual.

Tooth enamel forms in the early years of human life and is not remodeled afterwards (Hillson 1996). Moreover, the age of formation of different teeth is variable per tooth type (element) and is relatively consistent within and between populations. For example, deciduous teeth mineralize approximately between the prenatal period and 1st year after birth, first molars from ca. birth to 3rd year, second molars and premolars between roughly the 3rd and 8th years, and third molars between approximately the 8th and 14th years of age (AlQahtani et al. 2010). Differences in strontium isotope ratios between teeth formed at different ages can therefore be an indication for residential change during childhood or adolescence.

A major unresolved question with such approaches is what difference in $^{87}Sr/^{86}Sr$ ratios between teeth of a given individual is large enough to be clearly identified as resulting from mobility? Since strontium primarily enters the body through dietary sources, and because diets usually vary at different stages of life, whether due to seasonal changes in resource availability or due to changes in eating habits over time, it is likely that the strontium ratios will be slightly different even within the teeth of a person who spent his/her entire life in a single location. Moreover, in isotopically varied landscapes, strontium concentrations may differ widely, not only between different food types but also between similar food types with distinct, although nearby, biogeochemical origins (Laffoon 2012: 54). Researchers often mention 0.001 as a minimal offset between the $^{87}Sr/^{86}Sr$ ratios of two different teeth that is significant enough to demonstrate an individual's movement or migration (Knipper et al. 2014: 826; Kootker et al. 2016: 14; Scheeres et al. 2014: 504; Scheeres et al. 2013: 3620; Slater et al. 2014: 124). Unfortunately, a proper justification for this specific cut-off is not usually provided.

The most promising approach to inter-tooth offset determination and its justification was recently proposed by Knipper and colleagues (Knipper et al. 2018). Through analysis of differences in strontium isotope ratios in pairs of deciduous teeth and between a deciduous tooth and a permanent first molar from the same individuals, they concluded that for detection of residential changes at the site of Basel-Gasfabrik in Switzerland, the cut-off value is around 0.00064 or 0.00073. By consequence, offsets lower than this cut-off (among teeth from the same individual) may indicate permanent residence, while larger offsets suggest possible residential change (Knipper et al. 2018: 745).

We attempted to repeat a similar procedure on a larger sample from multiple locations, by comparing intra-individual offsets in $^{87}Sr/^{86}Sr$ ratios among three different types of tooth pairs (from the same individuals): 1) deciduous vs. deciduous, 2) deciduous vs. permanent first molar, and 3) first molar vs. another first molar (Table 1 in Online Resource 1[2]). This sample set contains 49 individuals from 17 sites, including 11 children previously analyzed by Knipper et al. (2018). Our results are in general accordance with theirs. The maximum absolute offset is 0.00077 with an average of 0.00020 ± 0.00022 ($\Delta^{87}Sr/^{86}Sr$ tooth 1 - tooth 2; n = 49 pairs, 1 SD). Two standard deviations from the mean of absolute differences are therefore 0.00063. It should be emphasized that the observed differences come from the teeth of individuals reflecting up to ca. 3 years of age. It can be argued that older children may have experienced even more significant changes in their diet and thus even greater differences in their $\Delta^{87}Sr/^{86}Sr$ values even for local or non-mobile individuals and populations. However, this data set is still very small and regionally biased (majority of sites come from Europe), so it would be risky trying to

[2] Supplementary material (Online Resource 1) for this Case Study can be found online at https://doi.org/10.1007/s12520-019-00868-7.

generalize this result for all other sites. As Figure S2.1 indicates, the cut-off value could vary considerably from site to site.

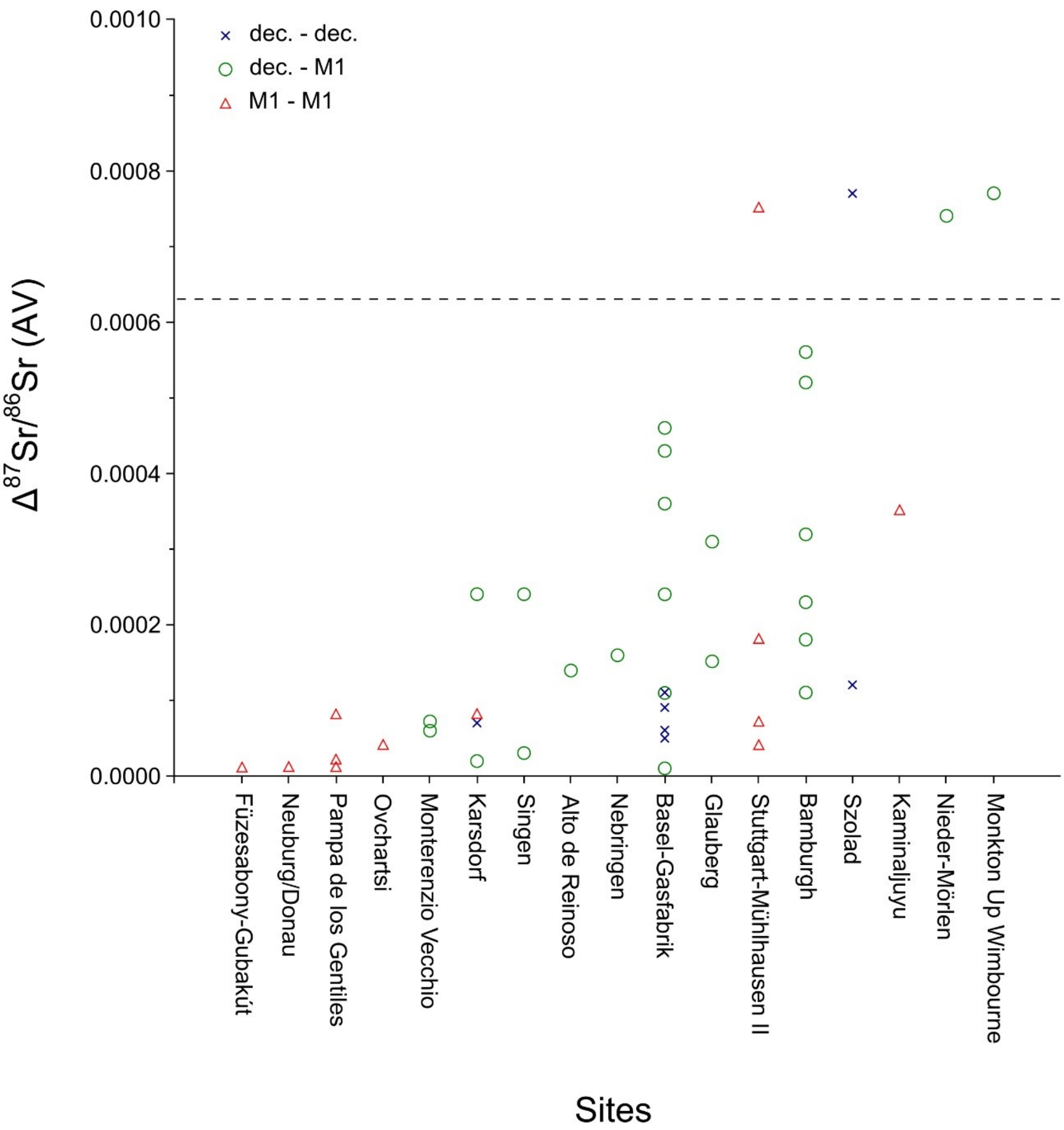

Fig. S2.1. *$\Delta^{87}Sr/^{86}Sr$ between teeth forming in early childhood (n = 49). Legend: dec. = deciduous; M1 = permanent first molar; AV = absolute value. Dashed line is at 0.00063 (= two standard deviations from the mean of absolute $\Delta^{87}Sr/^{86}Sr$).*

In this study we do not apply a specific cut-off value. Although the proposed value of 0.001 might be conservative enough for use with inter-site comparisons, the current lack of data on intra-individual variation in strontium isotope values does not permit an assessment of its broader validity at this time. On the contrary, we can expect large regional differences due to numerous confounding variables such as differential ranges of local variation, the spatial extent of isotopic homogeneity, variable catchment areas, long-distance food transport, and culturally mediated differences in the sourcing of food resources, just to name a few. More research at multiple scales needs to be done on this topic in future.

2.3. Methods

We compiled human strontium isotope data from studies that were published before April 2018. We focused only on data for tooth enamel and we included only individuals with two or more dental elements which form at different ages. The databases used to find the information for this study was primarily Web of Science, combined with more limited searches on GoogleScholar and ResearchGate. Various combinations of the following search terms were used: strontium, Sr, enamel, isotope. On Web of Science we limited the Research Areas to Anthropology and Archaeology. It should be noted that the database created is not exhaustive, but rather is biased towards data published in English and searchable through the mentioned web search tools.

The strontium isotope values were compiled along with ancillary information about the skeletons and sites (Table 2 in Online Resource 1). We created a unique ID for each individual and Site Code for each site purely for analytical purposes. The identification of each individual is possible through the column Burial that we have taken from the original literature. Sex and Age variables were also extracted from the published datasets. Next, we created three tooth categories: 1) Early (including deciduous teeth, incisors, canines and permanent first molars); 2) Middle (including premolars and permanent second molars); and 3) Late (third molars). The Early category corresponds approximately with the ages of 0-3 years, the Middle category with 3-8 years, and the Late category with 8-14 years of age. In case there were more teeth from the same category we preferred molars, because these were more commonly analyzed. In case there were two or more of the same teeth analyzed (e.g. two second molars) we averaged their values (in database labeled with *). Since not all authors use FDI World Dental Federation notation, we labeled teeth in a simplified but consistent manner: I1 = central incisor, I2 = lateral incisor, C = canine; P1 = first premolar; P2 = second premolar; M1 = permanent first molar; M2 = permanent second molar; M3 = third molar; dec. = deciduous tooth. Resulting analyses should not be affected by this simplification, since the same teeth types have very similar ages of formation which overlap considerably between different locations in the dental arcade (left/right, mandible/maxilla; AlQahtani et al. 2010). The $^{87}Sr/^{86}Sr$ ratios are reported to five decimal places. Offsets between two teeth are presented as follows: ΔL-E = Late tooth – Early tooth; ΔM-E = Middle tooth – Early tooth; ΔL-M = Late tooth – Middle tooth.

Table 3 in Online Resource 1 contains ancillary data for all sites, including summarizing numbers of individuals in the database, references and assignments to modern countries. In case of six regional case studies (see below) the sites also contain the column Period. This category refers to the dating of the skeletal assemblages and is both relative and approximate due to a lack of absolute data on the one hand and in order to increase the sample size per period on the other. Therefore, the aim of the subsequent analyses is not to identify the exact differences between the periods but rather to indicate the main trends.

Statistical comparisons were performed using IBM SPSS Statistics version 23 for Windows.

2.4. Dataset

We collected data for 1043 individuals from 122 sites (Tables 2 and 3 in Online Resource 1). The most common tooth pairs were Early-Late (n = 700), followed by Early-Middle (340) and Middle-Late (285), with some individuals represented by multiple pairs. As shown in Figure 2.1 the most sites and individuals come from Europe (71 sites and 477 individuals), while other continents are represented less. Twenty-six sites (371 individuals) come from Americas, 22 sites (133 individuals) from Asia and 3 sites (62 individuals) from Africa. The majority of sites contain 10 or fewer individuals, while the largest sample (n = 119) comes from Cahokia, IL, USA. From a chronological perspective, the earliest data come from African site of Gobero (9500 to 8200 cal BP) and Near-East site of Basta (7500–7000 cal BC), while the latest come from colonial era (post-medieval) cemeteries in Cape Town, South Africa and Barbados, West Indies (both 17th-19th centuries AD).

It would be impractical to report and discuss the results for each site. For that reason, we decided to select six regions as archaeological case studies based on the size of the associated regional multi-tooth $^{87}Sr/^{86}Sr$ datasets: 1) Cis-Baikal in Siberia, 2) Southeastern Arabia; 3) Peru; 4) American Midwest; 5) Cape Town in South Africa; and 6) Central Europe (Fig. 2.1). The Central Europe case study contains data for a long temporal span (from 6th millennium BC till 1st millennium AD) and is additionally divided into different time periods (Fig. 2.2).

Before presenting the results, we first describe all regions briefly. The first regional case study is Cis-Baikal, Siberia. Multiple strontium isotope signatures were obtained from 54 individuals at three hunter-gatherer cemeteries dating from 8000 to 4000 BP BP (Haverkort et al. 2010; Haverkort et al. 2008; Weber and Goriunova 2013). Apart from the fact that these are the only forager populations in the database, this sample is remarkable because strontium ratios for all three molars (M1, M2 and M3) are available for most individuals. This allows tracking of differences across three distinct age categories.

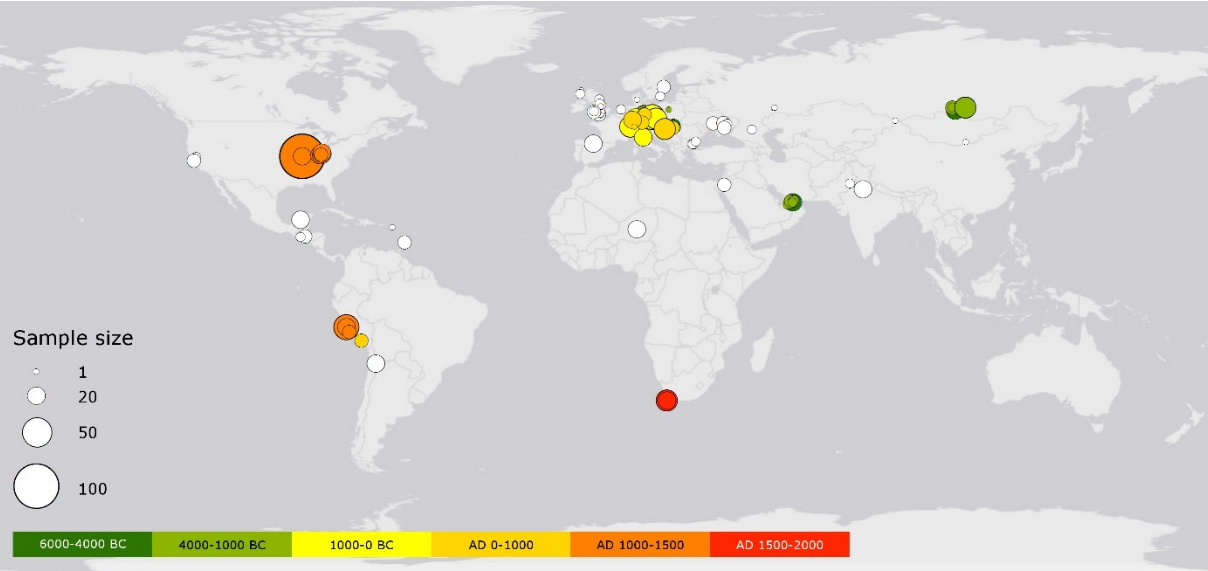

Fig. 2.1. *Map of all sites represented in the dataset. Sites from six regional cases studies are highlighted and categorized by periods.*

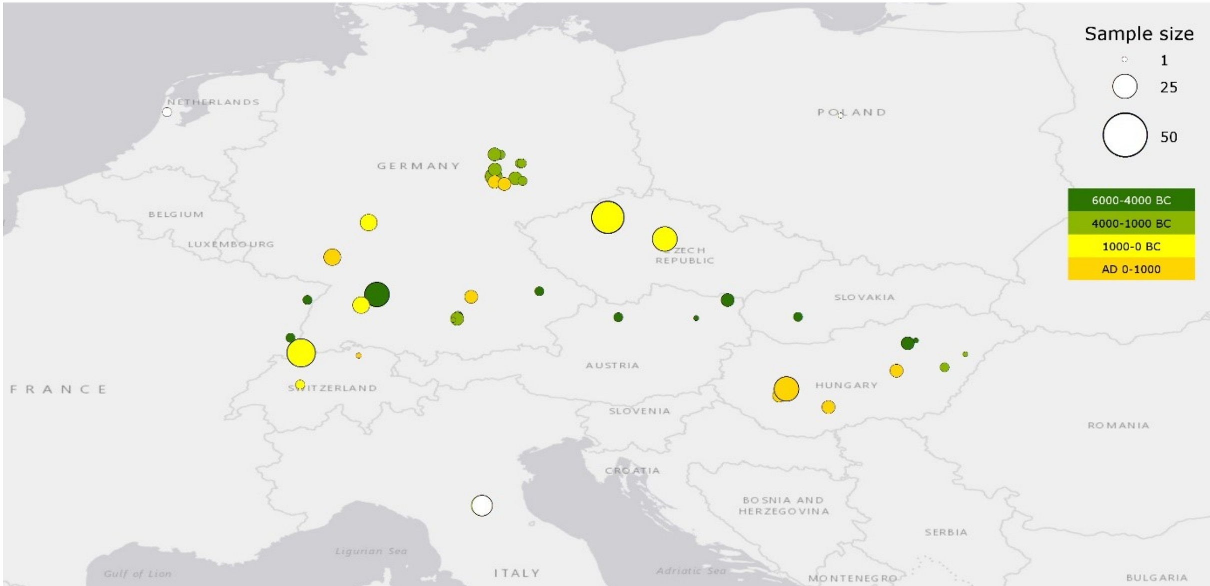

Fig. 2.2. *Detailed map of all sites from Central Europe. Sites are categorized by periods.*

The second regional sample consists of 45 individuals from 10 southeastern Arabian sites, in modern-day United Arab Emirates (UAE). Of these, 24 individuals come from the Neolithic graveyard of al-Buhais 18 and shell midden Umm al-Quwain (Kutterer and Uerpmann 2017), 19 individuals come from seven Bronze Age tombs (Gregoricka 2014), and two skeletons were recovered at Jebel al-Emeilah, dating to Middle Sasanian period (Kutterer et al. 2015). Some sites are located on or near the coasts of the Persian and Oman Gulfs such as Umm al-Quwain, Umm an-Nar Island, Tell Abraq, Mowaihat or Unar 1, while al-Buhais 18 and Jebel al-Emeilah are situated in the inland desert basin.

Seventy individuals from five sites represent the Peruvian region. Nine individuals derive from two Wari sites (AD 600-1000) – peripheral village Beringa in the Majes Valley of southern Peru (Knudson and Tung 2011) and secondary center Conchopata in the central Peruvian Andes (Tung and Knudson 2011). Fifty-four individuals belong to two sites in the Rimac Valley inhabited by Ychsma people – Armatambo and Rinconada Alta (Marsteller et al. 2017), while seven Chincha people are from site of Pampa de los Gentiles (Knudson et al. 2016). Three latter sites are dated to the Late Intermediate Period (AD 900-1470).

The American Midwest studies represent a combination of two close regions – the Mississippi River floodplain of the American Bottom, and the Fort Ancient region around the mouths of the Great and Little Miami Rivers in Ohio. Researchers working in both regions have produced data from 201 individuals in total. More than half comes from the Cahokia site, located near the modern-day city of St. Louis, Missouri (Slater et al. 2014; Thompson et al. 2015), and the rest are from seven Fort Ancient sites (Cook and Price 2015). The majority of tooth pairs are Early-Late (n = 183). Only four individuals have data for teeth from all three childhood categories. The most individuals are dated from the 11^{th} to 15^{th} centuries AD.

Cobern Street (Kootker et al. 2016), and Victoria & Albert Marina Residence (Mbeki et al. 2017) are two 18^{th}-19^{th} century burial grounds in Cape Town, South Africa. Since both are "informal" or paupers cemeteries, people buried there include slaves, sailors, soldiers, convicts, and exiles. Similar to the Cis-Baikal studies, first, second and third molars of many individuals were analyzed enabling the study of multiple migrations during childhood.

The Central Europe category is here broadly defined, ranging from Alsace in the west to Hungary in the east, and from central Germany in the north to the Alps and Pannonian Plain in the south (Fig. 2.2). Forty-two sites can be divided into four main periods: Neolithic (6^{th}-5^{th} millennium BC); Eneolithic/Chalcolithic/Bronze Age (4^{th}-2^{nd} millennium BC); Iron Age (1^{st} millennium BC); and Roman/Migration/Early Medieval (1^{st} millennium AD). Although we are aware that such categorization is far from perfect, for example, lengths of periods are different and sites from different periods do not exactly overlap each other geographically, we argue that it can at least illustrate some interesting similarities or differences.

2.5. Results and Discussion

In the overall dataset, a majority of individuals (around 66% or 77% depending on the tooth pair) possess an offset between two paired teeth smaller than 0.0005 (Fig. S2.2). The number of individuals for whom the offset is lower than 0.001 varies from 77.5% (ΔL-M) to 87.0% (ΔL-E). The percentage for ΔM-E is 82.2% (Tables 2.1 and 2.2). The number of individuals with an offset between 0.001 and 0.002 varies from 7.1% to 13.7%, while individuals with $\Delta^{87}Sr/^{86}Sr$ between two teeth greater than 0.002 represent 5.9 – 8.8% of the sample.

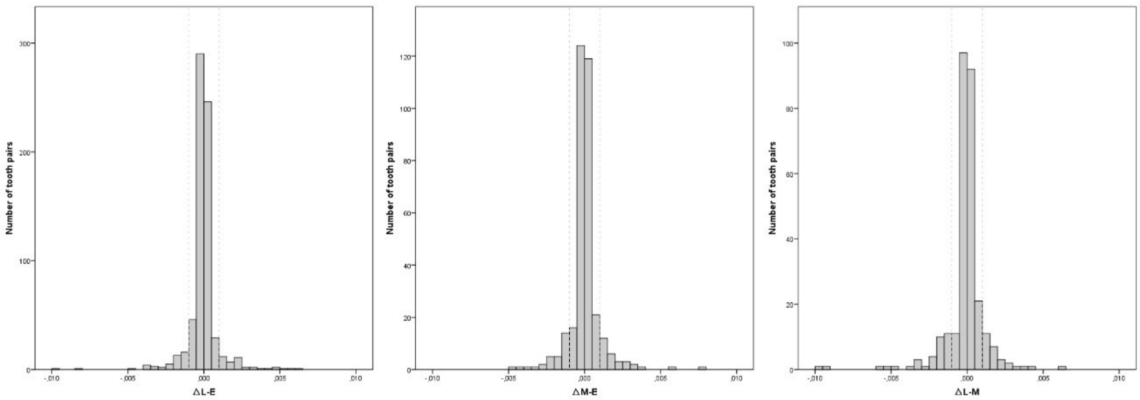

Fig. S2.2. *Histograms of $\Delta^{87}Sr/^{86}Sr$ between Early and Late teeth (ΔL-E), Early and Middle teeth (ΔM-E), and Middle and Late teeth (ΔL-M). Outliers were excluded.*

Table 2.1. *Percentage of different tooth pairs according to offset size*

Tooth pair	**n**	**≤ 0.001**	**0.001-0.002**	**0.002-0.003**	**≥ 0.003**
ΔL-E	700	87.0 %	7.1 %	2.9 %	3.0 %
ΔM-E	340	82.1 %	11.2 %	3.8 %	2.9 %
ΔL-M	285	77.5 %	13.7 %	3.5 %	5.3 %

Table 2.2. *Basic statistical description of different tooth pairs.*

Tooth pair	**n**	**Minimum**	**Maximum**	**Mean**	**SD**	**Mean (AV)**
ΔL-E	700	-0.01494	0.00624	-0.00009	0.00125	0.00052
ΔM-E	340	-0.00478	0.01313	0.00006	0.00127	0.00059
ΔL-M	285	-0.02273	0.00607	-0.00024	0.00208	0.00085

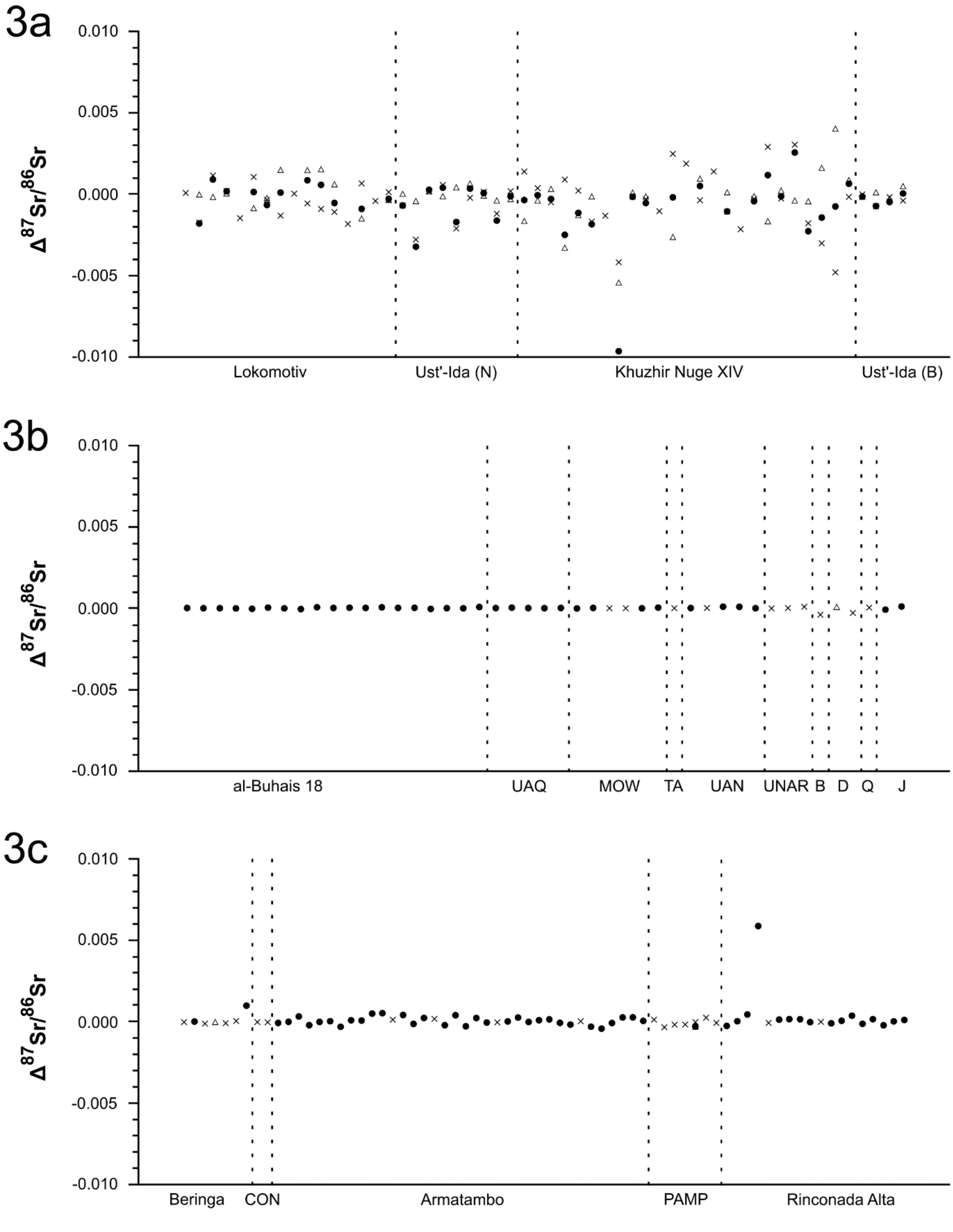

Fig. 2.3. *Comparison of Δ^{87}Sr/^{86}Sr variability in different regions/periods. (3a) Cis-Baikal; (3b) Southeastern Arabia; (3c) Peru. Abbreviations: N = Late Neolithic; B = Bronze Age; UAQ = Umm al-Quwain 2; MOW = Mowaihat Tomb B; TA = Tell Abraq; UAN = Umm an-Nar Island; UNAR = Unar 1; B = Bidya 1; D = Dibba 76; Q = Qidfa 4; J = Jebel al-Emeilah; CON = Conchopata; PAMP = Pampa de los Gentiles. Symbols: full circle = ΔL-E; cross = ΔM-E; triangle = ΔL-M.*

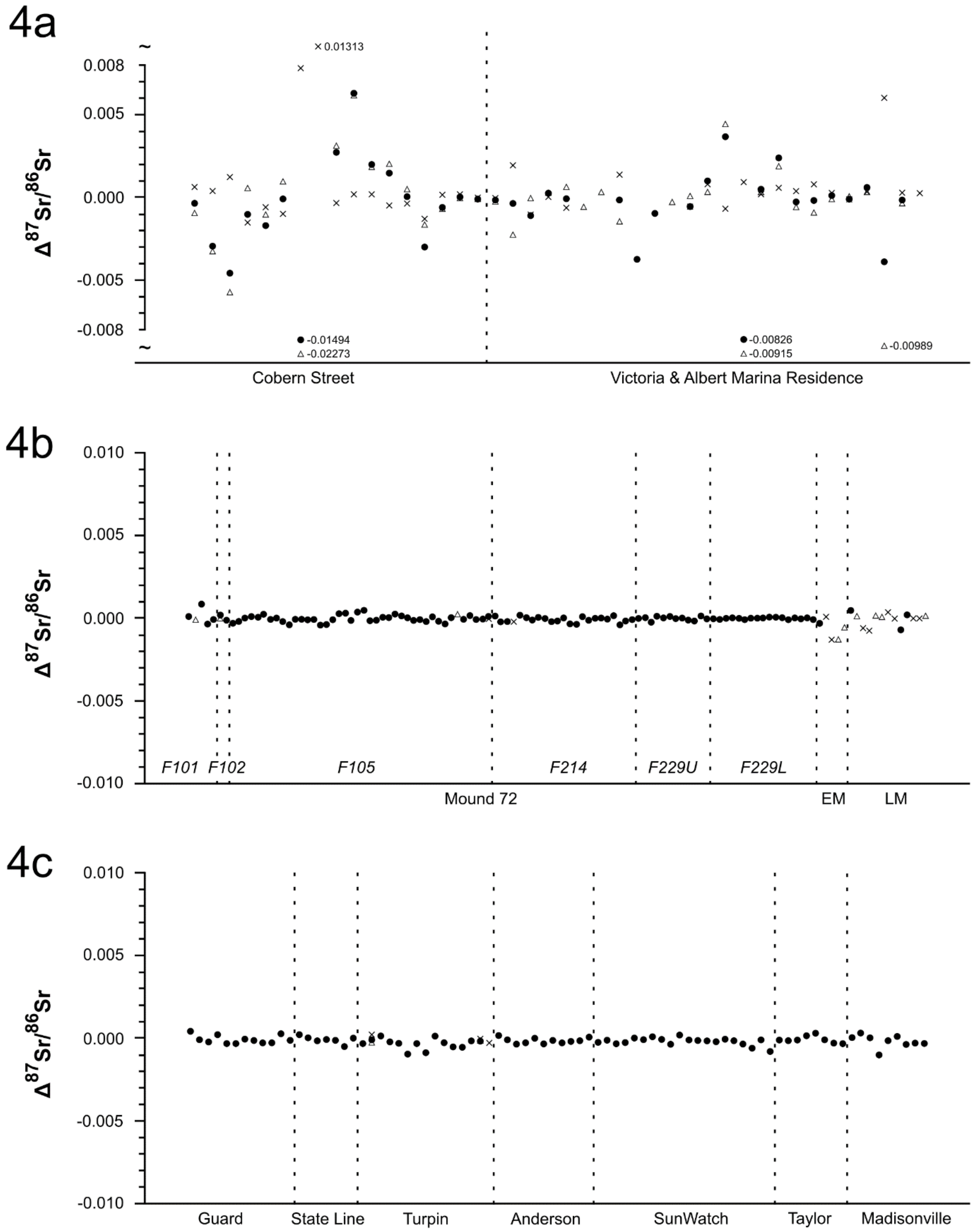

Fig. 2.4. *Comparison of $\Delta^{87}Sr/^{86}Sr$ variability in different regions/periods. (4a) Cape Town; (4b) Cahokia; (4c) Fort Ancient. Abbreviations: EM = Another Early Mississippian; LM = Later Mississippian. Symbols: full circle = ΔL-E; cross = ΔM-E; triangle = ΔL-M.*

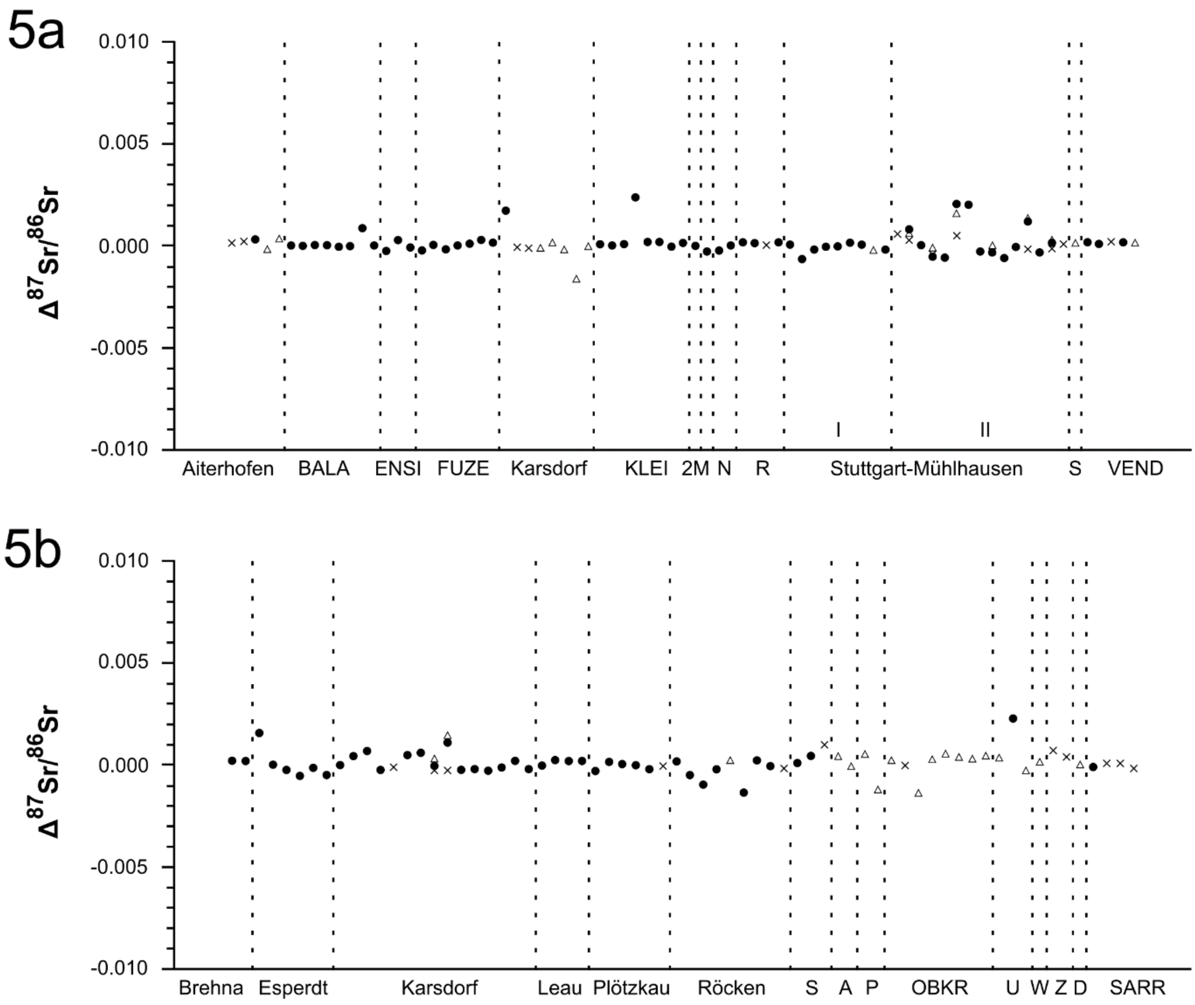

Fig. 2.5. *Comparison of $\Delta^{87}Sr/^{86}Sr$ variability in different regions/periods. (5a) Neolithic CE; (5b) Eneolithic-Bronze Age CE. Abbreviations: BALA = Balatonszárszó; ENSI = Ensisheim-Les Octrois; FUZE = Füzesabony-Gubakút; KLEI = Kleinhadersdorf; 2M = Mezőkövesd-Mocsolyás and Mitterndorf im Tullnerfeld; N = Nitra; R = Rutzing; S (5a) = Souffelweyersheim; VEND = Vendenheim; S (5b) = Serbitz; A = Augsburg-Hugo-Eckener-Straße; P = Haunstetten – Postillionstraße; OBKR = Königsbrunn - Obere Kreuzstraße; U = Haunstetten - Unterer Talweg; W = Wehringen – Hochfeld; Z = Zauschwitz; D = Debrecen-Dunahalom; SARR = Sarretudvari-Örhalom. Symbols: full circle = ΔL-E; cross = ΔM-E; triangle = ΔL-M.*

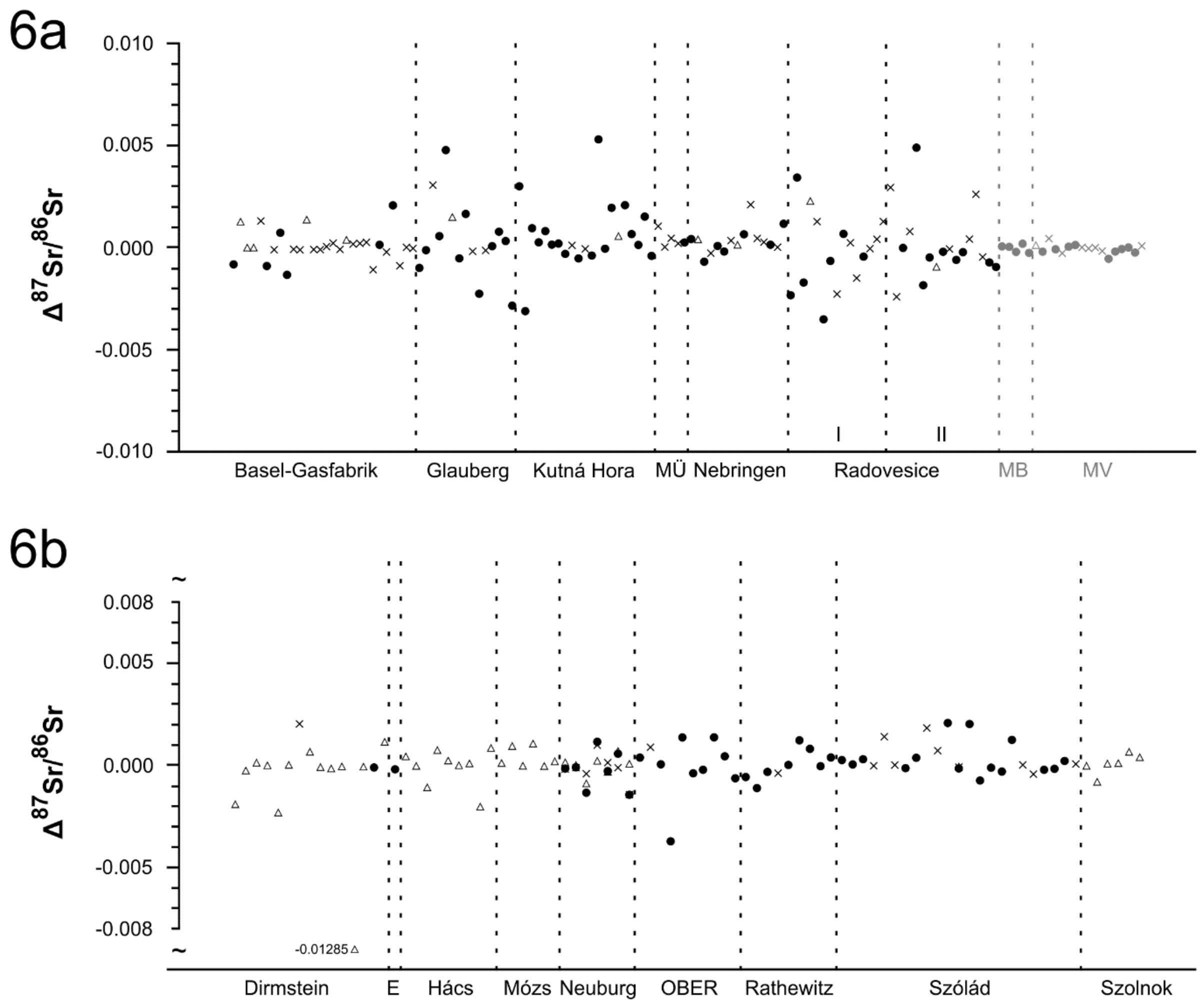

Fig. 2.6. *Comparison of $\Delta^{87}Sr/^{86}Sr$ variability in different regions/periods. (6a) Iron Age CE; (6a) Roman-Early Medieval CE. Abbreviations: MÜ = Münsingen-Rain; MB = Monte Bibele; MV = Monterenzio Vecchio; E = Elsau; OBER = Obermöllern. Symbols: full circle = ΔL-E; cross = ΔM-E; triangle = ΔL-M.*

As could be expected, the reported Δ^{87}Sr/^{86}Sr variability differs significantly between different regions and time periods (Figs. 2.3-2.6, Table 2.3). While individuals at some sites exhibit consistently low Δ^{87}Sr/^{86}Sr values, for example, in Southeastern Arabia (ΔL-E: minimum=-0.00010; maximum=0.00010; σ=0.00004, n=34), other individuals had very large differences between two teeth, for example, those buried in Cape Town (ΔL-E: minimum=-0.01494; maximum=0.00624; σ=0.00340, n=37).

There are also differences between tooth pairs across sites and regions, indicating that people moved during different periods of their childhood. For example, in Cis-Baikal Lokomotiv, large Δ^{87}Sr/^{86}Sr is common between early and middle teeth as well as between middle and late teeth (Fig. 2.3a). However, because the dietary change is frequent and directed to sources with both lower and higher strontium isotope ratios, the resulting difference between early and late teeth is reduced. By contrast, greater differences seem to be more frequent rather between early and middle childhood than between middle and late childhood at Late Neolithic Ust'-Ida. The highest overall variability in this region can be then seen in the Khuzhir-Nuge XIV individuals.

Both case studies of Cis-Baikal and Cape Town (Fig. 2.3a and 2.4a) demonstrate the importance of analyzing more than two teeth per individual. Many of these individuals exhibit a large offset between all three tooth pairs indicating multiple dietary/residential changes during childhood. Others exhibit small ΔE-L, but large ΔE-M and ΔL-M. If only early and late forming teeth are analyzed, as is the practice of most studies, the changes occurring amongst these individuals might not be observable at all.

In general, small $\Delta^{87}Sr/^{86}Sr$ values (≤ 0.0001) which can be observed, for example, in Southeastern Arabia (Fig. 2.3b), may indicate either a lack of residential mobility between early childhood and late adolescence, or that mobility did occur but was solely within or between isotopically similar areas. Although some researchers suggest that even a difference of 0.00005 between two teeth is "large enough to be considered as evidence of a change of the predominant living areas between childhood and adolescence" (Kutterer and Uerpmann 2017: 85), we suggest caution in this regard because such a small offset could also be caused only by slight dietary change independent of any movement (cf. Knudson et al. 2016).

High $\Delta^{87}Sr/^{86}Sr$ values among forager communities of the Cis-Baikal region are not surprising due to the character of these populations. As researchers (e.g., Haverkort et al. 2010), however, rightly note, due to the nature of hunting-gatherer subsistence strategies, it is difficult if not impossible to interpret these results purely in terms of residential mobility. First, the formation of each permanent molar's enamel takes several years so the measured $^{87}Sr/^{86}Sr$ values of bulk enamel samples are merely averages of the strontium intake during that time period and thus cannot provide information about short-term (i.e. annual or seasonal) movements (Montgomery 2010). Second, people likely did not move from one geochemical province to another in perfect periodicity. Their residence at different places could be of variable duration on each occasion, in addition to varying between individuals, and over time. Third, climate change could significantly influence the availability of specific faunal and floral sources, and since most sampled individuals come from different generations, they might consume different diets even within the same catchment area. Fourth, the size of the catchment area from which resources were obtained could also change over time and expand to geochemically distinct areas.

The results from the Cape Town burial populations are in accordance with the very high number of identified non-locals at these sites, with 54.5% at Cobern Street and 63% at Victoria & Albert Marina Residence, and with the main conclusion that migration was primarily related to long-distance forced migrations of enslaved individuals (Kootker et al. 2016; Mbeki et al. 2017). On the other hand, one needs to consider that the presumed local range is exceptionally wide, from 0.7086 to 0.7179, which can also partially explain unusually high $\Delta^{87}Sr/^{86}Sr$ values.

A third region with highly variable $\Delta^{87}Sr/^{86}Sr$ is Iron Age Central Europe (Fig. 2.6a). Several mechanisms have been proposed to explain this pattern. First, the observed differences could be caused by varying land use strategies in the geologically heterogeneous environments, in which many of these sites are situated (Scheeres et al. 2014; Scheeres et al. 2013). Compared to earlier periods, new technological improvements, such as iron ploughshares, enabled exploitation of less fertile soils and gave people more flexibility in selecting farming land. "Cultivated land plots may have changed frequently, even within a few years (alternating Sr isotope ratios within the same jaw), or fluctuated gradually" (Scheeres et al. 2013: 3622). This explanation can be supported by comparison with two Iron Age sites in Italy (MB and MV on Fig. 2.6a), which are in more homogeneous geological settings and have less variable $\Delta^{87}Sr/^{86}Sr$. The second option is that high $\Delta^{87}Sr/^{86}Sr$ in individuals reflects the residential change of larger groups that involved whole families, which would support the idea of historic "Celtic migrations" based on ancient written sources (Scheeres et al. 2014: 507). Third, mobility during childhood can be also explained in terms of fosterage, which could have lasted from infancy until marriage and whereby children might have been raised by one foster family or successive fosterers (Knipper et al. 2018; Scheeres et al. 2014). This possibility is documented in written sources and was supported by strontium analysis of children and juveniles (Müller-Scheeßel et al. 2015). Possible participation of juvenile boys in seasonal herding of cattle was also suggested for some sites, for example Münsingen-Rain (Scheeres 2014: 32-33), while for the Glauberg hillfort, researchers propose the hypothesis that high $\Delta^{87}Sr/^{86}Sr$ was caused by supplying food from different settlements, representing the economic hinterland of this "princely seat" (Knipper et al. 2014). Other explanations include settlement centralization, or children representing hostages or slaves (Knipper et al. 2018). It should be emphasized that all of these different types of mobility might have existed simultaneously and that strontium isotope analysis alone cannot distinguish between them.

The rest of the sites in the compiled data set exhibit $\Delta^{87}Sr/^{86}Sr$ variability that is intermediate between the aforementioned examples. In many such cases, childhood mobility has been inferred based on the observed $\Delta^{87}Sr/^{86}Sr$ values, but the exact number of mobile individuals cannot be accurately estimated without more detailed studies of the local (and regional) geological, environmental, and archaeological contexts. Detailed discussions of the case specific contexts and interpretations of all of the strontium isotope studies cited herein are nevertheless beyond the scope of this review and we refer the reader to the original papers.

Table 2.3. *Descriptive statistics for 10 case study regions/periods.*

Region (tooth pair)	**n**	**Mean (AV)**	**SD**	**Region (tooth pair)**	**n**	**Mean (AV)**	**SD**
Cis-Baikal	**54**			**Cape Town**	**42**		
ΔL-E	44	0.00101	0.00174	ΔL-E	37	0.00191	0.00340
ΔM-E	54	0.00111	0.00149	ΔM-E	37	0.00125	0.00271
ΔL-M	44	0.00086	0.00141	ΔL-M	38	0.00226	0.00463
SE Arabia	**45**			**Neolithic CE**	**77**		
ΔL-E	34	0.00003	0.00004	ΔL-E	59	0.00033	0.00060
ΔM-E	10	0.00009	0.00016	ΔM-E	15	0.00022	0.00028
ΔL-M	1	0.00003	-	ΔL-M	17	0.00042	0.00069
Peru	**70**			**E/BA CE**	**68**		
ΔL-E	51	0.00031	0.00085	ΔL-E	42	0.00038	0.00060
ΔM-E	19	0.00009	0.00013	ΔM-E	12	0.00028	0.00040
ΔL-M	2	0.00017	0.00015	ΔL-M	18	0.00045	0.00063
Cahokia	**119**			**Iron Age CE**	**116**		
ΔL-E	102	0.00014	0.00020	ΔL-E	59	0.00116	0.00172
ΔM-E	11	0.00033	0.00049	ΔM-E	46	0.00066	0.00106
ΔL-M	10	0.00028	0.00047	ΔL-M	11	0.00078	0.00090
Fort Ancient	**82**			**R/M/EM CE**	**86**		
ΔL-E	81	0.00024	0.00026	ΔL-E	41	0.00065	0.00099
ΔM-E	3	0.00018	0.00025	ΔM-E	19	0.00059	0.00085
ΔL-M	2	0.00022	0.00014	ΔL-M	42	0.00076	0.00210

Legend: n = number of individuals (for region/period; in bold) and number of tooth pairs. Mean (AV) = mean from $\Delta^{87}Sr/^{86}Sr$ absolute value.

2.5.1. Possible outcomes and explanations of multiple tooth analysis

Analyzing multiple teeth per individual can provide new insights into childhood mobility; nevertheless, the range of possible explanations is wide and varied. For this summary, we assumed that the local isotope range is defined correctly, and we excluded the possibility of post-mortem mobility (e.g., Keegan 2009). For simplicity we consider analysis of only two teeth (early and late). We also highlight the well-known fact that $^{87}Sr/^{86}Sr$ analysis cannot distinguish mobility between two locations with similar bioavailable $^{87}Sr/^{86}Sr$. Therefore, all $^{87}Sr/^{86}Sr$ analyses potentially underestimate the real numbers of nonlocal individuals and consequently the true amount of mobility. This can be solved only through incorporation of other evidence, whether they are additional isotopic analyses (e.g., oxygen or lead) or complementary archeological or historical data.

We summarize potential outcomes and interpretations involved in multiple tooth $^{87}Sr/^{86}Sr$ analysis in Figure 2.7 and Table 2.4. The complexity and variability in the results obtained from strontium isotope analyses using the multiple tooth sampling approach are illustrated via several hypothetical outcomes. Outcomes 1A and 1B, in which both teeth have local signals and their explanation thus looks straightforward, do not prove that individual did not move during their life. They only suggest that he/she did not move between regions with different bioavailable $^{87}Sr/^{86}Sr$ ranges. Especially in case of 1B, where the $\Delta^{87}Sr/^{86}Sr$ between early and late teeth is greater than the defined offset for the site (e.g., 0.001), possible childhood mobility cannot be excluded, although the change in dietary sources is equally probable.

Other outcomes indicate dietary or residential change more directly. Outcomes 2A and 3A refer to the cases when one of the teeth has a local $^{87}Sr/^{86}Sr$ signal and the second one a non-local $^{87}Sr/^{86}Sr$ ratio. In outcome 2A, the "local" tooth is an early one, indicating an individual's local origin and dietary/residential change during late childhood. The person might consume imported non-local food, move away temporarily or start a more mobile lifestyle. The reverse situation is represented by outcome 3A that indicates a non-local origin and migration to the site during childhood. However, both outcomes might be also explained in terms of migration during adulthood from region with similar $^{87}Sr/^{86}Sr$ ratios. Although these outcomes seem to be clear evidence for dietary/residential change, in practice it should be interpreted with caution, because the boundary between local/non-local signatures are often not very clear. Outcomes 2B and 3B are clearer in this sense, because the $\Delta^{87}Sr/^{86}Sr$ between teeth is greater than the offset defined for the site.

Table 2.4. *Potential outcomes and explanations involved in strontium isotope analysis of two teeth from same individual.*

Local/non-local		**$\Delta^{87}Sr/^{86}Sr$**	**Possible explanations**
1A:	Both teeth local	< OFFSET	- Locally born, no residential change, no change in dietary sources - (Non-)locally born, mobility between regions with identical $^{87}Sr/^{86}Sr$ ratios
1B:		> OFFSET	- Locally born, no residential change, but change in dietary sources (e.g. varying land-use strategies) - (Non-)locally born, mobility between regions with similar, although not identical, $^{87}Sr/^{86}Sr$ ratios
2A:	ET local LT non-local	< OFFSET	- Locally born, no residential change, but change in dietary sources (consumption of imported non-local food) - Locally born, mobility during childhood (e.g. residential change, fosterage, herding) - Non-locally born, residential change during adulthood from region with similar $^{87}Sr/^{86}Sr$ ratios (but for which both ET and LT are local)
2B:		> OFFSET	- Locally born, no residential change, but change in dietary sources (consumption of imported non-local food) - Locally born, mobility during childhood (e.g. residential change, fosterage, herding) - Non-locally born (in region with identical $^{87}Sr/^{86}Sr$ ratios), multiple residential changes/changes in dietary sources (at least one during childhood and one during adulthood)
3A:	ET non-local LT local	< OFFSET	- Non-locally born, residential change during childhood - Non-locally born, residential change during adulthood from region with similar $^{87}Sr/^{86}Sr$ ratios (but for which both ET and LT are local) - Locally born to mother consuming non-local food
3B:		> OFFSET	- Non-locally born, residential change during childhood - Non-locally born, change in dietary sources during childhood and residential change during adulthood - Locally born to mother consuming non-local food
4A:	Both teeth non-local	< OFFSET	- Non-locally born, no residential change or change in dietary sources during childhood, but immigration to the site during adulthood - Non-locally born, mobility between regions with identical $^{87}Sr/^{86}Sr$ ratios during childhood, and immigration to the site during adulthood - Locally born to mother consuming non-local food, and consuming non-local food during his/her entire childhood (with or without mobility)

4B, 4C:	> OFFSET	- Non-locally born, residential change during adulthood and residential change/change in dietary sources during childhood - Non-locally born, residential change during childhood, but consuming non-local food during the time of LT formation - Non-locally born, residential change during childhood, which appeared exactly during the time of LT formation[1] - Locally born to mother consuming non-local food, and consuming non-local food (different from that consuming by his/her mother) during his/her entire childhood (with or without mobility)

Legend: ET = Early tooth (e.g. M1); LT = Late tooth (e.g. M3); OFFSET = Δ87Sr/86Sr between two teeth which is not likely produced only by small change in eating habits (e.g. 0.001).

[1)] Therefore, Sr ratio in LT is combination of local and non-local signatures (it is possible only when LT Sr ratio is between ET Sr ratio and local range; i.e., first 4B example in Fig. 2.7.).

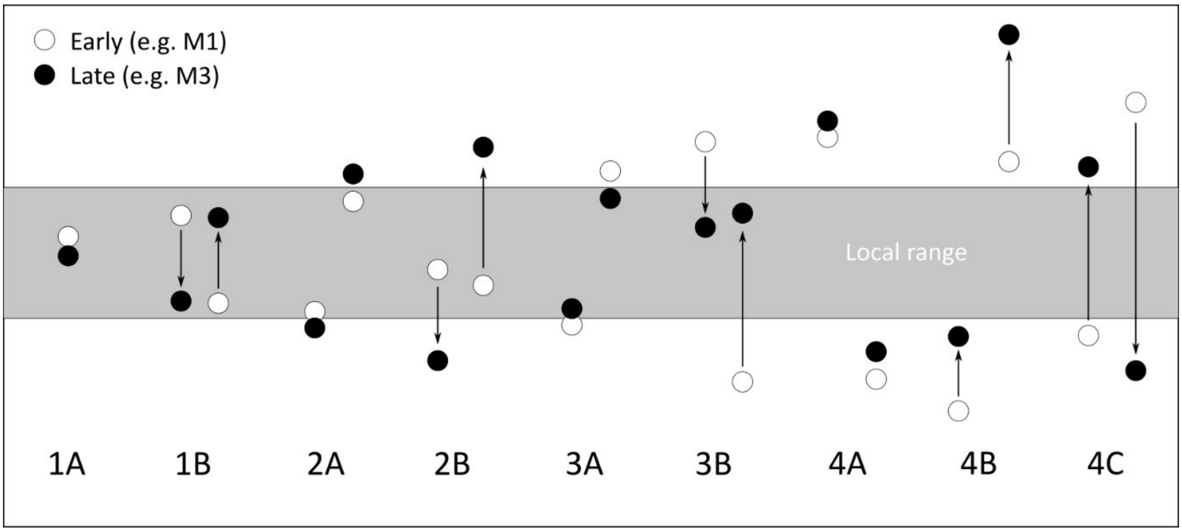

Fig. 2.7. *Potential outcomes of strontium isotope analysis of two teeth from the same individual.*

Outcome 4A (both teeth with non-local signals and relatively small $\Delta^{87}Sr/^{86}Sr$) suggests dietary/residential change after adolescence. Although additional mobility during childhood cannot be excluded, outcomes 4B and 4C provide a better evidence for multiple mobility events during an individual's lifetime. However, since individuals in these cases are probably non-local, it is impossible to estimate the precise $\Delta^{87}Sr/^{86}Sr$ offset value typical for their home location.

Adding the third tooth (e.g. M2 for middle childhood) into the analysis can further specify the age at which dietary/residential change occurred. On the other hand, the range of possible explanations becomes even wider. Regarding the possibility of distinguishing between change in dietary sources and residential mobility strontium isotope analysis does not provide a simple answer. Other multiple tooth isotopic analyses ($\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$) or other archaeological methods need to supplement this method.

2.5.2. Possible interpretations of childhood mobility

There is no simple interpretation for any of the multiple tooth analysis outcomes (Fig. 2.7). Anthropological and historical literature provides many examples of different types of childhood mobility, which can result in the same or similar Sr isotope outcomes in human teeth. For this reason, it is necessary to complement Sr isotope results with other lines of evidence. Some of the main types of childhood mobility are discussed below; although this list should not be considered exhaustive it is intended to illustrate the diversity of this phenomena.

2.5.2.1. Residential change of whole kin group

Probably the most common movement of children was together with their kin group, whether as migration of a single family or a larger community group. The potential reasons for residential change include many factors, for example, economic, demographic, social, ideological, ecological or political. Nevertheless, it is worth noting that migration patterns often comprise a two-way flow of people including migration and return migration (Anthony 1990: 904), and thus it is possible that some of these children returned to their region of birth later in life, while other children might be born in the new environment and moved with their returning parents (Hadley and Hemer 2011: 75).

2.5.2.2. Fosterage

Fosterage, sometimes called "children circulation" (Leinaweaver 2008), is a practice characteristic of many societies, e.g., medieval Ireland or modern-day Peru, when a child does not reside with his/her own parents. Distinct from adoption, the child's natural parents remain the acknowledged parents. Scholars distinguish several types of fosterage. A main distinction is made between crisis fosterage, by close family kin, and allegiance fosterage. The latter can be further divided between patronal allegiance fosterage (child-raising by status superior) and cliental allegiance fosterage (raising by status inferior; Parkes 2006: 359). Fosterage can be for free, so-called fosterage for love, usually undertaken by close kin or family friends, or parents may pay a fosterage fee, which depended on the child's sex and parents' status (Hemer 2014: 137). The main functions of this practice are the formation of alliances between households and/or the provision of education (Hemer 2014: 138). Fosterage could have lasted from infancy until marriage and children might be fostered by a several successive fosterers (Parkes 2006: 362). This would divide financial burden associated with rearing a child between multiple families, and at the same time extend the allegiance network (Hemer 2014: 138). Sometimes, children are also fostered if poor families have difficulties providing sufficient sustenance for them. A wealthier fostering family may provide children with basic needs, while receiving extra labor in return (Lancy 2018: 200; Sieff 1997: 523). Besides fosterage, children might have been raised by institutions, for example, a monastery or boarding school. Another example of fosterage is in cases when children primarily receive specialized training from a master in a craft, art, or medicine, such as apprenticeship (Lancy 2012).

2.5.2.3. Herding

Many studies of the role of children in different societies showed that they are often involved in the tasks of keeping livestock even from a very young age (Knipper 2009: 294-297). In Peru, for instance, children participate in herding chores since they are barely able to walk and may be entrusted with a small herd alone by the age of 5 or 6 years (Bolton et al. 1976: 467). Similarly, African Fulani boys are actively involved in cattle herding activities with their older brothers or father from the age of 6, but sometimes even earlier (Denga 1983: 171; Lott and Hart 1977: 181). In terms of gender, men and boys are usually responsible for herding livestock (Lancy 2018: 92; Whiting and Edwards 1988: 63-66), however, there are examples of both girls and boys being involved in herding activities. For example, children of both sexes take care of llamas and alpacas in the Andes (Bolton et al. 1976: 467) and among Tanzanian Datoga there are about the same number of female and male herders. Small livestock and calves are almost equally guarded by girls and boys, while there are slightly more males amongst cattle herders (Sieff 1997: 536-537). Kel Ewey Tuareg children of both sexes also work from early age. At about the age of 7, they help their older siblings to watch over the goats while they are grazing. At about 10 years old, girls start to herd goats on their own, whereas boys travel with their fathers and camel caravans for several months on distances up to 900 kilometers (Spittler 2012: 59-61). Overall, in most pastoralist societies children spent many hours away from the settlement in herding activities (Lancy 2018: 117-118).

2.5.2.4. Forced mobility

Children and women have often been overrepresented amongst captives in many societies (Cameron 2016), and since warfare, raiding and kidnapping were common in many times and places, unwilling (and usually violent) or forced migration of children is also a possible interpretation in many contexts. Some captured children might be adopted or married into families, while some become slaves. Others were kept as hostages or occupy some marginal positions such as household servants. Children did not have to be captured to end up in slavery. They could be also sold by their poor parents in return for food in times of starvation or they were born as slaves (Patterson 1982). Once a child became "property", he/she could be traded, and moved, from one master to another. Interestingly, some children were also part of the other side of the coin. For example, written, as well as archaeological, evidence shows that children clearly accompanied Viking armies during raids (Hadley and Hemer 2011: 65). And it is possible that some individuals age 10 or even younger might be directly involved in combat (Kamp 2001: 26).

2.5.2.5. Child marriage and post-marital residence

Although the marriage age is often set at 18 in the majority of modern countries, it is not rare when people, especially girls, got married much younger. The United Nations Population Fund estimates that 12% of girls around the world become brides before the age of 15 (Loaiza and Wong 2012). Amongst some schools of Islamic legal thought, for example, the range of minimum marriageable ages for males is between 15 and 18, while for females this extends from a high of 17 down to as young as 9 (Büchler and Schlatter 2013). Similarly, in Ancient Rome the legal minimum age of marriage for girls was 12 and for boys 14, but there is also evidence for children married at 6 and 7 (Hopkins 1965). In early medieval Germanic societies people also usually married very young, girls aged 12 to 14 and boys between 14 and 16 (Wemple 1993: 229). Therefore, in some rare cases multiple-tooth analysis can potentially reveal post-marital mobility occurring at a young age, since third molars develop relatively slowly and the process of crown mineralization is not completed until approximately 14 years of age (AlQahtani et al. 2010).

Temporary matrilocal residence was common among some societies. For example, young indigenous couples living on Aleutian Islands in the Northern Pacific Ocean remained with the wife's parents after their marriage and moved to the husband's family home only after the first child was born (Lantis 1984: 176). Similarly, men from the North American tribe Havasupai usually lived in their wife's parents' camp until she had borne one or two children. Afterward the couple might establish their new home near either his or her parents' camp (Spier 1928: 222). Post-marital residence was initially matrilocal also among the South American Tupinamba, but the husband's goal was to free himself and his wife from dependence on the in-laws and move to his own parents' longhouse (Métraux 1948b: 111-112). In such cases, the residential mobility of newly born or very young children can be revealed through differences in strontium ratios between the early forming teeth (e.g. deciduous teeth which start to mineralize in utero) and later forming ones.

2.6. Conclusion

Although the analyzed dataset has clear spatial and temporal biases and is lacking in representativeness, this study has revealed several important findings. The reported $\Delta^{87}Sr/^{86}Sr$ variability differs significantly between different regions and time periods. This cannot be explained only by different patterns of subsistence or by diverse geological conditions around each site, and thus must reflect to some extent different patterns of childhood mobility in the past. Previous applications of the multiple tooth sampling approach for strontium isotope studies of human paleomobility have clearly demonstrated that childhood mobility was more common than previously recognized. The increasing number of studies utilizing this approach in recent years perhaps illustrates a renewed interest in social (e.g., age-related) variation in patterns of human migration and mobility, as well as methodological advances permitting higher resolution reconstruction past lifeways and life histories. Nonetheless, the various potentials, limitations, and complicating variables of the multi-tooth sampling approach merit more explicit consideration.

First, a minimal $\Delta^{87}Sr/^{86}Sr$ cutoff of 0.001 to detect residential change during childhood/adolescence has been proposed and applied in several recent studies. This proposed cutoff (0.001) is approximately two orders of magnitude larger than the typical measurement error (0.00001) of strontium isotope analysis (2SE) and thus is extremely unlikely to be the result of analytical error or random variation. However, as the degree of normal variation in $^{87}Sr/^{86}Sr$ within a single (non-mobile) individual is not well characterized, caution is merited in the use of such an absolute cutoff value for distinguishing between local and non-local individuals. Future research should focus on more precise estimation of the expected range of $^{87}Sr/^{86}Sr$ variation between different tissues within a single individual (e.g., intra-individual variation). The approach proposed by Knipper et al. (2018) should be expanded to larger datasets including individuals that are documented to have been stationary (non-mobile) and to a greater diversity of biogeochemical and geographical settings.

Multiple tooth $^{87}Sr/^{86}Sr$ analysis, as well as isotopic provenancing in general, has its limitations. The extent of identified childhood mobility will generally remain an under-estimation, since it is usually impossible to reveal mobility between two places with similar bioavailable $^{87}Sr/^{86}Sr$ signatures. This limitation is, however, not specific to the multiple tooth sampling approach, but is inherent to (single) isotope approaches more generally. Therefore, it is beneficial to supplement this method, when possible, with other isotopic proxies, for example, multiple tooth $\delta^{18}O$, $\delta^{15}N$ and $\delta^{13}C$ analyses or other archaeological methods. Of course, childhood mobility can be also revealed by analyzing isotope ratios in the remains of children themselves (i.e., of individuals who died during childhood, as opposed to tissue samples from adults which form during childhood). Such an approach permits the identification of child migrants that did not survive to adulthood (Hadley and Hemer 2011: 72). Conversely, isotope analysis of certain deciduous teeth that form solely or primarily *in utero*, could in principle be used to investigate the mobility/migration patterns of mothers during pregnancy.

As nuanced interpretations cannot be deduced from multiple tooth $^{87}Sr/^{86}Sr$ analysis alone, because every outcome can be explained in several different ways, the results should always be placed within an appropriate archaeological, historical and ethnographic context. In order to reveal dietary/residential changes at finer temporal resolutions it is preferable to analyze teeth from three age categories (e.g., M1, M2 and M3). The incorporation of four or more permanent teeth does not provide much additional information in this respect, since the formation ages of many teeth overlap. By contrast, the multiple tooth sampling approach involves significantly higher investments in time and costs than the traditional single tooth sampling approach, and it also destroys a larger amount of archaeological material, since the strontium isotope analysis is a destructive method, as is the case with most types of biochemical analysis of human remains. As such, decisions about which sampling approach to employ will likely be influenced by these practical considerations, as well as the specific contexts of the individual case studies. Therefore, analysis of multiple tooth should be conducted only in cases where there is a justified assumption that the results will provide new and meaningful findings.

3. CASE STUDY 2. Identifying post-marital residence patterns in prehistory: A phylogenetic comparative analysis of dwelling size[3]

3.1. Introduction

Post-marital residence rules specify where a person resides after marriage and, accordingly, influence social organization of human societies. In modern wage-based economies, most newlyweds tend to establish a new household separate from their respective families (neolocal residence). However, in traditional societies couples typically live with or near one's parents (Peoples and Bailey 2011). About 71% of all societies listed in the *Ethnographic Atlas* (Murdock 1967) are predominantly patrilocal, while 11% are matrilocal. Ambilocality, multilocality, avunculocality, and neolocality are less frequent, together accounting for the remaining 18% of societies (Divale and Harris 1976). However, the same distribution does not apply to hunter-gatherer societies, which have a more flexible social organization, being most frequently ambi-/multilocal (Marlowe 2004). The decision regarding who will leave home after marriage and who will stay with their own kin affects many important aspects of social organization (Peoples and Bailey 2011), including descent systems and kinship terminology (Murdock 1949), wealth inheritance rules (Agarwal 1988), modes of marriage (Divale and Harris 1976), community size (Korotayev 2004), division of labor (Korotayev 2003), migration (Divale 1974), and warfare (Ember 1974; Ember and Ember 1971). Murdock argued that "when any social system undergoes change, such change regularly begins with a modification in the rule of residence" (Murdock 1949: 221). This notion that a change of post-marital residence rule drives change in other aspects of social organization, not *vice versa*, has become known as "Main Sequence Theory".

Exact definitions of post-marital residence patterns vary considerably (Mattison et al. 2019). Some scholars use "patrilocality" as a general term for residence with or near the husband's family (e.g. Jordan et al. 2009; Peoples and Bailey 2011), while others (e.g. Fortunato 2011; Stojanowski and Schillaci 2006) distinguish between "patrilocality" (residing in the husband's father's household) and "virilocality" (residing with the husband's kin in a more general sense). The same applies to "matrilocality" and "uxorilocality", referring to residence with or near the wife's kin. "Ambilocality" refers to residence with or near the kin of either

[3] This case study was published as **Hrnčíř V.**, Duda P., Šaffa G., Květina P., Zrzavý J. (2020). 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. All co-authors have agreed to use the article as part of this Ph.D. thesis.

spouse, while "multilocality" refers to the situation where couples move between the households of both sets of parents. "Avunculocality" can be considered a special case of virilocality, when a couple lives with the husband's maternal uncle. In this study, we use "patrilocality" for both patri- and virilocality and "matrilocality" for both matri- and uxorilocality, since they cannot be distinguished in prehistoric patterns by the currently available methods.

Scholars have employed various methods of identifying post-marital residence patterns in prehistoric societies from archaeological records. Primarily, they have focused on skeletal morphology, since inferring any kind of social organization from the variability or spatial distribution of material culture can be misleading (Allen and Richardson 1971; Dumond 1977). Traditionally, bioarchaeologists examined morphological variation in skeletal and dental traits to identify differences between males and females (for an extensive review of this approach see Stojanowski and Schillaci 2006). According to the theory, the sex with the greater within-group morphological variability is assumed to be the more mobile one. For instance, greater female variability corresponds to greater female migration and thus could indicate patrilocality.

With more recent advances in scientific methods, the focus of bioarchaeologists has moved to isotopic and ancient DNA analyses. For example, researchers using strontium isotope analysis of human tooth enamel (Bentley 2006) found significantly more variance in the distribution of $^{87}Sr/^{86}Sr$ signatures among females than among males in early Neolithic Central Europe (5500–5000 BC), indicating patrilocality during this historical period (Bentley et al. 2012). The same residence pattern has also been proposed for the late Neolithic (2700–2400 BC) communities in Eulau (Haak et al. 2008), Bergrheinfeld and Lauda-Königshofen (Sjögren et al. 2016), and Early Bronze Age (2150–1700 BC) Lech River valley (Mittnik et al. 2019), all in Germany, where females fall outside the local strontium range, indicating that their place of birth (and childhood) was elsewhere. Similarly, but in the opposite direction, isotopic evidence suggests a possible transition to matrilocality during the second millennium BC in Thailand (Bentley et al. 2005; Bentley et al. 2007). Sex-biased mobility differences can also be inferred from ancient DNA sequences (specifically mtDNA and Y-chromosomal haplotypes). Patrilocal societies should have relatively lower Y-chromosomal diversity and larger mtDNA diversity within a population, while the opposite pattern is expected for matrilocal societies. This has been demonstrated in present-day patrilocal and matrilocal groups in northern Thailand (Oota et al. 2001) and also applied in archaeology, e.g. for suggesting that Neanderthals in Iberia (ca. 49,000 BP) were patrilocal (Lalueza-Fox et al. 2011), or that the prehistoric North American Hopewell community (100 BC to AD 400) was matrilocal (Bolnick and Smith 2007). However, more recent studies have shown that the association between DNA diversity and post-marital residence pattern is much less straightforward and not universal (Gunnarsdóttir et al. 2011; Kumar et al. 2006; Ly et al. 2018; Vigilant and Langergraber 2011). Other attempts to infer past social organization are based on population genetic analyses. For example, an abrupt reduction in Y-chromosomal diversity (compared to mtDNA) inferred across several Old World populations around 8,000–4,000 BP (Karmin et al. 2015), has been interpreted as evidence of predominant patrilineality and patrilocality during this period (Zeng et al. 2018).

Anthropologists have applied phylogenetic comparative methods, adopted from evolutionary biology (Mace and Pagel 1994; Nunn 2011), to reconstruct the evolution of cultural traits. Using language trees as a proxy for historical relationships between populations, the evolution of post-marital residence rules has been reconstructed in Austronesian (Fortunato and Jordan 2010; Jordan et al. 2009), Bantu (Opie et al. 2014), Indo-European (Fortunato 2011; Fortunato and Jordan 2010), and Tupi (Walker et al. 2012) language families. The results of these studies suggest that early Austronesians were matrilocal and matrilineal, the first Bantu were patrilocal and patrilineal, early Indo-Europeans practiced patrilocality and/or neolocality, and Tupi ancestors were matrilocal. Recently, Moravec et al. (2018) modelled transitions in post-marital residence rules in five language families (Austronesian, Bantu, Indo-European, Pama-Nyungan, and Uto-Aztecan) and found that there is no universal pattern of evolution for post-marital residence rules, although patrilocality seems to be the most common state across space and time. Apart from reconstructing the history of various cultural practices, the phylogenetic comparative approach is useful for studying associations between cultural traits, while controlling for phylogeny. For example, Jordan (2007) demonstrated that in Austronesian societies, changes in post-marital residence preceded changes in descent systems, whereas Opie et al. (2014) found that in Bantu societies, a change in descent system was always followed by a shift away from the ancestral post-marital residence state. Surowiec et al. (2019) found, using a worldwide sample of societies, that matrilineal descent emerges first, followed by a shift towards matrilocality, more often than *vice versa*, challenging Murdock's (1949) Main Sequence Theory. Walker et al. (2010) demonstrated that the prevalent belief in partible paternity is associated with matrilocal residence in Carib, Macro-Je, Pano, and Tupi language families.

Cross-cultural researchers have attempted to identify correlates of post-marital residence patterns through statistical analysis of ethnographic data (Ember and Ember 2009). The association between average house floor area (AHFA) and post-marital residence (PMR) was first demonstrated by Ember (1973). In his seminal paper, he showed, using two cross-cultural samples, that AHFA in matrilocal societies is usually more than 51–56 m^2, while the majority of patrilocal societies have smaller houses. (Note that we use "house" and "dwelling" interchangeably in this paper, both terms referring to residential building). Subsequent studies by Divale (1977) and Brown (1987) confirmed his findings. According to Divale (1977)], any archaeological site that had an AHFA less than 42.7 m^2 could be inferred to have had patrilocal residence with 95% confidence. Conversely, an AHFA larger than 79.2 m^2 indicates a matrilocal residence. Brown (1987) did not suggest any cut-off value; nevertheless, his test confirmed the correlation. Mean AHFA values in his sample were 27.4 m^2 for patrilocal societies and 78.4 m^2 for matrilocal ones. Two decades later, Porčić (2010) tested these findings. He combined all data from the previous studies into a larger sample of 80 societies and added a new variable into the analysis: the mode of subsistence. His results confirmed the association between AHFA and PMR, but the mode of subsistence had a significant effect on the correlation. The AHFA-PMR association was only significant in agricultural societies, improving the prediction rate by almost 25%, but not in foraging or pastoral societies. This finding was positively received by archaeologists, as dwelling size is usually easy to determine, and has been applied to various archaeological contexts, e.g. to historical northern Iroquoian groups (AD 500–1300; Hart 2001), Chaco Canyon region (AD 900–1150; Peregrine 2001b; Peregrine and Ember 2002; Schillaci and Stojanowski 2002, 2003), Hohokam culture (AD 0–1450; Ensor 2013, 2017), and Neolithic Greece (6600/6500–3300 BC; Souvatzi 2017).

In order to explain his findings, Ember (1973) argued that matrilocal societies tended to have larger houses because married sisters find it easier to live together than non-sisters and thus these societies tend to form larger households. In Divale's (1977) opinion, larger matrilocal households enhance trust and cooperation between unrelated brothers-in-law who did not know each other before marrying into the community. In this respect, large matrilocal households serve a similar function as men's houses, where men from different families eat, work and sleep together. According to Porčić (2010), the absence of agriculture generally implies more mobile subsistence strategies such as foraging or pastoralism. People in mobile societies tend to spend less time and energy building houses and thus have smaller dwellings made of lighter materials, regardless of their post-marital residence rules.

However, these studies suffer from several methodological issues. First, they only considered two types of PMR: matrilocal and patrilocal. Neolocality was excluded from Ember's original study because he found that it correlated with the presence of monetary exchange and markets (Ember 1967). Ambilocality and multilocality were also not considered because another cross-cultural study (Ember and Ember 1972) found them to be associated with recent depopulation. Avunculocality was omitted simply because it is rare, present in less than five percent of world cultures (Ember 1973).

Second, previous studies did not control for the non-independence of societies due to common ancestry. As Galton pointed out in the 19th century (see the discussion in Tylor 1889), societies cannot be treated as statistically independent. Similar cultural traits can reflect convergent adaptations to similar socio-ecological pressures as well as common ancestry. This realization later became known as "Galton's problem". Anthropologists have attempted to minimize Galton's problem by using subsets of distantly related societies that were assumed to be effectively independent, such as the Standard Cross-Cultural Sample (Murdock and White 1969). However, failure to take relatedness into account leads to elevated Type I and Type II error rates, even in the datasets designed for the purpose of mitigating Galton's problem (Dow and Eff 2008; Minocher et al. 2019) . Common ancestry can be accounted for with a use of phylogeny, which captures the expected covariance among societies. It allows not only to test for a correlation between AHFA and PMR while controlling for non-independence, but also to detect independent (convergent) changes in AHFA in response to changes in PMR or other aspects of social organization. Using phylogenetic comparative methods, we can determine whether large houses are a predictable response to matrilocality and whether AHFA can inform us about the social organization of prehistoric societies.

Moreover, except the presence of agriculture in Porčić's study (2010), other aspects that could impact AHFA were not considered. Although Porčić also assumed that house construction material and settlement patterns can significantly affect the house size, he did not include these variables into his analyses. Household wealth is another factor which is positively correlated with house size in many societies (for references see Kohler et al. 2017, Supplementary Table 1), indicating that large dwelling does not always mean more household members. Apart from residential and symbolic functions, exceptionally large dwellings could also serve other purposes, such as storage, meeting, defensive or ritual. The appearance and size of dwellings could be significantly influenced also by sociopolitical settings and colonialism. Some types of building materials and technologies could have made it possible to build larger houses, while intercultural contact could have led to change of architectural style.

In the present study, we re-examine the association between the AHFA and PMR using a different sample of societies, revised AHFA values, and a finer continuous variable that captures all types of PMR. Our analysis includes additional explanatory variables, specifically the presence of agriculture, fixity of settlement, and house construction material, while controlling for non-independence using a time-calibrated phylogenetic supertree of human populations based on genetic and linguistic data (Duda and Zrzavý 2016, 2019).

3.2. Methods

3.2.1. Study variables

The AHFA data for 80 societies were taken from Porčić's study (2010), which were collected from three previous studies (Brown 1987; Divale 1977; Ember 1973). We added 22 new populations for which the AHFA was reported by Brown (1987) but not included in previous analyses because they were not (strictly) patrilocal or matrilocal (see S1 Supplementary material). Where possible, we checked the data against their original sources (see S1 Supplementary material). AHFA values were log-transformed to ensure a normal-like distribution of the data.

Data on post-marital residence rules, the presence of agriculture, fixity of settlement, and construction material were obtained from the open-access *Database of Places, Language, Culture, and Environment* (D-PLACE; Kirby et al. 2016). All study variables are described in Table 3.1 (see also Table A in S1 Supplementary material). The variable "Marital residence with kin: prevailing pattern [EA012]" was chosen as a proxy for post-marital residence because the same variable in the *Ethnographic Atlas* (Murdock 1967) was used in previous studies and it is more finely-resolved than the similar variable "Transfer of residence at marriage: prevailing pattern [EA011]". Original categories were reduced to a five-point scale, which captures a tendency towards matrilocality.

Three additional explanatory variables were dichotomized: agriculture into "agriculture not important" and "agriculture important" according to Porčić (2010); settlement into "mobile" and "sedentary" indicating fixity of settlement; and material into "impermanent" and "durable" indicating durability of wall material of the prevailing type of dwelling.

AHFA and PMR were additionally dichotomized in order to test for correlated evolution (see Phylogenetic comparative analysis). AHFA was coded as "small" and "large", with a cut-off value of 65 m^2 as per Porčić (2010); PMR was coded as "non-matrilocal" and "matrilocal".

Table 3.1. *Description of study variables.*

Name	Original source	Original scale	Transformation
AHFA (ord)	Ref. (Porčić, 2010) or primary sources in S1 Supplementary material	Continuous measure between 0 and ∞	Log-transformed to ensure a normal-like distribution of the data
AHFA (bin)	"As above"	"As above"	Dichotomized into small (< 65 m^2) and large (> 65 m^2)
PMR (ord)	*D-PLACE* – Marital residence with kin: prevailing pattern [EA012]	1=Avunculocal 2=Ambilocal 3=Avuncu-uxorilocal 4=Avuncu-virilocal 5=Matrilocal 6=Neolocal 7=Separate 8=Patrilocal 9=Uxorilocal 10=Virilocal 11=Ambi-uxo 12=Ambi-viri	Reduced to five-state continuous trait indicating tendency towards matrilocality: 0 = 1, 4, 8, 10 on original scale 1 = 12 2 = 2, 3, 6, 7 3 = 11 4 = 5, 9
PMR (bin)	"As above"	"As above"	Dichotomized into non-matrilocal (1–4, 6–8, 10, 12 on original scale) and matrilocal (5, 9, 11)
Agriculture	*D-PLACE* – Agriculture: intensity [EA028]	1=No agriculture 2=Casual agriculture 3=Extensive or shifting agriculture 4=Horticulture 5=Intensive agriculture 6=Intensive irrigated agriculture	Dichotomized into agriculture not important (1–2 on original scale) and agriculture important (3–6)
Settlement	*D-PLACE* – Settlement patterns [EA030]	1=Nomadic bands 2=Seminomadic communities 3=Semisedentary communities 4=Impermanent settlement 5=Dispersed homesteads 6=Hamlets 7=Villages/towns 8=Complex settlements	Dichotomized into mobile (1–2 on original scale) and sedentary (3–8)
Material	*D-PLACE* – House construction: wall material [EA081] or House construction: roofing materials [EA083][a]	1=Stone, stucco or brick 2=Plaster, clay or similar 3=Wood or bamboo 4=Bark 5=Hides or skins 6=Fabric 7=Mats 8=Grass 9=Adobe, clay or brick 10=Open walls 9[EA083]=Earth or turf 10[EA083]=Ice or snow	Dichotomized into impermanent material (2,4,5,6,7,8,10 on original scale and 10 from variable EA083) and durable material (1,3,9 and 9 from variable EA083)

[a]Populations with a character state 11 = "walls indistinguishable from roof or merging into the latter" in variable [EA081] were scored based on variable [EA083].

3.2.2. Phylogenetic comparative analysis

To apply phylogenetic methods to our global sample of societies, we leveraged a time-calibrated supertree of human populations (Duda and Zrzavý 2016, 2019). This supertree (i.e. a tree of trees) was based on 388 genetic and linguistic phylogenies published between 1990 and 2017, and time-calibrated using 265 node-age constraints derived from genetic, linguistic, archaeological, historical, and epigraphic data. A subset tree of 86 populations (from a total of 102; the others were not included in the phylogeny) for which AHFA values were available was used as a phylogenetic control (Fig. 3.1, Table A in S1 Supplementary material). We measured phylogenetic signal of individual continuous and binary traits using Pagel's λ (Pagel 1999) and Fritz and Purvis's D (Fritz and Purvis 2010), respectively. The λ values for each multistate trait were estimated using the *phylosig* function in the R package *phytools* (Revell 2012). D values for each trait in our sample were estimated using the *phylo.d* function in the R package *caper* (Orme et al. 2013). The maximum likelihood (ML) reconstruction of ancestral states was performed using the *fastAnc* function and the resulting estimates were plotted using the *contMap* function in the R package *phytools* (Revell 2012).

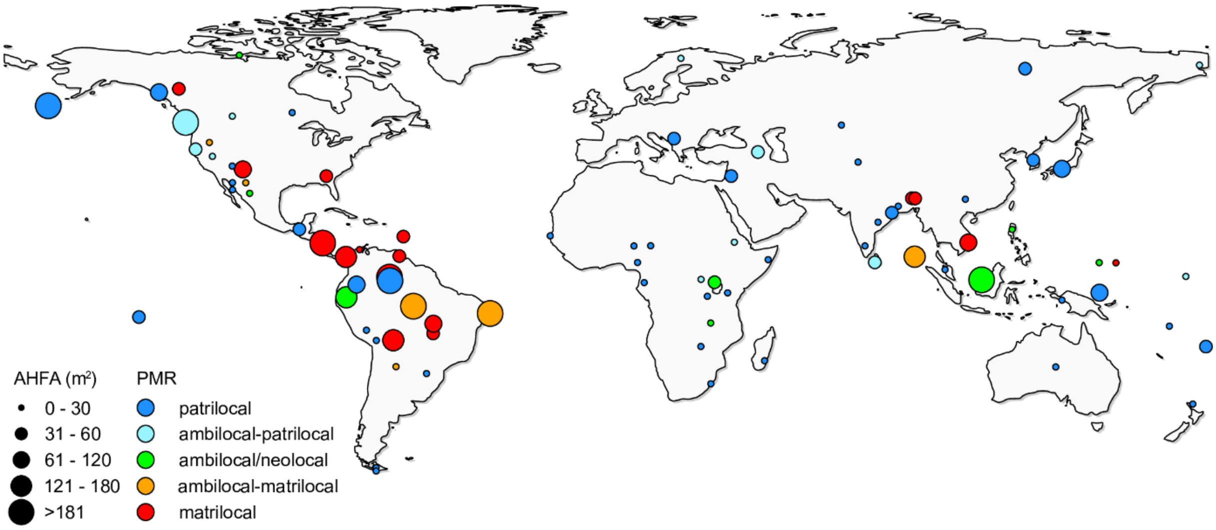

Fig. 3.1. *World map showing the distribution of the 86 sample societies. Dot size corresponds to the average house floor area (AHFA); colors indicate the post-marital residence (PMR) pattern.*

We modelled a probability that AHFA is a linear function of the explanatory variables, using phylogenetic generalized least squares (PGLS) regression as implemented in the *pgls* function of the R package *caper* (Orme et al. 2013), while simultaneously controlling for phylogenetic signal (as measured by the ML estimate of λ) in the residuals of each model. We assessed the explained variance by the model with an adjusted coefficient of determination (R^2) and based our model selection on the Akaike information criterion (AIC).

We tested for correlated evolution between dichotomized (binary) versions of AHFA and PMR using Pagel's (Pagel 1994) test for correlated evolution as implemented in the *fitPagel* function of the R package *phytools* (Revell 2012). Pagel's method assumes a correlation between two binary traits when the dependent, eight-parameter model, in which the probability of change in one trait depends on the state of the other trait, fits the data better that the independent, four-parameter model, in which evolution in each character is independent of the state of the other character. A goodness-of-fit test based on a likelihood ratio was used to compare log likelihoods of the two models.

3.3. Results

All independent variables showed a relatively low but non-random phylogenetic signal (Table 3.2). The dependent variable AHFA displayed an effectively random phylogenetic structure ($\lambda = 0.103$, $p = 0.269$).

***Table 3.2**. Phylogenetic signal of study variables.*

Variable	Phylogenetic signal	p-value
AHFA (ord)	λ = 0.103	0.269
PMR (ord)	λ = 0.139	0.031*
Agriculture	D = 0.383	< 0.001*
Settlement	D = 0.732	0.037*
Material	D = 0.767	0.037*

Pagel's λ for continuous variables (λ values are between 0 and 1, where 0 indicates no phylogenetic signal) and Fritz and Purvis's D for binary variables (D values are also between 0 and 1, but with 1 indicating no phylogenetic signal.); $p \leq 0.05$ indicates that we can reject the "random distribution" hypothesis.

The ML reconstruction of ancestral states (Fig. 3.2) indicates that the last common ancestor of sample societies had very small houses (11.7 m^2) and was patrilocal (point estimate 0.3 on a scale from 0 to 5). There is a general tendency towards an increase in AHFA. Dwelling size has decreased in only a few lineages (e.g. aboriginal Australians, populations of Patagonia and Tierra del Fuego, and Maori people in New Zealand; Fig. 3.2A). The reconstruction indicates multiple independent increases in AHFA in societies that shifted towards a more flexible (ambi-/neolocal) post-marital residence pattern and towards matrilocality in North and South America and in East Asia (Fig. 3.2B).

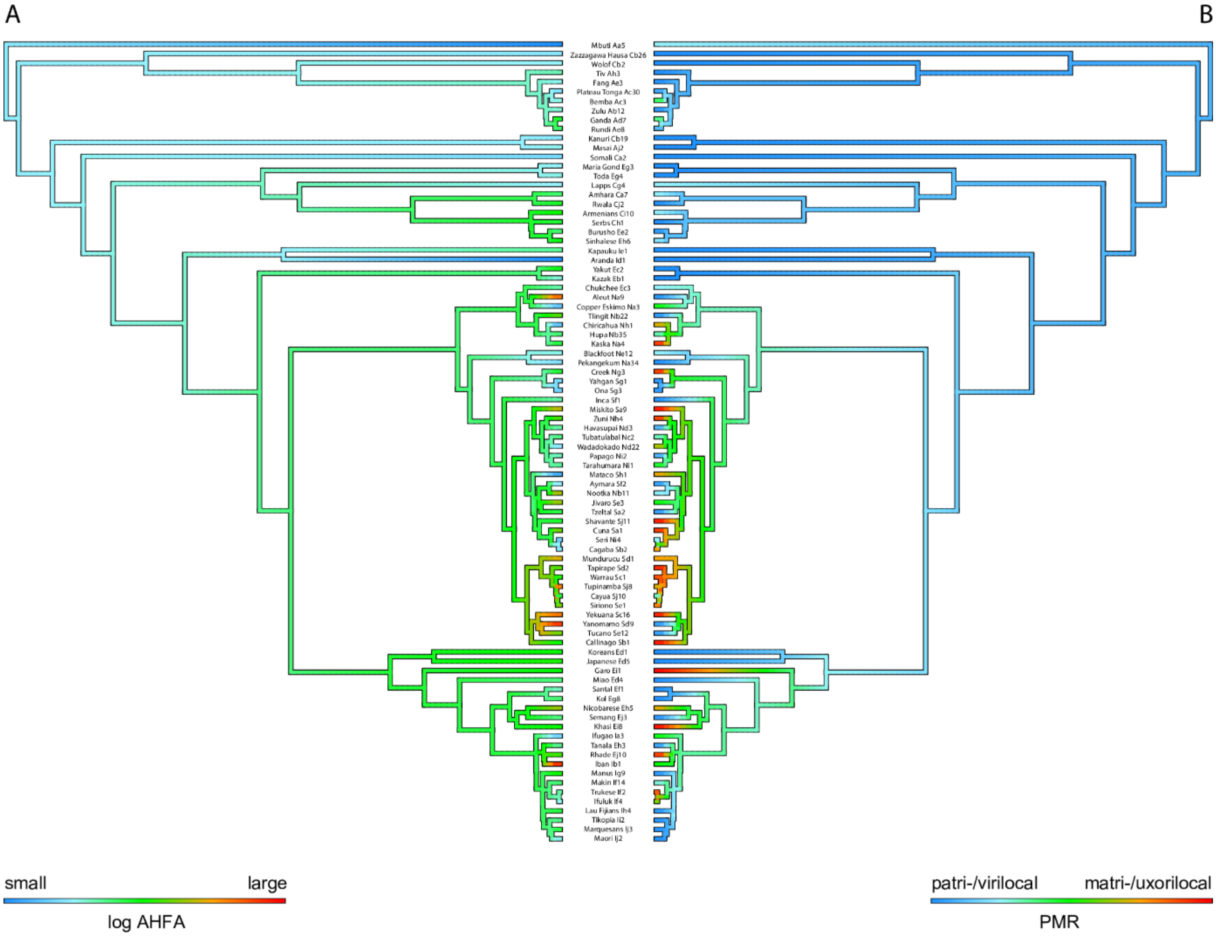

Fig. 3.2. *The evolution of (A) AHFA and (B) PMR across the phylogeny. Colors of internal branches correspond to the inferred ancestral state based on maximum likelihood reconstruction of ancestral states in the R package phytools.*

AHFA and PMR are significantly positively associated according to the PGLS analysis (Fig. 3.3A, Table 3.3). The same result is obtained when a binary version of PMR is used, which is more comparable to the previous study by Porčić (2010); however, both p and adjusted R^2 values are lower. The five-state continuous trait explains about 10% of the total variance in AHFA. AHFA also shows a positive association with agriculture, but only when the binary version of the trait is used (Table 3.3). The association between AHFA and agriculture loses significance once fixity of settlement is taken into account. The settlement is the single best predictor of AHFA (Fig. 3.3B, Table 3.3), explaining about 16% of the total variance. The single best model (with highest R^2 and lowest AIC) is the one that combines AHFA and PMR with settlement (Table 3.3). Construction material is not significantly associated with AHFA.

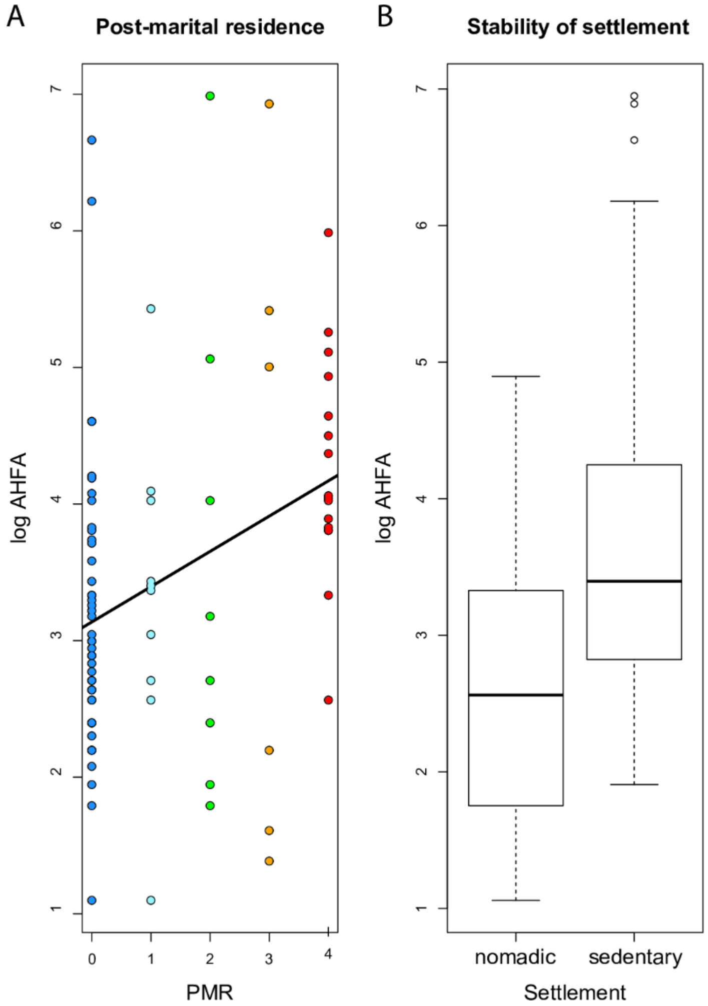

Fig. 3.3. *The association between (A) AHFA and PMR and (B) AHFA and settlement. The color coding for PMR states corresponds to Fig. 3.1.*

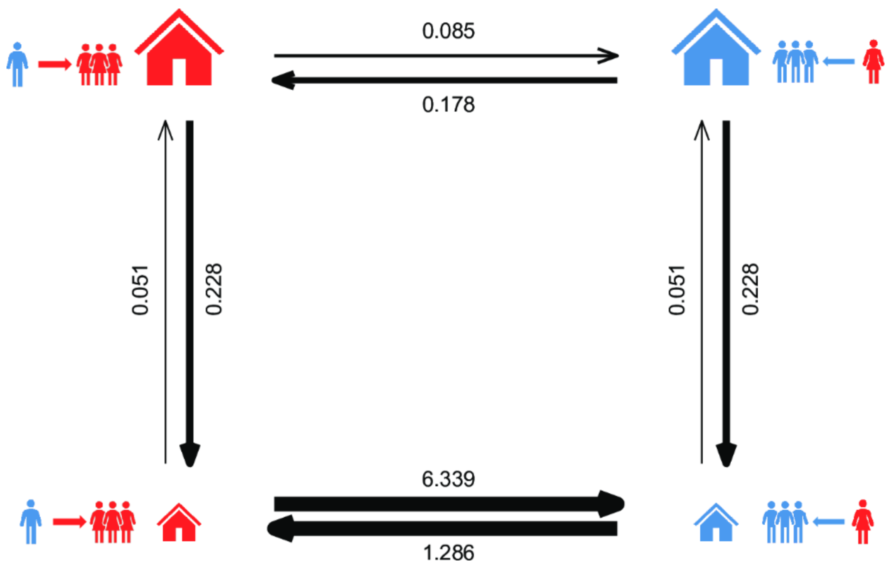

Fig. 3.4. *Transition rate matrix for the correlated evolution between AHFA (dependent variable) and PMR. Widths of arrows are proportional to rates of change.*

Table 3.3. *Model comparison for AHFA. Models include different explanatory variables, differently coded variables, different combination of variables, and phylogenetic control.*

Model	**p-value (F-statistic)**	**Adjusted R^2**	**AIC**
AHFA~PMR (ord)	0.002*	0.097	275.8615
AHFA~PMR (bin)	0.004*	0.086	276.9319
AHFA~Agriculture (bin)	0.003*	0.085	275.8165
AHFA~Agriculture (ord)	0.328	0.000	283.4568
AHFA~Settlement	< 0.001*	0.163	268.1564
AHFA~Material	0.091	0.022	281.5124
AHFA~PMR (ord) + Settlement	< 0.001*	0.235	261.7224
AHFA~PMR (ord) + Settlement + Agriculture (bin)	< 0.001*	0.235	263.4807
AHFA~PMR (ord) + Settlement + Material	< 0.001*	0.239	263.0849
AHFA~PMR (ord) + Agriculture (bin) + Settlement + Material	< 0.001*	0.231	264.8841

Table 3.4. *Model comparison for the evolution of AHFA and PMR based on Pagel's test for correlated evolution.*

Model	**Log-likelihood**	**Likelihood ratio**	**p-value**	**AIC**	**wAIC**
Independent	-93.48	-	-	196.99	0.005
Both dep.	-86.67	15.64	0.003	189.34	0.264
AHFA dep.	-89.73	9.51	0.008	191.47	0.091
PMR dep.	-87.79	13.40	0.001	187.58	0.637

The test for correlated evolution indicates that AHFA and PMR are indeed correlated on phylogeny ($p < 0.001$). The model with PMR as a dependent variable provides the best fit to the data (Fig. 3.4, Table 3.4.), indicating that the change in house size precedes the change in residence. The combination of small house and patrilocal residence is both the ancestral state and evolutionarily the most stable state. The combination of large houses and patrilocal residence as well as small houses with matrilocal residence are evolutionarily unstable, resulting in a change of house size or a change of post-marital residence rule. It is rare for a matrilocal society with large houses to transition directly to patrilocality; decreases of house size are more common in matrilocal societies and these are generally followed by the transition to patrilocal residence (Fig. 3.4).

3.4. Discussion

3.4.1. Cross-cultural association between matrilocality and house size

Post-marital residence is not an isolated aspect of human social organization but is closely tied to other social structures. Societies with larger houses tend to be matrilocal (although very large dwellings can be associated with any type of residence pattern). The association remains significant even when the historical relatedness of sampled societies is controlled for and multiple explanatory variables are included in the model.

In contrast to previous studies (Brown 1987; Divale 1977; Ember 1973; Porčić 2010), we applied phylogenetic comparative methods. The previous sample compiled by Porčić (2010) was geographically imbalanced, consisting mainly of closely related American societies that shared a common ancestor no more than 16,000 years ago (Llamas et al. 2016). Our results confirm that these societies are indeed not statistically independent. In our study, all variables except AHFA showed a non-random (although relatively low) phylogenetic signal.

In our sample, although AHFA had a globally random phylogenetic structure, a detailed view at the local level showed that closely related populations often built similar dwellings. For example, there were several regional architectonic traditions of large houses in North America. Longhouses were typical for Iroquoian cultural groups (Kapches 2007), circular earth-covered lodges were known from tribes of the Plains (Linton 1924), and hardwood plankhouses could be found among hunter-gatherers on the Northwest Coast (Stewart 1984). Three studied South American Tupi-Guaraní populations, namely Mundurucu (Murphy 1960), Tapirape (Wagley and Galvão 1948), and Tupinamba (Métraux 1948b), also lived in similar dwellings: large rectangular houses with walls made of bark or palm leaves, arranged around a central village plaza.

The single best predictor of AHFA is the fixity of settlement (Table 3.3, Fig. 3.3B); mobile populations prefer to live in small, easy to build houses. Agriculture, when coded as a binary trait ("not important" or "important"), was found to have a positive association with AHFA, as has been previously documented (Porčić 2010), but this association loses significance once the fixity of settlement is included into the model. Although it is true that "the presence or absence of agriculture should be less difficult to infer archaeologically than mobility patterns" (Porčić 2010: 408), both traits are not in perfect correlation. While the majority of pastoralists and hunter-gatherers are indeed quite mobile, foragers subsisting predominantly on fishing are more sedentary (Marlowe 2005), such as those of the northwest coast of North America living partially or fully sedentarily in large houses (Ames 1994).

Construction material was not found to be significantly associated with AHFA. This can be partially explained by a less than ideal choice of variable to represent durability of house construction material in our study. For example, in houses with framed constructions, framing material is a much better indicator than wall material (e.g. long houses of Tupinamba, which were occupied for several years, were made of palm thatch on a wooden frame; Métraux 1948b). Unfortunately, framing material is not coded in *Ethnographic Atlas* (Murdock 1967) or *D-PLACE* (Kirby et al. 2016). Nevertheless, the architectural tradition of large houses might be influenced by the availability and quality of building materials. For example, "ironwood" was essential for longhouses of Borneo (Metcalf 2010), cedar wood for Pacific Northwest plank houses (Stewart 1984), and the long leaves of the motacú palm for the simple but quite large dwellings of the Siriono people (Holmberg 1950).

Previous studies (Brown 1987; Divale 1977; Ember 1973; Porčić 2010) documented the correlation between dwelling size and post-marital residence; our results are in support of their findings (Fig. 3.3A). Large houses usually indicate large households and these might be preferentially occupied by married sisters rather than non-sisters (Ember 1973). This argument is based on the finding that in polygynous societies, sororal co-wives usually live together in the same house, while nonsororal co-wives tend to live in separate houses, or at least in separate apartments of the large dwelling (Murdock 1949: 30-31). Instability of households where brothers and their spouses co-reside (so-called patrilocal joint families) was also documented, for example, in India (Lamphere 1974: 106) or pre-revolutionary China (Harrell 1999: 402-403). In both cases, co-resident nuclear families usually broke up after the death of the father; the division was often accelerated by quarrels between wives. On the other hand, even sisters are not immune to verbal and physical aggression towards each other. Cross-cultural survey found that sisters are often aggressive towards each other in eight percent of societies, and probably in additional eight percent of societies when they are co-wives, while aggression between sisters-in-law is not substantially higher, in 14 percent of societies (Burbank 1987).

Another, not necessary competing, explanation is that large households improve the integration of unrelated brothers-in-law into a matrilocal community (Divale 1977). It might also be true that traditional residence typologies do not reflect the true complexities of ethnographic variation (see below). In some of the so-called matrilocal societies, men and women spend more time with their kin at different community levels; for example, while men spend more time with kin at the village level, possibly to facilitate male alliances, women spend more time with kin at the extended household level, possibly to facilitate allomaternal care (Walker 2015).

Notably, societies with very large AHFA (over ca. 200 m^2) were not associated with any particular type of residence. There are seven such societies in our sample. Three of them are patrilocal or predominantly patrilocal (Aleut, Nootka, Yanomamo), three are matrilocal or predominantly matrilocal (Makitare, Mundurucu, Tupinamba), and one is ambilocal (Iban). All of these were sedentary populations, but with different subsistence economies. The majority of them practiced extensive or shifting agriculture, although Aleut and Nootka were hunter-fisher-gatherers. None of them kept cattle, and only the Iban kept pigs (but note the cattle-keeping Miskito with the eighth largest AHFA in the sample, just below the 200 m^2 boundary). Except for Iban and Aleut, all societies with very large dwellings are from North or South America. Out of the 16 societies with known AHFA that were not included in the phylogeny (see Table A in S1 Supplementary material), an additional four societies, all from North America, lived in dwellings with an AHFA of over 200 m^2; three are matrilocal (Huron, Iroquois, Pawnee) and one is ambi-patrilocal (Bellacoola).

These examples show that the relationship between house size and post-marital residence is not straightforward and some other factors might influence household composition than those suggested above. In societies with very large houses, one household usually consisted of multiple families, for example, up to 30 in Tupinamba (Métraux 1948b), up to 40 in Aleut (Veniaminov 1840), or up to 50 in Iban (Freeman 1958), and it can be assumed that such large units were more resistant to dissolution due to disputes between individuals, than smaller households consisting of only two or three families. In a larger household, there were more mediators and authorities who could settle a dispute. Moreover, leaving of one family did not led to disintegration of the entire household.

The best model combined AHFA, settlement and PMR (Table 3.3). Smaller houses are associated with a migratory lifestyle and patrilocal residence, while large houses are typical for matrilocal sedentary societies. However, it is difficult to establish causality. Does the transition to matrilocality lead to larger dwellings, or does the increase in dwelling size lead to changes in the rule of residence? Divale's (1977) argumentation, i.e. that the function of large households is to enhance trust and cooperation between unrelated brothers-in-law, suggests the former possibility. Ember (1973) argues that large houses are preferentially occupied by women and their kin, indicating the latter. Our global phylogenetic analysis seems to support Ember's argumentation. Pagel's test for correlated evolution, based on binary traits, indicates that the increase of dwelling size is followed by transition to matrilocality, rather than *vice versa* (Fig. 3.4). However, these results must be interpreted with caution. The dichotomization of continuous traits comes with a loss of information. The dependence of PMR on AHFA could be partially explained by the inability to reconstruct ancestral PMR unambiguously in deeper nodes. That said, the reconstruction of ancestral states based on continuous traits also indicates that the AHFA increased before multiple independent transitions to matrilocality occurred. The reconstruction indicates that the last common ancestor lived in very small houses (ca. 12 m^2, close to dwelling size in African societies in our sample, such as Bemba, Fang, Masai, or Wolof). AHFA has increased steadily throughout history, regardless of social organization.

There is probably no universal explanation for the change in the dwellings size and/or in post-marital residence rules. It has been proposed that changes in post-marital residence rules can be initiated by migration (Divale 1974), depopulation (Ember and Ember 1972), or the emergence of commercialization (Ember 1967). A non-matrilocal residence is predicted by a very low female contribution to subsistence (Korotayev 2003) or by internal (rather than purely external) warfare (Ember 1974; Ember and Ember 1971). Other crucial factors can include the presence of alienable property and paternity uncertainty (Holden et al. 2003). Matrilineal and matrilocal social structures are negatively correlated with intensive agriculture (Aberlee 1961; Surowiec et al. 2019) and heritable forms of wealth (e.g. land, money, slaves or large domestic animals; Aberlee 1961; Holden and Mace 2003; Murdock 1949; Surowiec et al. 2019) in addition to lower levels of paternity confidence (Flinn 1981; Hartung 1985). Specifically, in lowland South American societies, matrilocality often co-occurs with belief in partible paternity, i.e. that more than one biological father can contribute to the formation of a fetus (Walker et al. 2010).

3.4.2. Reconstructing post-marital residence patterns in prehistoric societies: limitations of phylogenetic cross-cultural analyses

Our results suggest that average house floor area can be used as a proxy for post-marital residence pattern in prehistoric societies. However, before we start hypothesizing about post-marital residence in particular society, we must consider the limitations of cross-cultural studies.

This study, as well as previous analyses (Brown 1987; Divale 1977; Ember 1973; Porčić 2010), depend on data from ethnographic literature, which primary focus is usually not the size of dwellings or post-marital residence patterns. References to these cultural traits are often anecdotal and not resulting from empirical research. Data in large ethnographic databases (such as D-PLACE; Kirby et al. 2016) ordinarily capture each culture at a particular time (and location), making backward verification difficult. The sizes of dwellings can be re-examined archaeologically in some areas, but regarding post-marital residence, one must rely on the original ethnographic records. As the Goodenough-Fischer controversy on the Trukese marital residence demonstrated, ethnographers' conclusions can be sometimes contradictory, even when researchers compile a house to house censuses (Allen and Richardson 1971).

Using AHFA as a predictor variable is practical from an analytical perspective, but it sometimes simplifies the real situation. The range of house floor area can be wide, especially among societies with large houses, e.g. 70–900 m^2 among Aleut (Lantis 1970), 20–110 m^2 (exceptionally more than 900 m^2) among Garo (Burling 1963; Playfair 1909), and 100–500 m^2 among Tucano (Fulop 1954; Goldman 1963; Silva 1962). It is usually the case that no data are available on differences in household composition between the smallest and largest households in these societies, and it is not clear whether house size can affect post-marital residence within a population. It is also important to consider how much the size of a house reflects the size of a household. For example, a residential building does not necessarily represent a single space, whether in functional or social contexts. It can be divided into several apartments (e.g. in Iban longhouses; Freeman 1958) or it can include non-residential parts (e.g. stables in German hall houses; Baumgarten 1976). Some residential dwellings (e.g. those belonging to community leaders) can serve multiple functions, for example, as a storage area or as a venue for council meetings, feasts, ceremonies and other social gatherings. Furthermore, the house does not need to be inhabited by a nuclear or extended family members only. For example, among the Mundurucu, all post-pubescent men, single and married, relaxed and slept in the men's house, while women and children resided in family dwellings (Murphy 1960).

Household wealth differences can also have a substantial impact on the dwelling size (Kohler and Smith 2018; Kohler et al. 2017). Unfortunately, variables describing this factor are missing in ethnographic databases. Although some proxies such as "Social Stratification [SCCS158, SCCS1751]" or "Number of Rich People [SCCS1721]" are available in *D-PLACE*, for using household wealth as control variable in AHFA-PMR analysis, more relevant data based on the deeper review of ethnographic literature are necessary.

The traditional residence typologies (Murdock 1949) are also problematic and have been criticized (Allen and Richardson 1971; Walker 2015; Walker et al. 2013). Many studies, including ours, focus simply on the most frequent or "ideal" residence type of a population in question and ignore intra-community variation. This is useful in cross-cultural comparisons but can be misleading when reconstructing actual residence patterns of prehistoric societies. First, there are often considerable differences between residence rules and actual practices within a community (Allen and Richardson 1971; Barnes 1960). Secondly, a couple often changes residence during their marriage, especially after one or more children are born (resulting in temporary matrilocal residence). Taking primary and alternative residence in later years together with residence in the first years of the marriage into account, Marlowe (2004) concluded that majority of foragers (74%), as well as non-foragers (61%), were multilocal in the strict sense. Thirdly, residential rules apply differently to different community members. For example, in many matrilocal societies in Amazonia, chiefs and their sons usually resided patrilocally (Castro 1992: 375), and thus lived with more close kin than non-headmen (Walker et al. 2013). Similarly, among Garo living in northeastern India, multiple residence patterns were present, which were all vital to Garo social structure. As Burling (1963: 215-216) puts it: “Some men must move in with their wives’ families, while others must set up new households. Some men must move to their wives’ villages, while others must bring their wives to their own villages. […] Since it is not possible to say that any particular residence pattern is ‘preferred,’ it is unreasonable to demand that their custom be summed up by any such simple term as ‘matrilocal’.”

Lastly, with all cross-cultural studies based on ethnographic data, one needs to keep in mind that only a few studied societies were completely unaffected by colonialism or contact with modern civilization at the time of their description (Ember and Ember 1995). Most societies were exposed to various forms of cultural contact (e.g. epidemic diseases, the presence of missionaries, or trade with Westerners). These might have caused pacification, depopulation, changes in subsistence strategies or changes to social structure, including post-marital residence patterns or house size. It has been previously suggested that emergence of neolocality might have been caused by commercial exchange and industrialization (Ember 1967), while ambilocality is often a result of depopulation (Ember and Ember 1972). On the other hand, neither prehistoric nor historical societies lived in complete isolation. Imported artefacts were common in almost every archaeological culture and recent evidence for plague in the Bronze Age in Eurasia (Rasmussen et al. 2015) indicates that serious depopulations were not uncommon in pre-state societies.

3.5. Conclusion

Our analysis confirms the cross-cultural association between house size and post-marital residence. Societies with larger dwellings tend to be matrilocal (compared to societies with smaller dwellings tending towards patrilocality). This association applies to broad range of post-marital residence patterns (not only to strictly matrilocal or patrilocal residence) and remains significant after controlling for other explanatory variables (agriculture, fixity of settlement, and construction material) and phylogeny. The effect of agriculture on dwelling size seems to be a by-product of the effect of fixity of settlement.

Further research is needed to evaluate the effect of other factors on house size, such as differences in household wealth, sociopolitical organization, functional differences in dwelling use, or western influence. Future research could also focus on distinction between residence in the husband's or the wife's parents' dwelling (patrilocal and matrilocal) and residence within the husband's or the wife's community (virilocal and uxorilocal). Comparing the dwelling size with other measures of residence, such as Helm's measure (i.e. the relative number of co-residing primary kin living with men versus women; Helm 1965), could provide additional insight.

Our results suggest that average house floor area can be used as a material proxy for inferring post-marital residence patterns in prehistoric societies. That said, we agree with previous suggestions that "floor area alone should probably never be used as the sole index of residence" (Divale 1977: 114) and that the correlations found "should only be used as working hypotheses to be tested with other lines of data" (Porčić 2010: 420). Such data can be acquired using bioarchaeological methods (e.g. strontium and oxygen isotope or ancient DNA analyses) whose application in archaeological research has grown exponentially in recent years. Still, isotopic evidence must be interpreted with caution. Isotope analyses can distinguish mobility between different geological regions, but not within one community or between communities living in regions with similar isotopic signal (Bentley 2006). Interpreting isotope results in the terms of post-marital mobility is not always straightforward, since other types of mobility could lead to the same signal (Furholt 2017). The evidence from cross-cultural and bioarchaeological analyses can complement each other, providing a more elaborated interpretation of the past social reality.

4. CASE STUDY 3. Post-marital residence patterns in LBK: Comparison of different models[4]

4.1. Introduction

Post-marital residence (PMR) is one of the key components of social organization, since it affects social structures in many important ways, including descent systems and kinship terminology (Murdock 1949), modes of marriage (Divale and Harris 1976), wealth inheritance rules (Agarwal 1988; Marlowe 2004), division of labor (Korotayev 2003), community size (Korotayev 2004), migration (Divale 1974) and warfare (Ember 1974). The decision on who leaves their own kin and moves to the spouse's community is also crucial for developing and maintaining regional social networks such as intra-community alliances and exchange ties (Mauss 1990). Unfortunately, the identification of post-marital residence patterns in preliterate societies is complicated as they leave almost no direct traces in the archaeological record. Scholars thus attempt to use various proxies, which, however, often lead to different conclusions.

In the case of the Linear Pottery culture (*Linearbandkeramik*, LBK), the archaeological culture of the first farmers in the European temperate zone (ca. 5500–4900 cal BC, Fig. 4.1), many ideas about post-marital residence rules have been proposed on the basis of different approaches. Soudský (1962: 198; 1966: 55) suggested that matrilocality (husband moves to wife's group) and matrilineal kin relations were characteristic of Linear Pottery populations based on predominantly female fingerprints found on the ceramics and the distribution of different ceramic motifs. Contrarily, van de Velde (1979a: 148-149, 165-168; 1979b) suggested patrilocal post-marital residence (wife moves to husband's group) together with a matrilineal line of descent based on ceramic analyses from the sites of Elsloo and Hienheim. Other researchers (Eisenhauer 2003a: 561; 2003b: 322; Strien 2000: 33) also concluded that patrilocality was more probable due to a large uniformity of ceramic production across the LBK which presupposes great mobility of female potters and regional variability of chipped stone artefacts most likely produced by less mobile men. The analysis of grave goods was used as another type of evidence for the rejection of matrilocality (Pavúk 1972: 73). Lower status of grave goods in female burials and the prevalence of prestigious spondylus jewelry in male and children's graves, however, did not convince Podborský (2002a: 254; 2002b: 335), who still

[4] This case study has been written together with Petr Květina and Václav Vondrovský. The manuscript has been submitted to Journal of Anthropological Archaeology in March 2020. All co-authors have agreed to use the article as part of this Ph.D. thesis.

adhered to the earlier view of matrilocality and matrilineality and the prominent position of women, especially in areas of agricultural production and cult (although he definitely refused matriarchy or gynecocracy). This whole approach, which attempts to infer the type of social organization from the variability or spatial distribution of material culture, however, has long been criticized (e.g. Allen and Richardson 1971; Dumond 1977).

A different kind of evidence has been proposed by cross-cultural researchers. Several studies (Brown 1987; Divale 1977; Ember 1973; Hrnčíř et al. 2020; Porčić 2010) found a correlation between house size and the post-marital residence pattern across different populations. Large houses (with floor area over ca. 65 m^2) indicate matrilocality, while smaller dwellings are more likely found among patrilocal societies. Milisauskas (1986: 217) and Ehrenberg (1989: 94-99) used this as evidence for matrilocality, since most floor plans of LBK longhouses exceed the proposed threshold. Eisenhauer (2003a: 571; 2003b: 326), however, argued that this argument is not valid for LBK houses. According to her view, longhouses served rather as homesteads inhabited by a single (large) family, who occupied only one third of the longhouse while other parts served as storage spaces etc. The actual living space was therefore much smaller than the floor plans would indicate (cf. section *2. Neolithic longhouses and their inhabitants*).

The focus of archaeologists has therefore moved directly to human remains, to morphological and isotopic variation between males and females. Eisenhauer (2003a), for instance, proposed patrilocality for a community buried in a mass grave at Talheim (late LBK, ca. 4900-4800 BC), since the buried men seemed to be more related than women based on tooth morphology. Her hypothesis was later supported by isotopic evidence (Bentley et al. 2008: 302). More recent and extensive strontium isotopic studies (Bentley et al. 2012; Bickle and Whittle 2013) subsequently found greater variability in $^{87}Sr/^{86}Sr$ ratios among females than among males, especially those buried with ground stone adzes. This led the authors to infer patrilocality for LBK society more generally, although alternative interpretations of the patterns have also been proposed (Bentley et al. 2012: 9329).

Currently, patrilocality is the most prevalent hypothesis. Besides isotopic analyses, it has been supported by modern DNA (Cavalli-Sforza and Minch 1997; Rasteiro et al. 2012; Seielstad et al. 1998), ancient DNA (Lacan et al. 2011; Szécsényi-Nagy et al. 2015), linguistic (Fortunato and Jordan 2010) and anthropological evidence (Holden and Mace 2003; Holden et al. 2003). All of these methods, nevertheless, have their limitations.

Although the results of genetic model approaches (e.g. Cavalli-Sforza and Minch 1997; Rasteiro et al. 2012; Rasteiro and Chikhi 2013) cannot be simply rejected, they were based primarily on present-day DNA distributions, which is problematic since many post-Neolithic demographic events greatly modified the genetic pool of modern populations (e.g. Reich 2018). Results of aDNA analysis of individuals buried in Cave I of Treilles, southern France (Lacan et al. 2011), indicating close parental relationships within the necropolis and therefore patrilocality, should also be taken with caution because they come from a much later archaeological context (3000 BC). The same goes with the results of phylogenetic comparative analysis of marital residence in Indo-European societies (Fortunato 2011; Fortunato and Jordan 2010) indicating that Proto-Indo-Europeans were patrilocal. As the recent genetic (Haak et al. 2015) and linguistic studies (Anthony and Ringe 2015) suggest, Indo-European people migrated to Central Europe from the Pontic-Caspian steppes during the Late Neolithic (around 2500 BC), more than two thousand years after the LBK. The differences observed in genetic diversity between males and females in a larger aDNA sample from Neolithic Europe (Szécsényi-Nagy et al. 2015; Szécsényi-Nagy et al. 2014) is more relevant evidence for patrilocality in the LBK. However, as researchers admit, the variation could be influenced by resolution biases or explained by other cultural factors, e.g. polygyny or male-biased adult mortality (Szécsényi-Nagy et al. 2015: 7).

Another type of supportive evidence for patrilocality in the LBK was the ethnographic association between livestock ownership (archaeologically well documented in this period; e.g. Gillis et al. 2017; Kovačikova et al. 2012) and patrilineality (Hedges et al. 2013: 368). Aberle's (1961) cross-cultural study showed that matrilineal descent is negatively correlated with large domestic animals, such as cattle, and positively associated with horticulture (i.e. agriculture without plough) at the same time. In his words, "*cow is the enemy of matriliny, and the friend of patriliny*" (Aberlee 1961: 680). His finding has been confirmed for Bantu-speaking cultures in Africa, where the adoption of cattle led to the loss of matrilineal descent in favor of mixed or patrilineal kinship (Holden and Mace 2003). Explanations have been proposed via the daughter-biased investment hypothesis (Holden et al. 2003). Since cattle are a heritable resource from which sons may benefit significantly more than daughters (cattle require defense against raiders, may be used for bride-price and may allow men to support several wives), they are more likely to be passed on through patriliny. In contrast, land inheritance in horticultural societies may benefit sons and daughters equally, and therefore matriliny is more frequent. Like in the case of the house size (Hrnčíř et al. 2020), however, the association is not absolute and "*all types of cultural transition involving the gain and loss of matriliny and cattle occur*" (Holden and Mace 2003: 2432).

The main shortcoming of the mentioned studies is their predominant focus on the simple dichotomy of patrilocality versus matrilocality. While the two categories are the most widespread post-marital residence patterns in traditional societies (Murdock 1967), much more variability exists, even among agricultural societies where the residence is generally less fluid than among foragers (Marlowe 2004). The aim of this paper is to present several different anthropological models based on ethnographic examples and discuss which of them could best fit the current knowledge about LBK society. In the first part, we summarize the current state of knowledge of LBK households and re-open discussion about the use of the house size as a proxy for inferring post-marital residence in European Neolithic. In the second part, we present several anthropological examples of societies with large houses and different post-marital residence patterns. Finally, we compare these models with the results of strontium isotope analyses from two LBK cemeteries: Vedrovice (Czechia) and Nitra (Slovakia).

4.2. Neolithic longhouses and their inhabitants

Longhouses are typical dwellings of the LBK and the subsequent archaeological cultures (Post-LBK, first half of the 5th millennium BC) such as the Stroked Pottery culture, Lengyel culture, Großgartach culture and Rössen culture (Coudart 1989). The geographical spread of these cultures and of longhouses was throughout Central Europe, from the Paris Basin in the west to Ukraine in the east (Fig. 4.1). LBK longhouses probably developed in the Carpathian Basin, specifically in western Hungary (Transdanubia) around 5500 cal BC, during the late Starčevo period (Bánffy 2013). The exact reasons why people started to build such large dwellings are unclear. Two main causes were proposed: 1) environmental (colder and wetter climate than in southern Europe where the first farmers came from) and 2) cultural (shared new identity, prestige, domestication of society; Bánffy 2013; Borić 2008; Hodder 1990).

LBK longhouses are archaeologically characterized by a five-row post construction, a rectangular to trapezoidal shape, a considerable length and a similar orientation towards the south or south-east. The length was relatively variable, from 10 to 45 meters, while the width was more uniform, between five and seven meters. Based on a dataset comprising 466 ground plans from 69 sites, the average house floor area was 119 m^2, with a median value of 104 m^2 (Fig. 4.2, S2 Supplementary Material). The house size seems to be similar across all three main phases of the LBK culture, although classic and late LBK show more varied values than early LBK houses (Fig. 4.3; S2 Supplementary Material). Other house features have not been preserved and their reconstruction is less clear.

The primary building material for the wooden posts was probably oak (Startin 1978). The walls were most likely made of wattle and daub, but the use of planks cannot be excluded in some parts of the wall (with a trench). The roof was probably gabled with a slope of about 45°, based on clay models and in view of the climatic conditions in the European temperate zone. The roofing material remains unclear. While earlier works assumed reed or straw thatch (Startin 1978), the use of wooden boards was also possible (Pavlů and Vavrečka 2012).

Floors are found very rarely (cf. Končelová and Květina 2015: 432). The possible reasons include the destruction of the surface by erosion (Whittle 1996: 163) or the fact that the floors were raised above the surrounding terrain. The hypothesis of raised floors is supported by the fact that the houses often stood on sloped terrain and that the climate during the LBK was more humid than it is today (Rück 2009). Moreover, a raised floor would provide better protection against enemies, the free space beneath the floor could serve as shelter for domestic animals or for storage, and household waste could end up there (Květina and Hrnčíř 2013). A similarly unresolved question is the existence of a second floor. While some researchers assume a second floor only in the front section, serving only as a granary (e.g. Coudart 2015), others do not rule out the presence of a residential second floor across the whole house (Czerniak 2016).

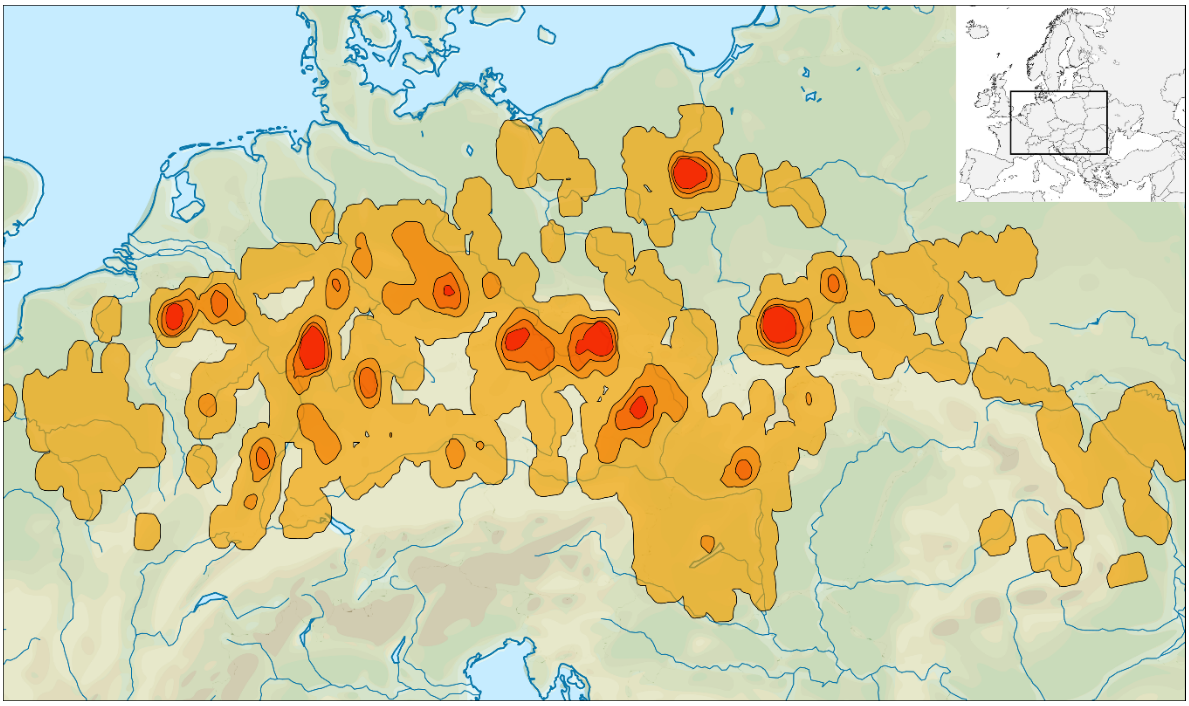

Fig. 4. 1. *Map of LBK distribution. Density mapping based on the data collected by the OBRESOC project (ANR-09-CEP-004). Background map of Europe by User:Dbachmann, Wikimedia Commons, distributed under a CC BY-SA 4.0 license.*

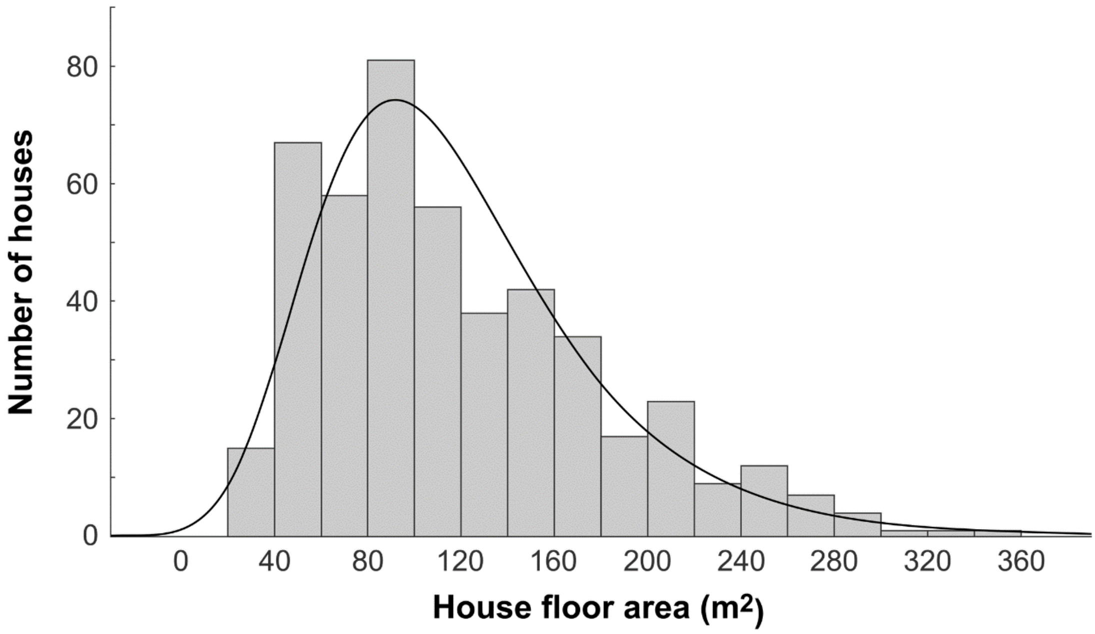

Fig. 4.2. *Histogram for the floor area in the analysed dataset (n=466).*

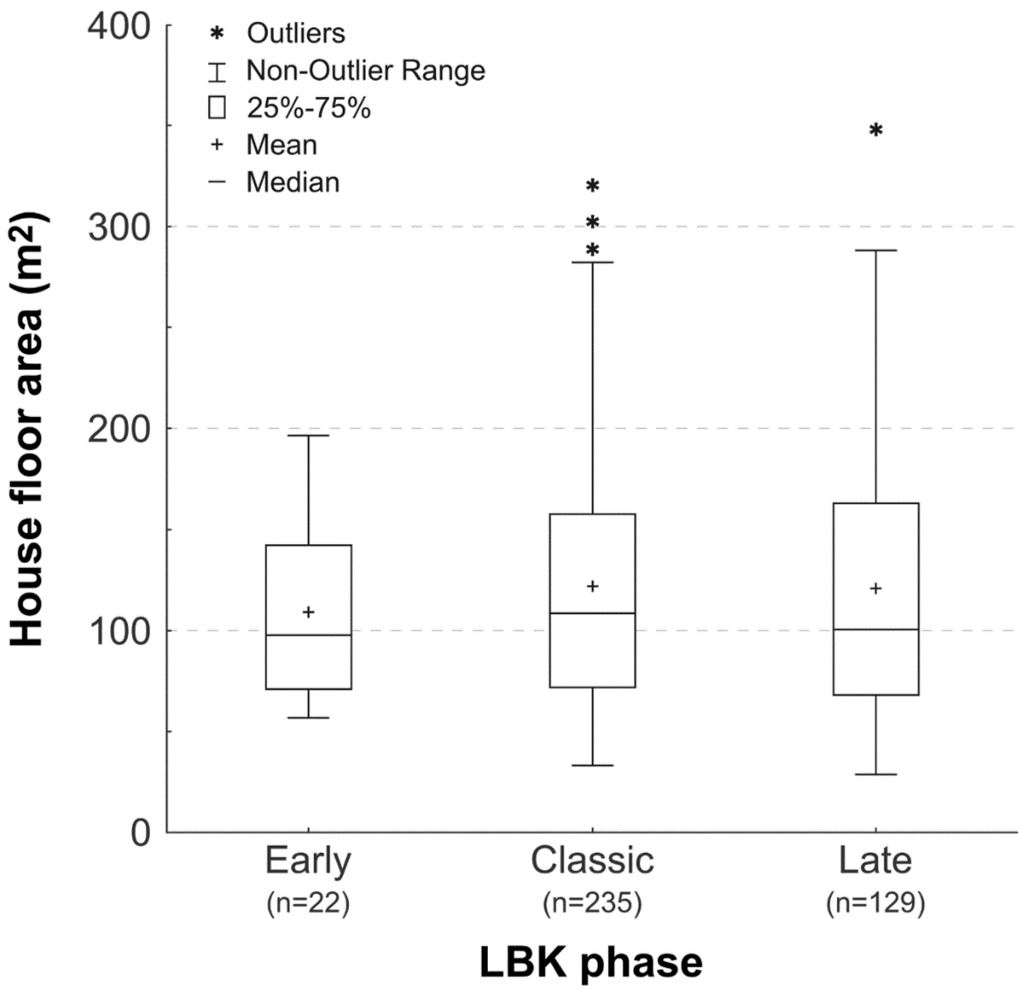

Fig. 4.3. *Variability of the floor area in different phases of the LBK culture. Only reliably dated houses are included (n=386).*

The basic typology of LBK houses was introduced by Modderman (1970, 1988), who divided longhouses into mono-, bi- and tripartite types based on the presence or absence of three distinct sections of the ground plan: the front, middle and rear one. His typology has been later elaborated by Coudart (2015). However, it is not clear whether the different house sections reflect different functions or whether their quantity corresponds to the number of household members. There are also opinions that the individual sections could be added gradually – the house expanded as more generations lived inside (Bradley 2001; Rück 2009); or that the houses could be divided into more than three parts (Czerniak 2018: 407).

It is assumed that the house served for habitation and probably also for food storage. Previous opinion that cattle were housed inside (Modderman 1970: 110) has not been supported by phosphate analyzes (Beneš et al. 2016; Stäuble and Lüning 1999). The storage function is often ascribed to the front part, while the middle part could be residential, and the rear part served for ritual purposes. However, some researchers suggested that the rear part was residential / sleeping (Coudart 2015: 316; Gomart et al. 2015: 245), while others consider it a shrine or mortuary built just before the abandonment of the house (Bradley 2001: 53).

For any analysis of the household economy, it is important to note that it is not clear whether the longhouses were inhabited year-round or only seasonally or for how long they were occupied before abandonment. Lifetime estimates vary significantly, from 20-30 years (Modderman 1970; Stehli 1989) to more than 100 years (Lenneis and Trebsche 2013; Rück 2009; Schmidt et al. 2005). Although the findings from pits near a particular house are usually considered as reflections of activities that took place inside, Květina (2010b) pointed out that the deposited artefacts might have originated also from other households and the filling process could continue well after the building was abandoned. If so, our chronologies and insight into domestic activities might be considerably distorted.

In terms of household size, relatively low figures are often given for such a large building. Five to seven persons are proposed most often (Lüning and Stehli 1989: 117; Stehli 1994: 109; Zimmermann 2003: 27; Zimmermann et al. 2009: 13), with a maximum of 10 or 12 (Modderman 1988: 76-77; van de Velde 1979a: 140). This is because the longhouse is usually regarded as a homestead, with only a small part of the house serving for residential purposes (Eisenhauer 2003a, b). On the other hand, ethnographic parallels suggest that much more people could live under one roof. Cross-culturally, the ratio of the total house floor area to the population size is 6-7 m²/person in sedentary societies (Porčić 2011). Considering the average LBK house floor area of 119 m^2, this leads to 17 to 20 persons. When the standard deviation of above-mentioned ratio (4.82 m²/person) is considered, one gets a much wider range of results: from 10 to 60 people for an average LBK household (cf. Czerniak 2016; Rück 2009: 179-180).

Did house size reflect the number of inhabitants, or did it serve some specific function? Opinions on this issue differ. Pechtl (2009) pointed out that extremely long houses (over 33 meters) were often built in different regions than enclosures. Based on that, he connected both types of monumental architecture with the prestige of their builders, although at different levels (household versus larger community). On the contrary, Czerniak (2018) argued that the length of the house was primarily related to its population and the prestige was only a secondary aspect. His argument is that extremely long houses occurred both within villages and in isolation. Extra-long houses outside villages thus did not necessarily demonstrate an exceptional status of their inhabitants; more probably, they provided more safety to the community and symbolized power towards other groups (e.g. hunter-gatherers). Different house size might also reflect a different economic role of the household within the community (Gomart et al. 2015; Hofmann and Lenneis 2017).

Because many uncertainties regarding the typical LBK household remains, we cannot simply reject cross-cultural findings concerning a correlation between the house size and post-marital residence (most recently Hrnčíř et al. 2020) as Eisenhauer (2003a, b) did. The functions of the different house sections are still unknown, and a hypothesis that extended families occupied LBK longhouses is possible. If larger households were present in the LBK, then, hypothetically, they might have consisted more likely of married sisters than of non-sisters, since the former find it easier to live together than the latter (Ember 1973). Similarly, larger households might improve the trust and every day cooperation between unrelated brothers-in-law and enhance their integration into a matrilocal community (Divale 1977).

4.3. Post-marital residence models

As mentioned above, the post-marital residence pattern in the LBK is most often considered within the patrilocal versus matrilocal dichotomy. Patrilocality or virilocality refers to residence with (patri-) or near (viri-) the husband's kin. Similarly, matrilocality or uxorilocality refers to residence with (matri-) or near (uxo-) the wife's kin.

The division into only two categories is, however, misleading for at least two reasons. First, rather than two categories, both residence patterns are two opposite ends of a wide range consisting of many intermediate stages (Fig. 4.4, Models 1-7). On the one hand, there are societies where absolutely all marriages are governed by the patrilocal rule (Model 1); on the other, societies where all marriages are governed by the matrilocal rule (Model 7). It should be noted that both variants are ideal states and probably no society had such perfect residential patterns in practice, because for every cultural rule there is always an alternative (Harris 1974; see ethnographic examples below). Instead of labeling a society as “patrilocal” or “matrilocal”, it is therefore more accurate to talk about “predominantly patrilocal” (e.g. Models 2-3), “predominantly matrilocal” (Models 5-6) or ambilocal (the ratios are balanced; Model 4) societies.

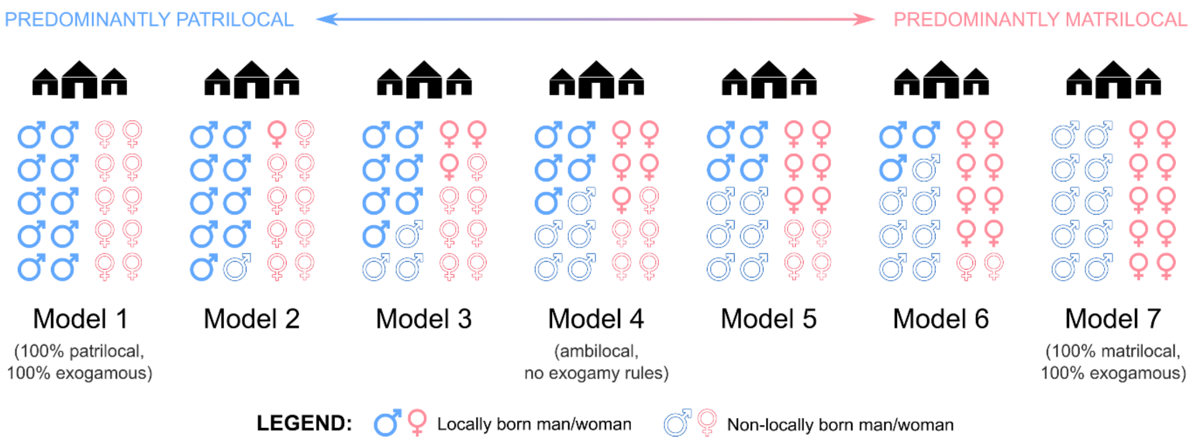

Fig. 4.4. *Different post-marital residence models on the patrilocal-matrilocal scale. Each symbol indicates 10% of male/female married population.*

Second, there are other types of post-marital residence beyond the patrilocal-matrilocal scale. These include, for instance, neolocality (the couple establish a new household separate from their respective families), avunculocality (the couple live in the household of the husband’s uncle), shifting residence (people frequently move from one house group to another without any strict rules) or natalocality (the husband and wife live apart, both residing with their natal families). Although these alternatives are usually not the predominant types of post-marital residence, their possible presence in society makes the overall residential pattern much more complex.

In the following section, we present several examples of ethnographic societies with different residential patterns that could be useful in the discussion of post-marital residence not only in the LBK but also in other prehistoric societies. It should be noted that this small sample certainly does not represent the full range of possible residential patterns. The main criterion for the selection was the uniqueness of the residential pattern and the completeness of the description of post-marital rules. A secondary criterion was the average dwelling size in the society, since several studies have shown that this cultural element correlates significantly with post-marital residence (see *Introduction* section). As the size of early Neolithic houses was usually between 70 and 150 m^2 (Figs. 4.2-4.3), societies with similarly large dwellings were preferred.

The aim is not to find the most accurate ethnographic analogy that would correspond to the LBK in all respects. The presented examples differ significantly from Early Neolithic society, not only in geographical location and environment but also in subsistence, the settlement pattern, technology or social organization. The examples serve primarily to illustrate the variability and complexity of post-marital residential rules.

4.3.1. Patrilocal residence – Tucano

An ethnographic example of a patrilocal society with large dwellings are the Tucano (or Tukano) people from the Vaupés region in northwestern Amazon (Arhem 1981; Goldman 1963; Silva 1962). The term refers to a group of several tribes speaking different languages who are often considered a single socio-cultural unit due to a high degree of intermarriage. The Tucano subsisted on many different seasonal resources and their activities included fishing, hunting, gathering and horticulture. Animal husbandry (chicken and pigs) played a minimal role in their subsistence. All community members usually belonged to the same patrilineal kin group (sib), which was exogamous. The tradition of the localized sibs usually resulted in community exogamy, but this was not a law. The sibs were hierarchically ordered and grouped into several phratries, which were also exogamous. Another typical feature of most of the Tucano groups was linguistic exogamy (husband and wife were from groups speaking different languages) resulting in a high degree of multilingualism. There was no strong political organization above the level of the sib. Local headmen possessed the highest authority, but even their powers were limited to persuasion.

Traditionally, the whole community lived in a single multi-family dwelling called *maloca*. It was a large rectangular house with a gabled roof and sometimes with an apsidal end. The size of the house varied according to the number of its occupants (from 20 to 100 people). An extended family of 25 or 30 individuals could live in a single 20 by 5 meters large dwelling (Fulop 1954: 102), but much larger *malocas* were documented too (Goldman 1963: 39; Silva 1962: 252, 256). The *maloca's* interior was divided (sometimes only virtually) into several compartments, each occupied by a nuclear family. A *maloca* usually lasted for five to ten years after which a new house was built, usually not far away from the old site.

Marriage between cross-cousins (real or classificatory) was preferred but not obligatory. Residence was predominantly patrilocal, but there were also some matrilocal exceptions.

Marriages were based on the exchange of women between the sibs. As Silva (1962: 619) describes: "*a father will give his daughter as a wife to the son of another family, in order to have a sister of the latter as a wife for his son*." If it was not possible to promise a girl of own family to another family, it was necessary to pay a bride-price or the bridegroom had to perform bride-service (labor for the bride's parents) lasting up to one year in the wife's *maloca*. Most marriages were monogamous, only the headmen generally had more than one wife.

Data about 48 marriages from one Tucano territorial group (Arhem 1981: Table 12) indicate that 92% of marriages were patrilocal and only 8% matrilocal. Taking into account the prevailing community exogamy, this pattern corresponds to Model 2 in Fig. 4.4.

4.3.2. Ambilocal residence – Iban

Ambilocal residence means that there is no tendency for patrilocality or matrilocality; the couple can live with either the wife's or the husband's parents. An example of such residence type are the Iban shifting cultivators from Borneo living in wooden longhouses (Freeman 1955, 1958). Traditionally, they kept chicken and pigs but no cattle. No large-scale unilineal kin groups, such as lineages or clans, were recognized in Iban society. They were mostly egalitarian without centralized political authority. The local headman had a primarily juridical role and his position was not hereditary. He could be the ritual leader of a longhouse as well, but the two positions were usually separate.

Each longhouse (usually 55 to 90 meters long; Freeman, 1958: 16) represented a whole village, a single autonomous community. It stood alone on the riverbank and consisted of a series of independently owned apartments. Each apartment was usually occupied by a three-generation family (average size of about seven members), which represented the basic social and economic unit of Iban society. There were no rules, beliefs or values resulting in either patrilocal or matrilocal residence; they both occurred with almost equal frequency. Similarly, family inheritance rules did not discriminate between the sexes. Whether the wife moved to the apartment of the husband's parents or the other way round was the result of great debate, sometimes lasting for days. As Gomes describes: *"Many matters are taken into consideration in deciding where they [married couple] are to live. If the daughter be an only child, her parents generally make it a condition of marriage, that the son-in-law should come and live with them, and work for them, but where the girl has many brothers and sisters, and the man has not, she is allowed to go and live in his house. Then, again, the question of social standing comes in, and if a girl marries beneath her she refuses to go to the house of her husband, and expects him to come to her"* (Gomes 1911: 122).

Marriages were strictly monogamous and never occurred between members of the same apartment, but the longhouse itself was neither exogamous nor endogamous. Nevertheless, there was a strong preference for marrying within the longhouse community. Approximately half of marriages was intra-longhouse, although there were not so many potential spouses. There was no neolocal residence, but when two nuclear families of siblings happened to live in one apartment, their interests very often diverged, the younger couple subsequently broke away and set up a new residential apartment in the same longhouse (or less often in another longhouse).

Data about 86 marriages from three longhouses (Freeman 1955: 38) show that 51% of marriages were matrilocal and 49% patrilocal. At the same time, 49% of marriages were within the longhouse (village) and 51% outside longhouse. Such pattern is a typical example of ambilocality, corresponding to Model 4 in Fig. 4.4.

4.3.3. Matrilocal and uxorilocal residence – Garo

The Garo people living in subtropical northeastern India (Burling 1963) are a great example of both matrilocal and uxorilocal residence. Traditionally, they were slash-and-burn cultivators, but since the early 20th century, they also practiced permanent wet rice cultivation. They kept chickens, pigs and cattle. Cows were never milked but used only for meat and as sacrificial animals. The Garos were divided into five exogamous matrilineal descent parts ("moieties"), each further divided into numerous smaller matrilineal lineages. Some villages included only one main lineage; others had two local lineages (but always from different moieties). The Garo were a mostly acephalous society. Except for wealth differences, there was no class distinction. One or more village headmen had mostly ceremonial functions, with relatively low authority in other affairs. The headmanship was connected with the household (usually the oldest one) rather than any individual man and was inherited by a son-in-law.

Villages were small, usually containing 10 to 60 bamboo family houses. Burling (1963: 48) states that houses were from 7.5 to 25 meters long and from 2.5 to 4.5 meters wide (i.e., the house floor area ranging between 19 to 112 m2). Nevertheless, Playfair (1909: 37) mentions that houses often exceeded 30 meters in length and even 80 meters long houses were documented. The size of the house reflected the family's economic and social status, but all dwellings were built in a similar way. The typical house was divided into three parts: a special room for the cattle and storage at the front, a large public room in the center and a smaller private sleeping room in the rear. Most of the houses also had a veranda on the side. The private sleeping room was used only by the eldest couple, while other family members slept in the central section (except for young boys who slept in a bachelors' house). The complete household included an old couple, their unmarried children, married daughter (the heiress), her husband and their children. The documented household size was usually smaller, however, ranging from two to eleven members, with an average of five. The house and other property was inherited in the female line. One of the daughters was selected to be the heiress. She was the only child who stayed in the parental home after marriage. All other daughters and boys moved away after their wedding. If the couple had no daughter, they adopted a close relative.

Two distinct types of marriage resulted in two different residential rules. Heir marriages were matrilocal (the couple moved to the wife's parents' house), while non-heir marriages were uxorilocal (non-heiress daughters set up a new house in the same village or even right beside their mother's homes). It is interesting to note that heir marriages were also avunculocal (the couple residing in a maternal uncle's house), since the Garo preferred matrilateral cross-cousin marriages (a man marries the daughter of his mother's brother). Although men always left their parental house, not all of them moved to a different village. Village exogamy was not the rule. A woman could marry a man from the same village if he belonged to a different matrilineal lineage. Under certain circumstances, it was not rare that a woman even moved to the husband's village. Another type of marriage was a replacement marriage, when a widowed man or woman married a new wife or husband. In these cases, the new spouse moved to the house of the widower or widow. Polygynous families existed when a man married a widowed or divorced woman and her true or adopted daughter.

Based on data of 70 married couples from the Rengsanggri village (Burling 1963: Table 1), 83% of married women were raised locally, while 17% came from different villages. Married men were usually from different villages (71%), but some of them were raised locally (29%). Such pattern approximately corresponds to Model 6 in Fig. 4.4.

Regarding the discussion on the complexity of post-marital residence, the following Burling's (1963: 215-216) note should be highlighted: "*All the residence patterns are necessary to Garo kinship structure as it exists today. Some men must move in with their wives' families, while others must set up new households. Some men must move to their wives' villages, while others must bring their wives to their own villages. [...] All residence patterns have their essential part in Garo social structure. [...] Since it is not possible to say that any particular residence pattern is 'preferred', it is unreasonable to demand that their custom be summed up by any such simple term as 'matrilocal'. It would seem inherently futile to force any simple typology of even such a superficially simple phenomenon as residence upon the societies of the world.*"

4.3.4. Matrilocal alternative – Mundurucu

The South American Mundurucu or Wuy Jugu people (Murphy and Murphy 1985) can be briefly mentioned as another example of a predominantly matri-/uxorilocal society. These tropical forest farmers, hunters, fishers and gatherers were originally very aggressive to their neighbors who therefore called them “red ants” (Mundurucu). Each village consisted of two to five large family dwellings and one men’s house, all arranged around a central plaza. All post-pubescent men lived in the latter, while the residential houses were occupied by a group of women and children related in the maternal line. In one of such villages, the proportion of matrilocal and patrilocal marriages has been calculated as 65% to 35% (*ibid*. 147), roughly corresponding to Model 5 in Fig. 4.4. Preferred patrilocal residence of the chief’s sons was only one of many reasons why the real situation differed from the ideal matrilocal rule. As Murphy and Murphy (*ibid*. 147) describe: “*The Mundurucú have a high death rate, and a high divorce rate as well, and most adults have been married at least twice. Children usually stay with their mothers when a marriage is terminated, but when the mother dies the children may stay with the father or in the late mother’s household. The preference for mothers and daughters or for sisters to stay together is indeed strong, but the bride’s mother may be dead, and she may have no living sisters. Under these circumstances, residence with her husband’s people may be the logical alternative.*”

4.3.5. Avunculocal residence – Tlingit

The Tlingit were an indigenous people living along the coastline of southern Alaska, between 55° and 60° north latitude (Krause 1956; Olson 1967). In the late 19th century, they were semi-sedentary fishermen who supplemented their livelihood by hunting and gathering. They lived in villages during the winter, but in the summer, individual clans and families dispersed into their fishing and hunting territories where they lived in simple shelters. The Tlingit were divided into tribes, clans and phratries. The tribes referred to approximately 13 geographical groups which, however, had no formal organization. Maternal clans, grouped into two exogamous phratries (moieties), were more important social groups. The clans were geographically independent; large clans could have houses in several villages. Each house had a house chief, whose office usually passed from uncle to nephew. Beyond the level of household, “clan chiefs” of the village or tribe was recognized, but their power was negligible. Among the Tlingit, there was a strong relationship between the boy and his mother’s brother (maternal uncle), stronger than with his own father. The nephew lived in his uncle’s house from a certain age and inherited from him. Social rank and status differences between individuals and families existed, based on the wealth, titles and achievements. There was, however, no sharp distinction between "nobles" and "commoners". Only slaves, captured in war or obtained through purchase, represented a truly distinct class.

Winter villages were situated on the ocean or river coastline. Smaller settlements were made up of several houses built in one row, while large villages could have up to 60 houses arranged in two rows. Each clan inhabited a separate house (one or more). The construction material for the walls and the gable roofs were wooden planks. The houses had a roughly square ground plan with a floor area around 100 m^2 (Krause 1956: 86), but houses with floor area over 250 m^2 were also known (Emmons 1991: 60-61). Smaller houses had a floor at ground level, but in larger ones, the central area with the hearth was sunken by about one meter. The quarters of the individual families were along the walls. The space between them was not separated by walls but only by various objects. Several families lived in one house. Larger households could contain tens of individuals. All male residents of the house were related by the maternal line (belonged to the same clan and moiety). Women could come from different clans (but always from the opposite moiety than men). The typical household consisted of "*the house chief, his wife, unmarried daughters, sons below eight or ten years of age, and one or more sisters' sons above that age; several brothers of the house chief, their wives, unmarried daughters, small sons, and nephews; the wives and small children of the nephews; aged persons belonging to that house; slaves*" (Olson 1967: 48).

Post-marital residence was ideally avunculocal – the couple lived in the house of the groom's maternal uncle. If he was also the bride's father, which happened often since this type of marriage was preferred, she lived in her natal house for all her life. When the newlyweds came from different villages, the bride usually moved to the husband's house. Marriages were always between different clans and moieties and usually between partners of equal social status. There was also a tendency to clan intermarriages; brothers usually married women who were sisters or clan sisters. Polygyny was common among wealthy men, and polyandry also existed.

Ethnographers did not provide exact numbers and proportions of different residential patterns among the Tlingit, or at least we do not know about any. However, it can be deduced from the descriptions summarized above that most men moved from one house group to another before they reached the age of ten. Women usually moved after marriage, except the case of cross-cousin marriages. If these residential movements took place more often within one village or rather between different villages is not clear.

4.3.6. Shifting residence – Nuu-Chah-Nulth

Shifting residence refers to a system in which people frequently move from one house group to another. Although such residence pattern is more typical of nomadic hunter-gatherers than sedentary agriculturalists, we believe it is still worth mentioning. The Nuu-chah-nulth, formerly referred to as the Nootka, can be mentioned as an example of this residential pattern (Drucker 1951; Koppert 1930). Like the Tlingit, they were semi-sedentary foragers from the Northwest Coast. The Nuu-Chah-Nulth lived on the west coast of Vancouver Island in present-day British Columbia at the end of the 19th century. They had a complex sociopolitical organization. Apart from local groups, there were tribes and larger confederacies. Their primary subsistence was fishing and hunting of marine mammals. Agriculture was unknown until the arrival of the Europeans; the only domesticated animal was the dog.

The Nuu-chah-nulth often moved due to seasonality of food resources. In addition to winter (tribal) villages, they had summer (confederacy) villages and fishing stations. The skeletons of large rectangular houses (9-12 × 12-30 meters, floor area of 110 to 360 m^2; Drucker, 1951: 69) stood in all these site types, although summer houses were usually smaller than winter ones. Up to 20 families occupied these houses. The walls and roof of the houses were made of planks that the families transported from one location to another. The spaces of the individual families were placed along the walls. They might be partially separated but did not represent separate rooms. The Nuu-chah-nulth were a hierarchical society with a hereditary rank system. People were divided into three classes: nobles, commoners and slaves. Members of all classes lived together under one roof, but the inner space was clearly arranged; the most honorable places in the corners were occupied by chiefs and other prominent lineage members, while lower rank members occupied the space between the corners.

Like the Nuu-chah-nulth moved from winter villages to summer fishing stations, they moved from one house group to another. The chiefs and members of the nobility, who usually followed the patrilocal rule, moved least often. As Drucker puts it: "*Chiefs tended to stay most of the time with the group in which they owned property (a corner of the house, seats, fishing places, etc.), whether this came from the paternal or maternal line. But even they moved about, and might spend a fishing season, a year, or even 2 years, with another group to whom they were related*" (Drucker 1951: 278). Commoners moved more frequently. "*A man might spend a year or two in his mother's house, the next in his wife's father's, then live with his father's mother's group, and later go to live awhile with his son-in-law. [...] If a man stayed too long* *in one house, his other relatives became jealous. They would think he didn't care for them any more*" (Drucker 1951: 279).

On the contrary, the aim of the chiefs was to attract lower-rank people to their house and keep them in their households for as long as possible. In general, marriages represented an alliance between families rather than between individuals. They were often arranged and accompanied by a series of gift exchanges. The rank of the suitor was the main factor taken into consideration by the girl's family. Polygyny was practiced especially among chiefs, with the wives living under one roof, the second one serving the first. There were no exogamous groups.

Because of the shifting residence, it is difficult to determine how many members of Nuu-chah-nulth local groups were raised locally. Higher-rank men were probably "more local" than higher-rank women, but most people moved constantly between different households (and sites) after marriage.

4.3.7. Neolocal residence with temporary matrilocality – Jivaro

Neolocality combined with temporary matrilocal residence was common among the Jivaro (or Shuar) people, who lived in tropical rainforest in modern-day Ecuador and Peru in the mid-20th century (Harner 1973). Their main subsistence was swidden horticulture, supplemented with hunting, fishing and gathering. Most families kept dogs and chicken, some also ducks and pigs. The basic social, political and economic unit was a polygynous family with a man as the head of the household. Polygyny was common, enabled by high male mortality due to frequent feuding and warfare resulting in a disproportionate ratio between adult females and males (approximately 2:1). The Jivaro people did not concentrate in villages and lacked any formal political organization. Nevertheless, two types of informal leaders could be found in almost each neighborhood (community cluster) – outstanding killers and shamans. The Jivaro lacked any clearly defined unilineal descent groups such as lineages, clans or moieties. Every person thus has different bilateral kindred. Each family constituted an independent local community living in a single dwelling, usually one or more kilometers apart from others. Cooperation among them was limited mainly to the purposes of warfare and head-hunting.

The house was usually built in a defendable location – on a steep hill, in the middle of the forest, near a small stream. A two-meter-high windowless wall was built of palm staves. The gabled roof was covered with palm thatch, reaching the height of 4.5 meters. The dimensions of the oval floor ground ranged from 7.5 to 11 meters in width to about 12 to 18 meters in length (Harner 1973: 44). The interior was unpartitioned but conceptually and functionally divided into men's and women's halves. The house was typically occupied by a polygynous family of nine people, rarely more than twenty (but cf. Métraux 1948a: 623 for much higher figures). The household typically consisted of a man, his wives (most often two) and several children. Other relatives might include a widowed mother, an unmarried brother or a married daughter with her husband during a period of temporary matrilocal residence. The relatively large floor area was needed to host visitors during drinking and dancing parties. One site was usually occupied for five to nine years, after which a new house was built three or five kilometers away the former location.

The preferred marriage was between cross-cousins. The practice of bride-service and temporary matrilocality was common, especially in the case of the man's first marriage. The newlyweds lived at the wife's parents' house usually until the birth of one or more children. After that, they built a new house in the neighborhood. Sororal polygyny – a man married two or more sisters – was preferred, but non-sororal type also existed. Sometimes, a man married a widow and (subsequently) her unmarried daughter. Wives were also occasionally acquired by capturing women and girls in warfare.

From the perspective of local versus non-local, it seems that most men lived in a new place after the marriage. As for women, the situation was more complex. At the household level, their residence was neolocal. At the neighborhood level, however, residence can be labeled as uxorilocal, since the new house stood usually not very far away from their parental house. Moreover, they lived matrilocally for several years after the wedding. In the case of subsequent non-sororal wives or wives captured in warfare, the residence was patrilocal, since temporary matrilocality was usually not practiced and the women moved directly to the man's already established household.

4.4. Strontium isotope analysis results versus post-marital residence models

Unlike traditional archaeological approaches studying human mobility based on different material proxies, strontium (Sr) isotope analysis can provide more direct evidence about the movement of specific individuals (for methodological review see e.g. Bentley 2006). The $^{87}Sr/^{86}Sr$ ratio measured from human teeth reflects the averaged geochemical signature of a territory from which an individual consumed food and water during his/her childhood or adolescence. The specific age to which the $^{87}Sr/^{86}Sr$ ratio relates depends on the sampled tooth, since different teeth mineralize in a different age. For example, first molars mineralize approximately between the birth and the 3rd year, second molars and premolars roughly between the 3rd and 8th years, and third molars approximately between the 8th and 14th years of age (AlQahtani et al. 2010). The comparison of the $^{87}Sr/^{86}Sr$ ratio between different teeth or against the local bioavailable Sr range can thus reveal single or multiple migration events during the individual's life and suggest if he or she was of local or non-local origin. One should bear in mind, however, that the sensitivity of strontium isotope analysis depends considerably on the diversity of the geological setting. In central Europe, for instance, differences in $^{87}Sr/^{86}Sr$ are detectable mainly between the granite and metamorphic rock uplands and the lowlands often covered in loess (Knipper 2011).

For the LBK period, strontium isotopic data were obtained from hundreds of human skeletons (Bentley 2013; Bentley et al. 2012; Bickle and Whittle 2013). Researchers found that the variance in $^{87}Sr/^{86}Sr$ was significantly greater among females than males and, simultaneously, significantly smaller for males buried with ground stone adzes than for males without them. These results were interpreted as evidence for a patrilocal kinship system (females moved for marriages) and for differential land use (males with adzes had access to preferred loess soils). Some alternative interpretations have been proposed but rejected; specifically, marginal land access for women and matrilocality for males without adzes (Bentley et al. 2012: 9329).

In the present text, we want to build on previous research by assessing the possible post-marital pattern during the LBK in more detail. We have shown already that post-marital residence is usually more complex than the mere patrilocal-matrilocal dichotomy. Several hypotheses (models) based on ethnographic examples will be presented and tested against the previously published strontium isotope data from two LBK cemeteries: Vedrovice (Czechia) and Nitra (Slovakia). With each hypothesis, we will attempt to assess if the strontium data exclude it or not and under what circumstances it is possible.

4.4.1. Two case studies: short summary

The Vedrovice and Nitra cemeteries were chosen, since they are the two largest excavated LBK burial sites in Czechia and Slovakia. $^{87}Sr/^{86}Sr$ data are available for 71 individuals in Vedrovice (Whittle et al. 2013: Table 4.2) and for 61 individuals in Nitra (Whittle et al. 2013: Table 4.15). Although these are relatively small samples, they belong to the largest LBK datasets. Two other large strontium datasets come from Schwetzingen (102 individuals) and Aiterhofen (64 individuals), both in Germany (Bickle and Whittle 2013). We have not included these two sites because they are situated in a region different from Vedrovice and Nitra. Our analysis is deliberately focused on an individual region, since interregional diversification is considered within the LBK cultural milieu (Modderman 1988).

4.4.1.1. Vedrovice site

The present-day village of Vedrovice is located 40 kilometers southwest of Brno, in the South Moravian Region of Czechia. The archaeological site near the village consists of four areas dated to the Early Neolithic period: a settlement with a large enclosure, "Široká u lesa" cemetery, "Za Dvorem" cemetery and a probable but not proved cemetery "U Kostela" (Ondruš 2002). The site was excavated in several campaigns between 1961 and 2000 during which 12 inhumations were found in the settlement area, 85 inhumations (out of 96 burials in total) at the cemetery "Široká u lesa" and 13 inhumations at the cemetery "Za Dvorem" (including five in settlement pits). Burials from the cemetery "Široká u lesa" were radiocarbon dated to a period spanning five or six generations during the 53rd and 52nd centuries BC (Pettitt and Hedges 2008). It is interesting to note that females outnumbered males (48 females, 26 males, 3 indeterminable adults) and the number of children burials (n=33) was strikingly low in Vedrovice (Dočkalová 2008).

Strontium data were gathered within two international bioarchaeological projects: *Biological and cultural identity of first farmers: multiple bioarchaeological analysis of a central European cemetery (Vedrovice)* (Lukes et al. 2008) and *The first farmers of central Europe: diversity in LBK lifeways* (Bickle and Whittle 2013). The former provided $^{87}Sr/^{86}Sr$ data for 22 individuals (Richards et al. 2008b), while the latter analyzed another 52 individuals (Whittle et al. 2013), resulting in a total number of 71 analyzed individuals, approximately two-thirds of all uncovered inhumations, including 18 juveniles, 19 males and 34 females. Fifty-nine individuals came from the cemetery "Široká u lesa", seven from the cemetery "Za Dvorem" and five from the settlement. Three individuals (73/79, 79/79 and 93a/80) were analyzed by both teams; in these cases, we preferred $^{87}Sr/^{86}Sr$ data from Bickle and Whittle (2013).

In their limited sample, Richards with colleagues (2008b) identified four adults (two females and two males) with different $^{87}Sr/^{86}Sr$ values than the majority of others. The main group, including all juveniles, formed a cluster with strontium values ranging from 0.7108 to 0.7115; the four outliers were interpreted as likely immigrants who grew up at a location different from Vedrovice. Since the site is located at the base of the Bohemian Massif where Precambrian and Paleozoic rocks contribute to loess and raise the resulting $^{87}Sr/^{86}Sr$ ratios, it is easier to identify individuals whose subsistence comes from regions with lower biosphere strontium ratios, such as the Hungarian Plain, located to the east and south of Vedrovice. Apart from strontium, sulfur isotopic analysis was also conducted on 50 individuals. Five individuals (three men and two women) had different values than most others, indicating they lived elsewhere during the last 10-20 years of their lives.

The larger sample (Whittle et al. 2013) showed somewhat different results. There was once again a main cluster of individuals, but now with a wider $^{87}Sr/^{86}Sr$ range from 0.7104 to 0.7120. Significant differences were detected between the sexes; females had larger $^{87}Sr/^{86}Sr$ variance than males and they also made up the majority of individuals outside the "local" $^{87}Sr/^{86}Sr$ range (14 out of the 16 outliers were women). Ten sampled men were buried with adzes and these "adze burials" had smaller $^{87}Sr/^{86}Sr$ variance than the nine none-adze male burials. There was no other significant correlation between $^{87}Sr/^{86}Sr$ and other burial goods or body configurations. Five individuals (four juveniles and one male) from the settlement fell into a narrower strontium range (0.711–0.713) than individuals from the cemeteries "Široká u lesa" and "Za Dvorem", but the sample size is small. Another significant correlation was found between females' strontium and nitrogen values suggesting that their geographical origin in childhood may have influenced their diet in adulthood. The authors (Whittle et al. 2013: 126) concluded that individuals from the settlement had been more probably local, and the different mobility patterns of men and women reflect patrilocal or virilocal practices.

In order to interpret the results of strontium isotope data from the viewpoint of post-marital residence, it might be useful to include into the analysis not only the sex but also the minimum and maximum age at which the possible residential change might have occurred. The minimum age at which an individual moved is determined by the analyzed tooth. For example, when analyzing the first molar (M1), strontium data give evidence about a diet / residence in the early childhood (from birth to 3 years of age), while data from the third molar (M3) reflect a period of life between 8 and 14 years of age. The maximum age at which a change of residence could occur is the estimated age of death. Another age limit that should be considered is the period of the first menstruation. It occurs in girls around the 13th/14th year (Thomas et al. 2001); it can be assumed that most girls married after that time, although pre-pubertal marriages could also occur (cf. Hopkins 1965).

Figures 4.5A-C show $^{87}Sr/^{86}Sr$ values of children, women and men from Vedrovice, including periods of life when their residence may have changed (Whittle et al. 2013: Table 4.2). The minimum age was determined by the type of analyzed teeth, specifically the lower limit (i.e. M1 = birth, M2 = 3rd year, M3 = 8th year). The maximum age was determined by the anthropologically estimated maximum age at death. In one case of the age category "Adult", the age of 40 years was used instead. In several cases of the age category "50+", the age of 60 was depicted in the figures. In the absence of information about the analyzed tooth, the age of 0 was used instead.

In order to determine the ratios of local / non-local men and women, at least in some basic figures, we attempted to determine the “local range”. Since strontium data from local animals are not available, a range of values for children and juveniles was used as the main indicator. Although this approach is not without problems (Bentley et al. 2004; Pollard 2011), it can be assumed that children were more likely local because they had less time to migrate than adults in their lifetime (Fig. 4.5; Bentley et al. 2008; Montgomery et al. 2005). The resulting “local” range based on two standard deviations from the mean is 0.71041-0.71203 (n=18; mean=0.711217; SD=0.000405), which roughly corresponds to the range of the main cluster as identified by Whittle and colleagues (cf. above).

Figures 4.5A-C show there are 15 female outliers (out of 34), one male outlier (out of 19) and one child outlier (out of 18). Assuming that these results not only reflect different diet during childhood but actually give evidence about mobility, young individual 3/66 can be seen as an example of migration occurring before the age of 9 (and probably not because of post-marital residence; Fig. 4.5A). Male outlier 99/81 could have moved at any time between the age of 8 and 30 for various reasons (Fig. 4.5B). By contrast, possible movements associated with post-marital residence rules may be evidenced by the fact that 6 out of 15 “non-local” women moved after the age of 8-14, including two girls who probably moved between their 8^{th}-14^{th} and 20^{th} birthdays, i.e. during the ideal “marriageable age” (Fig. 4.5C). On the other hand, 7 out of 19 “local” women died younger than 25 years. Strontium data alone cannot distinguish whether they had not married yet, had married within the Vedrovice community or had come from areas with a similar strontium signal.

If we want to convert strontium results into a type of model from Fig. 4.4, we can say that approximately 5% of men and 44% of women were foreign (Fig. 4.7). Unfortunately, however, it cannot be determined whether the remaining 95% of men and 56% of women were local or also foreign (from areas with a similar strontium signal).

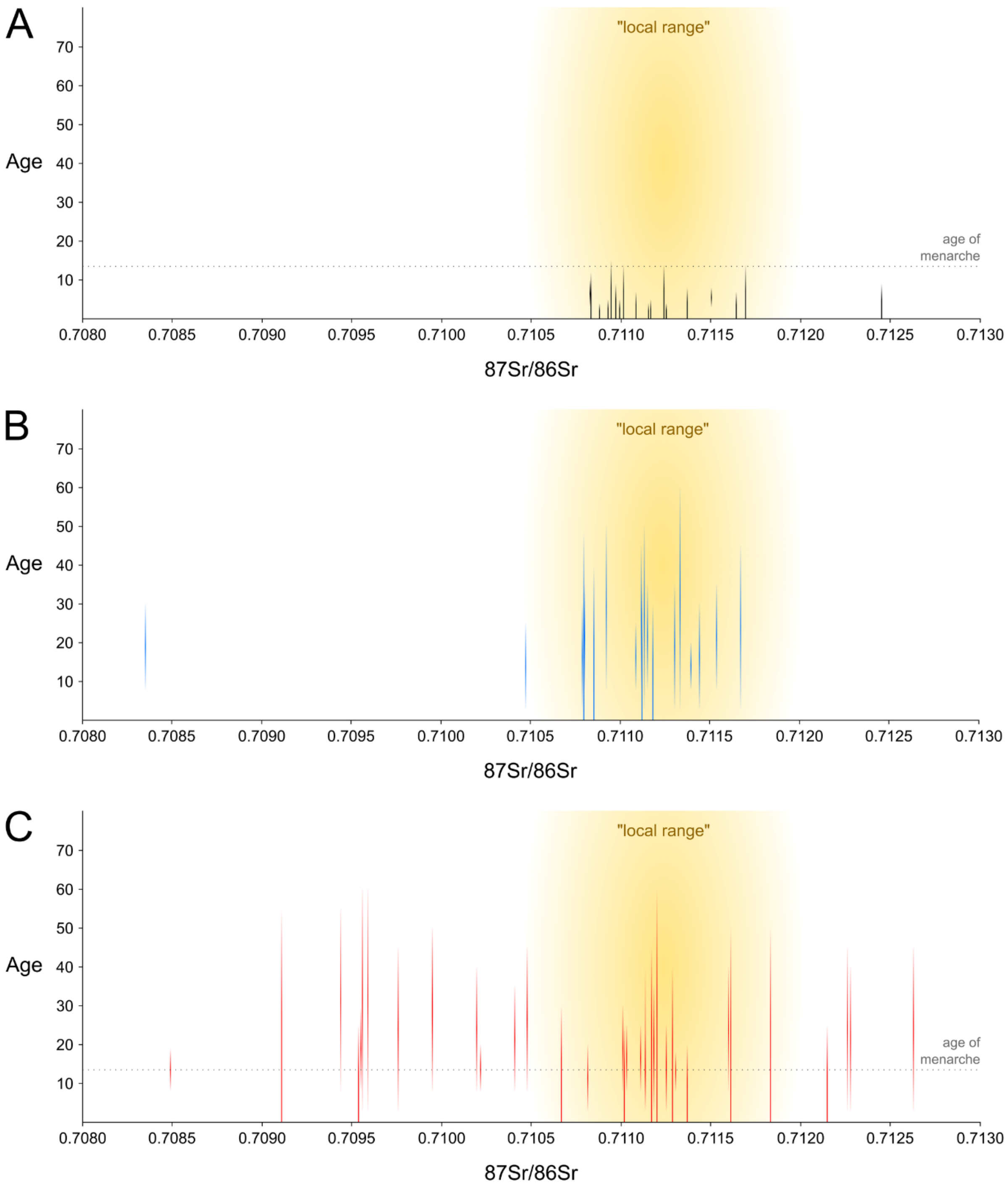

Fig. 4.5. *Strontium values and periods of life when mobility could occur for: A) juveniles (n=18), B) males (n=19), and C) females (n=34) from Vedrovice site. The "local range" is defined as 2 SD from the mean of juveniles' $^{87}Sr/^{86}Sr$ values.*

4.4.1.2. Nitra site

The present-day city of Nitra is situated in western Slovakia, 75 kilometers east of the capital, Bratislava. A Neolithic burial ground was found in the suburb of Horné Krškany. Rescue excavations were conducted in 1964–1965 (Pavúk 1972). The results of radiocarbon dating suggest that with a 95.4% probability, the use of the cemetery began in 5370–5220 cal BC and ended in 5210–4980 cal BC (Whittle et al. 2013: 143). With the same probability, the duration of the cemetery has been estimated at 20–360 years. Seventy-four burials dated to the Early Phase of the LBK were uncovered on an area of about 15 by 50 meters (Pavúk 1972). Probably not all graves of the cemetery were discovered; some may have been destroyed. Apart from inhumations, at least eight groups of cremated human bones, probably also belonging to the LBK, were found at the site (Pavúk 1972: 39). Whittle et al. (2013) identified 75 individuals, including 27 females, 18 males, four indeterminable adults, six adolescents, 16 juveniles and four infants. However, a more recent study of the osteological material identified 77 individuals, including 27 females, 19 males, three unsexed adults and 28 subadults (Tvrdý 2016). Like at Vedrovice, women outnumbered men, although in both cases, the difference is not statistically significant (χ^2 test, $p > 0.05$).

Strontium ratios were obtained from 61 individuals (approximately 80% of all excavated inhumations) within the project *The first farmers of central Europe: diversity in LBK lifeways* (Bickle and Whittle 2013). The sample included 23 females, 16 males, one unsexed adult and 21 juveniles (Whittle et al. 2013). The results showed a local cluster of children, men and women and several outliers predominated by women. The situation thus resembles that of Vedrovice, but the $^{87}Sr/^{86}Sr$ range was much narrower in Nitra. The site is located on the edge of loess lowlands, but the Tribeč Mountains covered by non-loess and radiogenic soils with expected higher Sr ratios are nearby. All seven individuals with $^{87}Sr/^{86}Sr$ values above 0.7097 or below 0.7090 were females or possible females. The sampled women had also significantly greater $^{87}Sr/^{86}Sr$ variance than men. However, contrary to Vedrovice, Nitra males buried with ground stone adzes did not have significantly smaller $^{87}Sr/^{86}Sr$ variance than those without adzes, although their mean $^{87}Sr/^{86}Sr$ was slightly lower. No other significant correlations were identified. Nevertheless, it is worth mentioning that four out of the five females with the highest $^{87}Sr/^{86}Sr$ were found in the widely spaced southern half of the site, indicating that geographical origin might have influenced the location of the individuals' graves in the cemetery. The authors (Whittle et al. 2013: 154) concluded again that the different strontium values in men and women were probably the result of patrilocality.

Once again, we have plotted the published strontium values into three graphs (Fig. 4.6A-C). Data on $^{87}Sr/^{86}Sr$ ratios, sex and sampled teeth were taken over from Whittle et al. (2013) but the estimated age from Tvrdý (2016), since his study contains more precise estimates. In cases of uncertain sex determination (e.g. F?, M? or where there was a difference between

Whittle et al.'s and Tvrdý's determination), we plotted the individuals in the graph with the more probable sex but depicted them in black color. There were two individuals with two sampled teeth. Possible male 69/65 had the same $^{87}Sr/^{86}Sr$ ratios for M1 and M3, but male 34/65 had different strontium values for the two teeth (Fig. 4.6B; violet color). Otherwise, we followed the same approach as described above.

The mean $^{87}Sr/^{86}Sr$ ratio of 15 Nitra children under the age of 10 is 0.709493 (SD=0.000107) resulting in an approximate "local" range of 0.70928-0.70971 (but cf. Whittle et al. 2013: Table 4.25). Using this range, there are two male outliers (out of 17) and seven female outliers (out of 23). Interestingly, male 34/65 shows "local" signal (0.7095) in early childhood (M1) but "non-local" (0.70925) at the age of 8 to 14 (M3). This indicates a change in his diet, but it is not clear if he moved away from Nitra during childhood and later came back, or the defined "local" range is too conservative and he consumed food from different parts of Nitra's surrounding during his late childhood. Similarly, $^{87}Sr/^{86}Sr$ ratios of both outlying males (0.70923 and 0.70920, respectively) are relatively close to the defined range and these individuals might actually be local (Fig. 4.6B). Two female outliers might have moved to Nitra between their birth and the age of 24 and 30, respectively, while the other five could have moved there anytime during the long period of more than 35 years of their lives (Fig. 4.6C). It is therefore more difficult to connect these movements specifically with post-marital residence rules than in the Vedrovice case, since the women might have moved in the early childhood with their parents or much later in life due to other reasons.

Taking the strontium results strictly as evidence for mobility, we can say that approximately 0-10% of men and 30% of women were of foreign origin (Fig. 4.7). However, as we have mentioned in the Vedrovice case, it cannot be determined whether the remaining 90-100% of men and 70% of women were local or also foreign (coming from wide areas of loess basins or granite uplands with a similar strontium signal which might blur local differences). Different proportions of local/non-local females between Nitra (30%) and Vedrovice (44%) can be explained either by different mobility patterns at these two sites or by different geological conditions (more "local" women in Nitra than in Vedrovice actually grew up somewhere else).

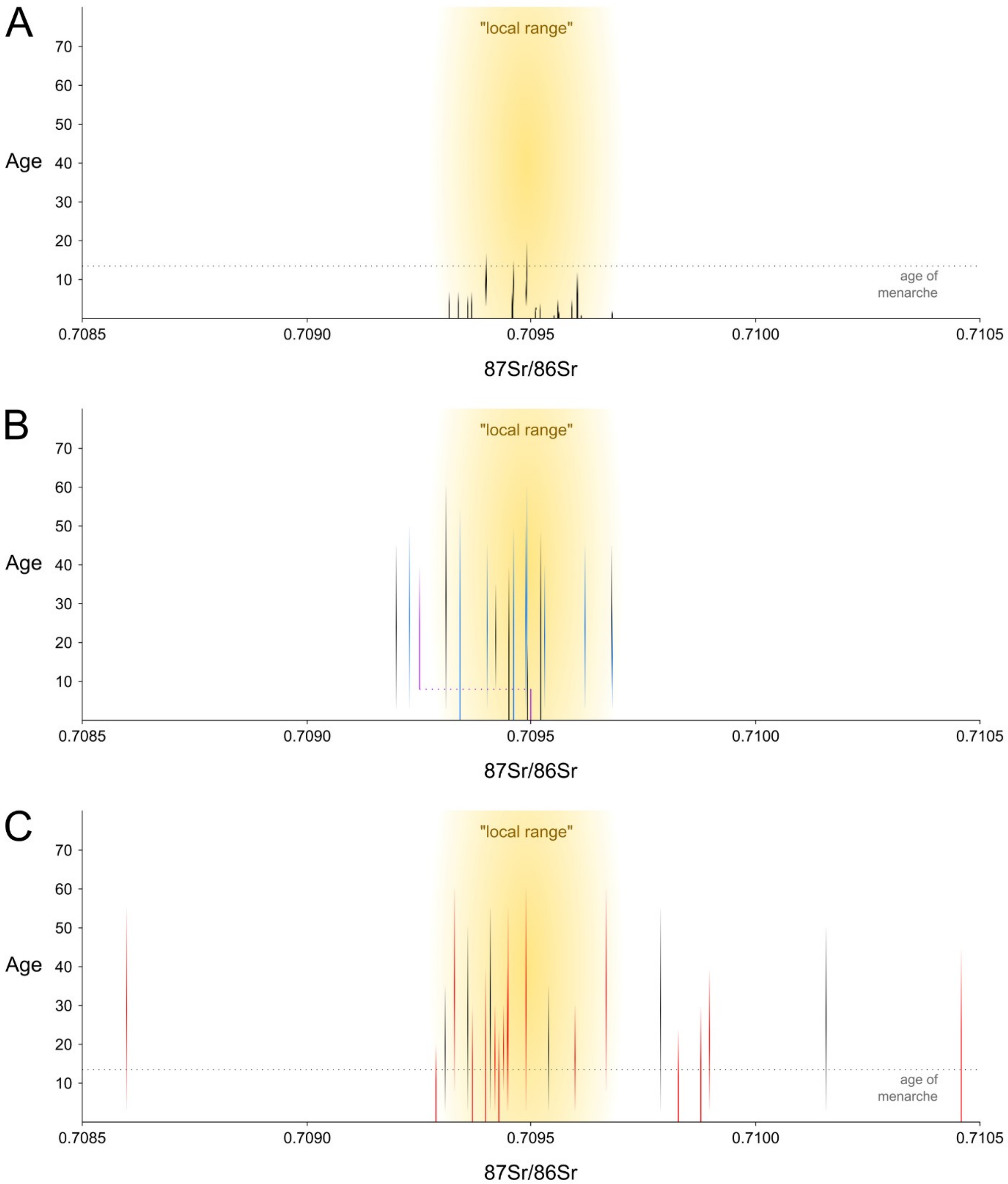

Fig 4.6. *Strontium values and periods of life when mobility could occur for: A) juveniles (n=21), B) males and probable males (n=17), and C) females and probable females (n=23) from Nitra site. The "local range" is defined as 2 SD from the mean of children's* $^{87}Sr/^{86}Sr$ *values.*

4.4.2. Post-marital residence patterns in LBK: Hypotheses

The strontium isotope results summarized above indicate that Vedrovice and Nitra women consumed food from more variable sources than men during their childhood. This was probably the result of their different origin rather than different dietary habits. If there were several groups consuming different diets in the same village, the variability should be visible also in children's Sr values. This is not the case, however, as children's Sr data are less variable than those of women.

Higher proportion of non-local women has been used as evidence for patrilocality (or virilocality) and exogamy (Whittle et al. 2013). This might be an oversimplification of a strongly variable reality. There are other post-marital residence (PMR) models whose possibility should be considered. In Table 4.1 and Figure 4.7, we present eight hypotheses, inspired by ethnographic examples above, and indicate assumptions under which they are possible. The probability of all hypotheses is then discussed in the *Discussion* section.

Fig. 4.7. *Six hypotheses (post-marital residence models) and their comparison to strontium isotope results for Vedrovice and Nitra. Simplified assumptions based on Table 4.1. Each symbol indicates 10% of male/female married population.*

***Table 4.1**. Eight hypotheses (post-marital residence models) and assumptions under which they are possible for Vedrovice and Nitra, considering strontium isotope results.*

Hypothesis (PMR model)	**Assumptions**
Strictly patrilocal (virilocal) and strictly exogamous	– All men identified as "local" in Vedrovice (c. 95%) and Nitra (c. 90-100%) were actually local or moved in for reasons other than post-marital residence (PMR). – All men identified as "non-local" in Vedrovice (c. 5%) and Nitra (c. 0-10%) moved in for reasons other than PMR, and/or were actually local but consumed different diet in childhood than the majority of others, and/or were incorrectly anthropologically identified as males (in the case of one individual in Nitra). – All women identified as "local" in Vedrovice (c. 56%) and Nitra (c. 70%) were actually non-local (from communities with similar bioavailable Sr ratios), and/or were not yet married, and/or were incorrectly anthropologically identified as females (in the case of four individuals in Nitra). – All women identified as "non-local" in Vedrovice (c. 44%) and Nitra (c. 30%) were actually non-local. – Male 34/65 from Nitra with "local" signal in early childhood and "non-local" in late childhood moved out for reasons other than PMR and then returned, or consumed different "non-local" diet during late childhood.
Predominantly patrilocal (virilocal) and predominantly exogamous	– Most men identified as "local" were actually local. – Men identified as "non-local" moved in because of PMR, and/or some of the men identified as "local" were actually non-local, and/or were not yet married. – Most women identified as "non-local" were actually non-local, and/or some of the women identified as "local" were actually non-local. – PMR was the main reason for mobility at both sites. – The analyzed individuals constitute a representative and unbiased sample of the Vedrovice and Nitra populations.
Ambilocal without any endo-/ exogamous rules	– Approximately half of the men identified as "local" were actually non-local, while all or most men identified as "non-local" were actually non-local and moved in because of PMR. – Most women identified as "non-local" were actually non-local, and some women identified as "local" were actually non-local. – Non-local women came from other communities than non-local men, since their Sr ratios are different. *or* – Women had a more variable diet during childhood (but the same residence as men). *or* – Most non-local men were not buried at the sites (but at different locations or in a different manner). *or* – Most non-local women moved in for reasons other than PMR (e.g. as captives/slaves).
Predominantly matrilocal (uxorilocal) and predominantly exogamous	– Most men identified as "local" were actually non-local, and/or not married yet, while all or most men identified as "non-local" were actually non-local and moved in because of PMR. – In Vedrovice, most women identified as "local" (c. 56%) were actually local, while some women identified as "non-local" (c. 44%) were actually local, too (but had a more variable diet during childhood), and/or moved in for reasons other than PMR. – In Nitra, most women identified as "local" (c. 70%) were actually local, and/or some of the women identified as "non-local" (c. 30%) were actually non-local, and/or some misidentified "local" males were actually females, while misidentified "non-local" females were actually males. *or* – Most non-local men were not buried at sites (but at different locations or in a different manner) and those analyzed represent a minority in the overall populations.

	or – Most non-local women moved in for reasons other than PMR (e.g. as captives/slaves).
Strictly matrilocal (uxorilocal) and strictly exogamous	– All men identified as "local" were actually non-local, and/or were not yet married, and/or were incorrectly anthropologically identified as males (in the case of six individuals in Nitra). – All men identified as "non-local" were actually non-local and moved in because of PMR. – All women identified as "local" were actually local. – All women identified as "non-local" were actually local (but consumed different diet in childhood than the majority of others), and/or moved in from different reasons than post-marital residence (PMR), and/or were incorrectly anthropologically identified as females (in the case of two individuals in Nitra). – Male 34/65 from Nitra with "local" signal in early childhood and "non-local" in late childhood moved out for reasons other than PMR and then returned, or consumed different "non-local" diet during late childhood. *or* – The sample is strongly nonrepresentative.
Predominantly avunculocal*	– Boys and men who moved to uncles' houses during childhood were either born in the village of Vedrovice (or Nitra) or in regions with similar Sr signal. – Men identified as "non-local" moved in during childhood (to an uncle's house), and/or moved in for reasons other than PMR. – Most women identified as "non-local" were actually non-local and moved in because of PMR. – Some or most women identified as "local" were actually non-local and/or were not yet married. – PMR was the main reason for female mobility and avunculate for male mobility.
Shifting residence**	– Sr data do not necessarily reflect a single location where an individual lived during their childhood but a mixture of different locations. – Women lived in more variable places (i.e. were more mobile) during childhood than men. *or* – Women had a more variable diet during childhood (but a similar residence as men). or – Most "non-local" women moved in for reasons other than PMR (e.g. such as captives/slaves).
Neolocal	– All men and women identified as "local" were actually non-local, and/or were not yet married. – All men and women identified as "non-local" were actually non-local and moved in because of PMR. – Married adult women came from different communities than married adult men, since their Sr ratios are different, or women had a more variable diet during childhood than men, or most non-local men were not buried at the sites (but at different locations or in a different manner).

*Avunculocality = Men move out during childhood, women after marriage - both subsequently live with the husband's uncle.
**Shifting residence = Nuclear families (or married individuals) regularly move from one household (community) to another, several times during their lives.

4.5. Discussion

4.5.1. Post-marital residence in two LBK sites based on strontium data

Assuming that the analyzed samples in Vedrovice and Nitra are representative and Sr data mainly reflect post-marital residence, the most likely model of PMR is predominant patrilocality (or virilocality) with predominantly exogamous communities (Table 4.1, Fig. 4.7). Most men seem to be local, while at least 30-45% of women are non-local. It can be expected that other non-local men and women were not identified by strontium analysis, as they could have come from regions with a similar bioavailable Sr signal but different communities. In Vedrovice, possible movements due to PMR are indicated by the minimum age of 8-14 years of several non-local women. Also, higher age of non-local women (average 35 in Vedrovice, 39 in Nitra) than local women (31 in Vedrovice, 34 in Nitra), albeit not statistically significant (Mann-Whitney test, $p > 0.05$), suggests that the former were already married. Differences in the proportion of non-local women between the two sites can be explained, for example, by different geology or by a different ratio of patri- / matrilocal or endo- / exogamous marriages.

On the contrary, strictly exogamous patrilocality and matrilocality can be ruled out. Both hypotheses are problematic for at least two reasons. First, they assume that all women (in the case of strict patrilocality) or men (in the case of strict matrilocality) identified as "local" were actually non-local or not married yet. Second, ethnographic studies suggest that strictly patrilocal/matrilocal and exogamous PMR was difficult to maintain in practice. Although such ideal residence rules might have existed, the actual practice was very different in many societies (Barnes 1960; see also section 3. Post-marital residence models above).

It is also important to note that exogamous rules, if they exist, usually do not concern villages but clans or other kinship groups, which need not be localized in a single settlement unit but rather spatially spread over a broader area. Therefore, exogamous rules are more difficult to detect with Sr data than the proportion of non-local men and women.

Neolocality, in the sense that all married adults (men and women) buried at Vedrovice or Nitra were not born in these two communities but moved there after marriage, is not very probable, either. Besides many disputable assumptions (Table 4.1), the main argument against this hypothesis is that neolocality is cross-culturally associated mostly with commercialization (Ember 1967) or nuclear families living in isolated houses (such as the "Jivaro model" above). Both are not applicable to the LBK, since there was no evidence of commercial exchange, and LBK people lived predominantly in regular villages with several houses. On the other hand, this does not mean that there were no neolocal couples in LBK communities. The spread of the early LBK within Central Europe would not have been possible without a certain degree of neolocality embodied in the social habitus. Founding settlers had to live neolocally, and probably some other couples (or families) moved to Vedrovice and Nitra as well, although perhaps not immediately after the wedding.

The avunculocality hypothesis can be neither confirmed nor excluded, since this PMR model is a specific type of patrilocality and more accurate data about the bioavailable Sr local range and the individuals' mobility are necessary. Assuming the hypothesis is valid, the data only suggest that men moved to the uncle's place at relatively short distances (within the village or the immediate neighborhood), while brides came from far away and apparently were not as related (e.g. uncle's daughters) as in the Tlingit case. A "non-local" child from Vedrovice who moved before the age of nine and male 34/65 (with two different Sr values) suggests some mobility during childhood, but it is unclear whether it represents movement to an uncle's house or another kind of mobility (or dietary change).

Ambilocality with a balanced proportion of endogamous and exogamous marriages ("Iban model"), shifting residence ("Nuu-Chah-Nulth model") or predominant matrilocality (or uxorilocality) seem to be less probable than predominant patrilocality (Table 4.1). None of these hypotheses can be ruled out, however, since the analyzed samples are probably not absolutely representative. Although not statistically significant, there is a clear predominance of buried women over men at both sites (48:26 in Vedrovice, 27:18-19 in Nitra). One possibility is that some men were buried at different places or in a different manner. This idea is supported by the fact that inhumation was not the only burial type during the Early Neolithic, as documented by the relatively small number of burial sites (n=54) in comparison to settlement sites (n=720) in the LBK distribution area (Pavlů and Zápotocká 2013: 89) as well as by cremated bones found at Nitra (Pavúk 1972). The low numbers of non-local men thus might have been caused by different burial rites of these individuals. We can speculate that these men were not considered full members of the community etc., but the question why non-local women were not also buried differently is more complicated to answer.

Captivity and polygyny offer a different explanation of unbalanced male-female ratios. It might be possible that some non-local women were abducted and later lived in Vedrovice and Nitra communities as wives, second wives or slaves. Abduction of young women could have resulted from wars and raids, as has been suggested for two LBK mass graves in Talheim (Bentley et al. 2008) and Schöneck-Kilianstädten (Meyer et al. 2015), both in Germany, as well as for the fortified settlement in Asparn/Schletz, Austria (Teschler-Nicola et al. 2000), or it might occur outside of war conflicts. Ethnography shows that beside culturally "orthodox" marriages, many irregular ways of acquiring brides, including violent abduction, could occur, depending on whether the girl's parents were willing, whether the girl herself was willing, and whether she was already betrothed to somebody else (Bateson 1932: 280-281). Such "abducted" women could skew the real proportion of local married men and women, making ambilocality or other PMR hypotheses possible. Of course, polygyny could be also present in the PMR pattern of predominant patrilocality. In such case, however, it is not a necessary assumption for explaining the Sr data.

Whether the non-local women, abducted or not, were from Post-Mesolithic hunter-gatherer (cf. Zvelebil and Pettitt 2008) or Neolithic farming communities, cannot be determined. There were no statistically significant differences in the number of grave good items, ^{13}C and ^{15}N values between local and non-local women, indicating that incoming women were treated in a similar way.

Strontium data indicate that men buried with adzes had access to preferred loess soils which has been proposed as another type of evidence for a patrilocal kinship system (Bentley et al. 2012). However, this does not necessarily mean that land was inherited from father to son. The inheritor could have been another close male relative who did not come from far away, such as a nephew (avunculocality) or son-in-law (matrilocality). Moreover, land ownership might have been tied to social units of different sizes rather than specific individuals (Pospisil 1972: 184-185).

4.5.2. Different post-marital residence patterns on different levels?

Societies living in large dwellings such as longhouses tend to be matrilocal (Hrnčíř et al. 2020). Based on strontium data, however, it seems that LBK society was an exception, like the Tucano example (see above), since predominant patrilocality is more probable than ambilocality or predominant matrilocality. Another explanation consists in the existence of different post-marital residence patterns on different levels (Walker 2015). Here we are facing the problem of distinguishing the geographical and social space, which do not necessarily overlap, in archaeological or cultural sources (Furholt 2017; Hillier and Hanson 1984: 258-259).

Although strontium data can reveal mobility on the level of regions (and distant villages), they are unable to discern it on the level of individual longhouses or indicate mobility between different non-localized social spaces (e.g. clans). Therefore, while men could live with more kin at the village level (as strontium data suggest), women could live with more kin at the level of the extended household (longhouse). A possible scenario combining the results of cross-cultural research and strontium analyses thus could be as follows:

The basic unit in the geographic space was a village consisting of a localized phratry. Post-marital residence on this level was ruled by the principle of exogamy and patrilocality. Women moved from one village (phratry) to another, while men stayed in the same village (phratry) for their whole life. The basic unit in the social space was a non-localized exogamous clan (black or gray). Each longhouse belonged to one clan and each clan could possess several longhouses in different villages. After the wedding, each woman was expected to live in the longhouse of the same clan she belonged to (matrilocal principle). Since men chose partners from another phratry and another clan, the newlyweds had to move to the longhouse of the wife's clan in the husband's village (Fig. 4.8).

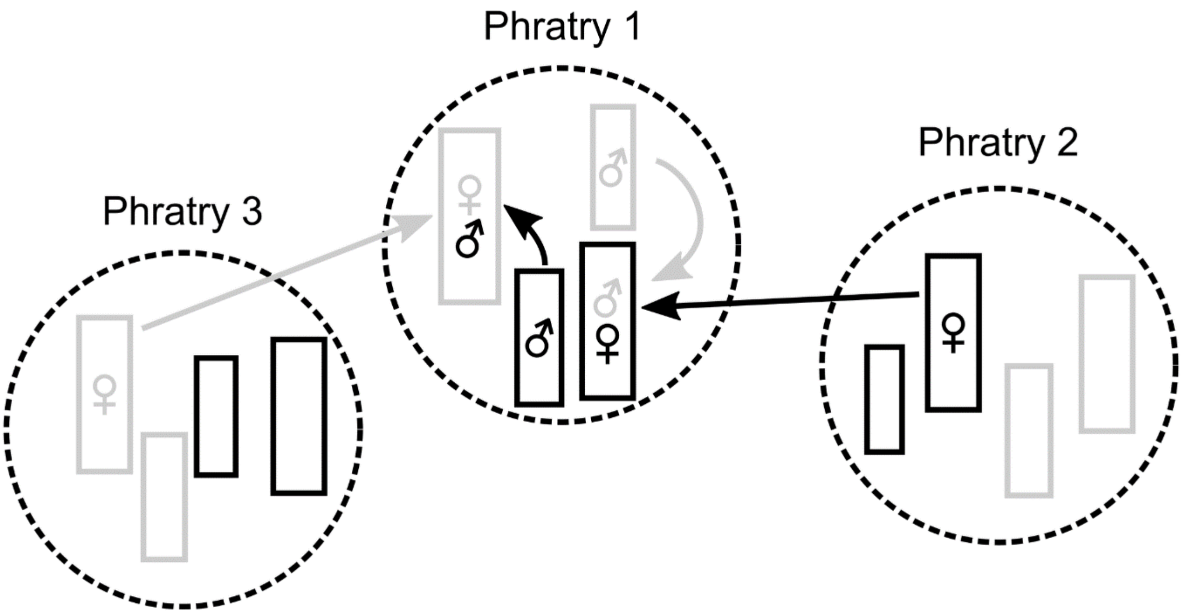

Fig. 4.8. *PMR model combining patrilocality on the village (phratry) level and matrilocality on the longhouse (clan) level. Three phratries (villages) are ruled by the principle of exogamy and patrilocality. Two clans (grey and black longhouses) are ruled by the principle of exogamy and matrilocality.*

The model presupposes several levels of social solidarity. This is not a purely theoretical idea, but a reality existing in the cultural domain of acephalous societies, for example, on the southwest coast of New Guinea (Ernst 1979; van Baal 1966). In the Marind-anim population (about 16,000 people), the society was divided into four territorial groups and a number of non-localized totemic patrilinear clans. The clans were further grouped into four phratries according to mythological and totemic "compatibility". The territorial groups were endogamous and the phratries were exogamous. The village was inhabited by members of several clans but belonged to a single phratry. From the viewpoint of post-marital residence, it was necessary to apply the rules of clan patrilinearity (no matter if exo- or endogamy), territorial group endogamy and phratry exogamy (no matter if patri- or matrilineality). Why this complicated division (which was in fact even more complex, as it also included moieties and sub-clans)? It was essential for practicing rituals that are usually associated with the process of hierarchical initiation within age cohorts. Each clan and every phratry possessed sacral rights to operate a particular ritual segment, and only by mutual cooperation could the necessary rituals be performed in their cyclic process. The marriage rules were intended to ensure that the "ownership" of the rituals would not be spread uncontrollably while preserving the totemic compatibility of the newlyweds.

4.6. Conclusion

There are many unknowns about LBK social organizations. It is not clear who inhabited the longhouse, whether a small nuclear family, a polygynous family, or an extended family with tens of members, and which social groups, such as clans, phratries or moieties, were recognized. Similarly, it is not clear which post-marital residence rules existed and what was the actual practice. Although strontium data appear to clearly indicate patrilocality (or virilocality) and community exogamy, we have attempted to show that other variants were also possible. The presented ethnographic examples show that post-marital residence patterns were often complex and cannot be summed up into a simple division between patrilocality and matrilocality.

Predominant patrilocality is one possibility in Vedrovice and Nitra, but ambilocality, avunculocality or shifting residence are also possible, especially when we consider that inhumation was not the only burial type during the Early Neolithic and, therefore, the analyzed samples might not be representative, or that polygyny and abduction of women could have existed. Moreover, while matrilocality was probably not practiced at the community (village) level, this does not exclude its presence at other levels (e.g. longhouse or some kind of non-localized social group).

5. Summary of the results and future perspectives

The aim of this thesis was to address selected problems regarding past human mobility.

In Case Study 1, we have demonstrated that multiple-tooth strontium analyses can reveal significant differences in past childhood mobility patterns between different regions and periods. However, the comparison of various datasets is not straightforward due to the great diversity of biogeochemical and geographical settings and future research on more precise estimation of the expected range of intra-individual variation is needed. The interpretation of different childhood mobility patterns is not simple, either. A brief review of anthropological and historical literature has shown that many types of childhood mobility (e.g. forced migration, fosterage, subsistence movements, residential change with a larger group) can result in the same or similar strontium isotope outcomes in human teeth. For this reason, the strontium isotope results should always be complemented with other lines of evidence (archaeological, historical, ethnographic or results of other natural science methods).

In Case Study 2, we have confirmed the cross-cultural association between house size and post-marital residence after controlling for phylogeny and other explanatory variables (agriculture, fixity of settlement, construction material). Our results indicate that post-marital residence and house size evolve in a correlated fashion, namely that matrilocality is a predictable response to an increase in dwelling size. As such, we suggest that average house floor area can be used as a material proxy for inferring post-marital residence patterns in prehistoric societies (i.e., larger dwellings indicate matrilocality, while smaller ones patrilocality). It should be stressed, however, that the association between two variables is not a perfect correlation but a trend with no simple explanation, as suggested by societies with very large dwellings (over c. 200 m^2) that are associated with all types of post-marital residence.

A confrontation of archaeological, ethnological and natural science methods was the aim of the last chapter discussing the issue of post-marital residence in the Early Neolithic. While the relatively large average house floor area of LBK houses (c. 120 m^2) indicate a predominant matrilocal social organization, strontium data from two burial sites indicate predominant patrilocality. The latter is undoubtedly possible, supported also by ancient DNA results (Szécsényi-Nagy et al. 2015), but other types of post-marital residence rules such as ambilocality, avunculocality or shifting residence cannot be ruled out, either, especially when we consider that polygyny or abduction of women could exist or that individuals buried at cemeteries might not be a representative sample of past LBK population. Assuming the complexity of post-marital residence rules, a model combining patrilocality and matrilocality at different social levels is also possible.

Due to the development of natural science methods, sometimes referred to as the third science revolution in archaeology (Kristiansen 2014), the focus of scholars studying past human mobility has shifted from cultural remains to human remains. In the future, we will thus certainly see many more research projects incorporating biogeochemical and genetic approaches. Still, isotopic and ancient DNA evidence must be interpreted with caution. As shown in previous chapters, the same strontium results can reflect different human behaviors; this is true of modern (MacEachern 2000) and ancient DNA (Burmeister 2016) alike. In addition to the further development of natural science methods themselves, the development of theoretical concepts such as *identity* (Graves-Brown et al. 2012; Květina 2010a) or *archaeological culture* (Eisenmann et al. 2018; Riede et al. 2019; Roberts and Vander Linden 2011), the study of multiple levels of human mobility together (e.g. Schachner 2012) as well as closer cooperation between the natural sciences and the humanities will be necessary.

Cross-cultural comparisons of ethnographic data enable researchers to identify diversity and commonalities in human societies. The knowledge of the range of human behavior enables archaeologists to better interpret archaeological evidence, while identification of common patterns can provide material correlates of past human behavior (Peregrine 2001a, 2004). The combination of synchronic and diachronic comparative approaches (i.e. analyzing cross-cultural historical data) then allows to investigate dynamic processes generating cultural change (e.g. Seshat: Global History Databank project; Hoyer and Reddish 2019; Turchin et al. 2015). Nevertheless, developing a standardized methodology for incorporating cross-cultural approaches into archaeological research remains the greatest challenge for the future.

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Supplementary materials

S1 Supplementary material for Case Study 2

Table A. *Populations in the study sample, including those not included in the supertree.*

SOCIETY	EA	Region	PMR	AHFA	MAT	AGR	SETTL	Ref. (AHFA)
Aleut	Na9	Subarctic America	0	501	D*	1	S	[1, p. 204]
Amhara	Ca7	Africa	1	30	I	5	S	
Aranda	Id1	Australia	0	3	I*	1	M	
Armenians	Ci10	West Asia	1	60	D	5	S	
Aymara	Sf2	South America	0	8	D	3	S	
Bemba	Ac3	Africa	2	15	I	3	S	[2, p. 100]
Blackfoot	Ne12	North America	1	15	I*	1	M	
Burusho	Ee2	South Asia	0	27	I	6	S	
Copper Eskimo	Na3	Subarctic America	2	6	I*	1	M	[3, p. 33]
Cagaba	Sb2	South America	4	13	I	3	S	
Callinago	Sb1	Caribbean	4	56	D	5	S	
Chiricahua	Nh1	North America	3	5	I*	2	M	
Chukchee	Ec3	Siberia	1	21	I	1	M	
Creek	Ng3	North America	4	49	I	3	S	
Cuna	Sa1	Central America	4	166	D	3	S	
Fang	Ae3	Africa	0	14	I	3	S	
Ganda	Ad7	Africa	2	56	I*	5	S	[4, p. 103]
Garo	Ei1	South Asia	4	57	I	3	S	
Gilbertese (Makin)	If14	Pacific	1	30	I	4	S	
Gonds (Maria Gond)	Eg3	South Asia	0	13	I	3	S	
Guarani	Sj10	South America	0	18	I*	3	S	[5, p. 82]
Hausa	Cb26	Africa	0	11	D	6	S	
Havasupai	Nd3	North America	0	19	I*	6	S	
Hupa	Nb35	North America	1	31	D	1	S	[6, pp. 13,16]
Iban	Ib1	Southeast Asia	2	1083	I	3	S	[7, p. 16, fig. 2]
Ifaluk	If4	Pacific	2	11	D	4	S	[8, p. 56]
Ifugao	Ia3	Southeast Asia	2	7	I	6	S	[9, p. 16]
Inca	Sf1	South America	0	21	D	6	S	[10, p. 166]
Japanese	Ed5	East Asia	0	66	D	6	S	
Jivaro	Se3	South America	2	158	D	3	S	[11, p. 94]
Kanuri	Cb19	Africa	0	11	D	5	S	
Kapauku	Ie1	Southeast Asia	0	24	D	3	S	

Kaska	Na4	North America	4	46	D*	1	M	[12, pp. 59-61]
Kazak	Eb1	Central Asia	0	15	I	2	M	
Khasi	Ei8	South Asia	4	58	D	3	S	
Kol	Eg8	South Asia	0	31	D	5	S	
Koreans	Ed1	East Asia	0	59	D	6	S	
Lapps	Cg4	Europe	1	13	I	1	M	
Lau Fijians	Ih4	Pacific	0	41	I	4	S	
Makitare (Yekuana)	Sc16	South America	4	398	D	3	S	[13, p. 136]
Manus	Ig9	Southeast Asia	0	67	(I)	2	S	
Maori	Ij2	New Zealand	0	11	I	3	S	
Marquesan	Ij3	Pacific	0	45	I	4	S	
Masai	Aj2	Africa	0	14	I*	1	M	
Mataco	Sh1	South America	3	4	I*	2	M	
Mbuti (Pygmies)	Aa5	Africa	1	3	I*	1	M	
Miao	Ed4	East Asia	0	28	D	6	S	
Miskito	Sa9	Central America	4	192	I	3	S	
Mundurucu	Sd1	South America	3	225	I	3	S	
Nicobarese	Eh5	Southeast Asia	3	149	I*	4	S	
Nootka	Nb11	North America	1	228	D	1	S	
Ojibwa (Pekangekum)	Na34	North America	0	10	D	1	S	
Ona	Sg3	South America	0	7	I*	1	M	
Paiute (Wadadokad)	Nd22	North America	3	9	I*	1	M	
Papago	Ni2	North America	0	18	I	6	S	
Rhade	Ej10	Southeast Asia	4	79	D	3	S	
Rundi	Ae8	Africa	0	28	I*	5	S	
Rwala	Cj2	West Asia	0	46	I	1	M	
Santal	Ef1	South Asia	0	17	D	6	S	
Semang	Ej3	Southeast Asia	0	26	I*	1	M	
Serbs	Ch1	Europe	0	42	I	5	S	
Seri	Ni4	North America	0	6	I*	1	M	
Shavante	Sj11	South America	4	45	I*	3	M	
Sinhalese	Eh6	South Asia	1	56	I	6	S	
Siriono	Se1	South America	4	139	I*	3	M	
Somali	Ca2	Africa	0	9	I*	5	M	
Tanala	Eh3	Madagascar	0	20	I	6	S	
Tapirape	Sd2	South America	4	90	I*	3	S	
Tarahumara	Ni1	North America	2	24	D	5	S	[14, p. 120]
Tikopia	Ii2	Pacific	0	25	I*	4	S	

Tiv	Ah3	Africa	0	20	D	3	S	
Tlingit	Nb22	North America	0	100	D	1	S	[15, p. 125]
Toda	Eg4	South Asia	0	15	I*	1	S	
Tonga (Plateau)	Ac30	Africa	0	9	I	3	S	[16, pp. 229-231]
Trukese	If2	Pacific	4	28	I	4	S	
Tubatulabal	Nc2	North America	1	29	I*	1	M	
Tucano	Se12	South America	0	100	(I)	(3)	(S)	
Tupinamba	Sj8	South America	3	1022	I*	3	S	
Tzeltal	Sa2	North America	0	36	(D)*	(3)	(S)	
Warrau	Sc1	South America	4	45	I	2	S	
Wolof	Cb2	Africa	0	13	I	3	S	
Yahgan	Sg1	South America	0	9	I*	1	M	
Yakut	Ec2	Siberia	0	56	D*	2	M	[17, p. 263]
Yanomamo	Sd9	South America	0	784	I	3	S	[18, p. 19]
Zulu	Ab12	Africa	0	16	I*	3	S	[19, p. 45]
Zuni	Nh4	North America	4	104	D	6	S	
NOT INCLUDED IN SUPERTREE								
Amahuaca	Se8	South America	0	26				
Azande	Ai3	Africa	0	9				
Bellacoola	Nb9	North America	1	409				[20, p. 257]
Hidatsa	Ne15	North America	4	153				
Huron	Ng1	North America	4	267				
Ila	Ac1	Africa	0	19				[21, p. 114]
Iroquois	Ng10	North America	4	210				[22, p. 181]
Klamath	Nc8	North America	1	42				
Mandan	Ne6	North America	4	136				
Maricopa	Nh5	North America	0	29				
Nambicuara	Si4	South America	1	16				
Omaha	Nf3	North America	0	11				
Pawnee	Nf6	North America	4	386				
Pukapukans	Ii3	Pacific	0	20				
Ramcocamecra (Canela)	Sj4	South America	4	32				[18, p. 13]
Wintun (Wintu)	Nc14	North America	1	13				[23, p. 122]

Legend:

EA = ID in Ethnographic Atlas [24].

PMR = post-marital residence: *0 = patrilocal, virilocal, avunculocal and avuncu-virilocal; 1 = ambilocal, with a marked preponderance of virilocal practice; 2 = ambilocal, neolocal and avuncu-uxorilocal; 3 = ambilocal, with a marked preponderance of uxorilocal practice; and 4 = matrilocal and uxorilocal.* Data adapted from D-PLACE variable EA012.

AHFA = average house floor area (in m^2). Data without reference are adapted from ref. [25].

MAT = wall material: I = *impermanent material; D = durable material. Label * means that walls are indistinguishable from roof or merging into the latter.* Data adapted from D-PLACE variable EA081 or EA083. *(I) or (D) = impermanent or durable material from another source than EA081 (see below).*

AGR = intensity of agriculture: *1 = no agriculture; 2 = casual agriculture; 3 = extensive or shifting agriculture; 4 = horticulture; 5 = intensive agriculture; and 6 = intensive irrigated agriculture.* Data adapted from D-PLACE variable EA028. *(3) = extensive or shifting agriculture from another source than EA028 (see below).*

SETTL = stability of settlement: *M = migratory settlement; S = sedentary settlement.* Data adapted from D-PLACE variable EA030. *(S) = sedentary settlement from another source than EA030 (see below).*

Changes to the original Porčić's sample

Porčić [25] uses AHFA of 65.7 m^2 for Kaska people from Divale's study [26]. According to primary literature [12], this value corresponds to circular lodge of the Dease river Kaska. However, the same author also mentions Upper Liard Kaska, who build smaller conical lodges with AHFA of 29 m^2. We therefore averaged both values into one, i.e., 46 m^2. In reference [25], AHFA for Iroquois is an average of Ember's [22] and Brown's [18] values. In our sample, however, we prefer to use Ember's value of 210 m^2, since Brown's code is for a single household cabin adopted after contact, not for traditional longhouse. Porčić [25] says he excluded Yakut due to conflicting reports of post-marital residence. In fact, the conflicting variable was AHFA – in Ember's sample 56 ft^2, while in Brown's 56.3 m^2. Since data in primary literature [17] are consistent with Brown's code, we included Yakut back into the sample. Porčić [25] codes Tanala's agriculture as "*not important*", however, the code in *D-PLACE* [EA028] describes intensity of agriculture as "*Intensive irrigated*".

Codes different to original variables in D-PLACE

Tucano and Tzeltal are not scored for variables EA028, EA030 and EA081. In case of Tucano, data for related population Cubeo (Se5) in D-PLACE was used instead. Tzeltal traditionally practiced extensive or shifting agriculture [27], lived sedentarily and had durable house walls made of wattle-and-daub or plain tree trunks tied with vines [28]. Manus is not scored for variables EA081, but their wall material is not durable – house is thatched with sago-leaf thatch from ridge pole to floor [29].

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S2 Supplementary material for Case Study 3

Our analysis is based on the dataset comprising 466 ground plans of Neolithic longhouses, where the floor area can be reliably reconstructed. Observing general trends, the floor area of LBK longhouses forms a positively skewed distribution with mean value 119 m^2 and median value 103.7 m^2. Outliers can be observed on the upper range (Fig. 4.2 in the main text). Ground plans included in the dataset come from 69 sites, which are spatially located on a major part of LBK distribution (Fig. A, Table B). Nevertheless, some parts of the eastern LBK zone constituting today's Ukraine, Romania, and Moldova remain underrepresented. Unfavourable soil conditions result here in a poor preservation of longhouse ground plans and problematic reconstruction of the floor area (see Saile et al., 2016). In combination with unequal research traditions and frequency of large-scale salvage campaigns, it is the western LBK zone, which is slightly overrepresented in our dataset (Fig. B).

Mapping mean and median values of floor area onto individual sites, no regional patterns or supra-regional trends can be observed. Longhouse size is randomly distributed (Fig. C). Also, the variability of dwelling size within individual sites, expressed by the floor area standard deviation, displays no clear pattern. It differs even within the same region (Fig. D). To track potential chronological variability, the dataset was divided into three groups corresponding with the main phases of the LBK culture – early, classic, and late (Fig. 4.3. in the main text). Although the early LBK houses are rather undifferentiated in their floor size, subsequent phases show more varied values. However, one should bear in mind that those chronological groups are strongly unbalanced in their sample size, as the early LBK houses suffer from worse preservation. They are represented by 22 ground plans only. On the other hand, central tendencies, with which cross-cultural analysis is dealing, are similar for all three groups (early LBK: $\mu=109$, $\tilde{x}=97.5$; classic LBK: $\mu=121.9$, $\tilde{x}=108.3$; late LBK: $\mu=120.9$, $\tilde{x}=100.4$), though a considerable contrast in group sizes thwarts any statistically significant testing of variance.

Despite some limitations mentioned above, we consider this dataset to be valid and representative for following the floor area of the LBK longhouses in general.

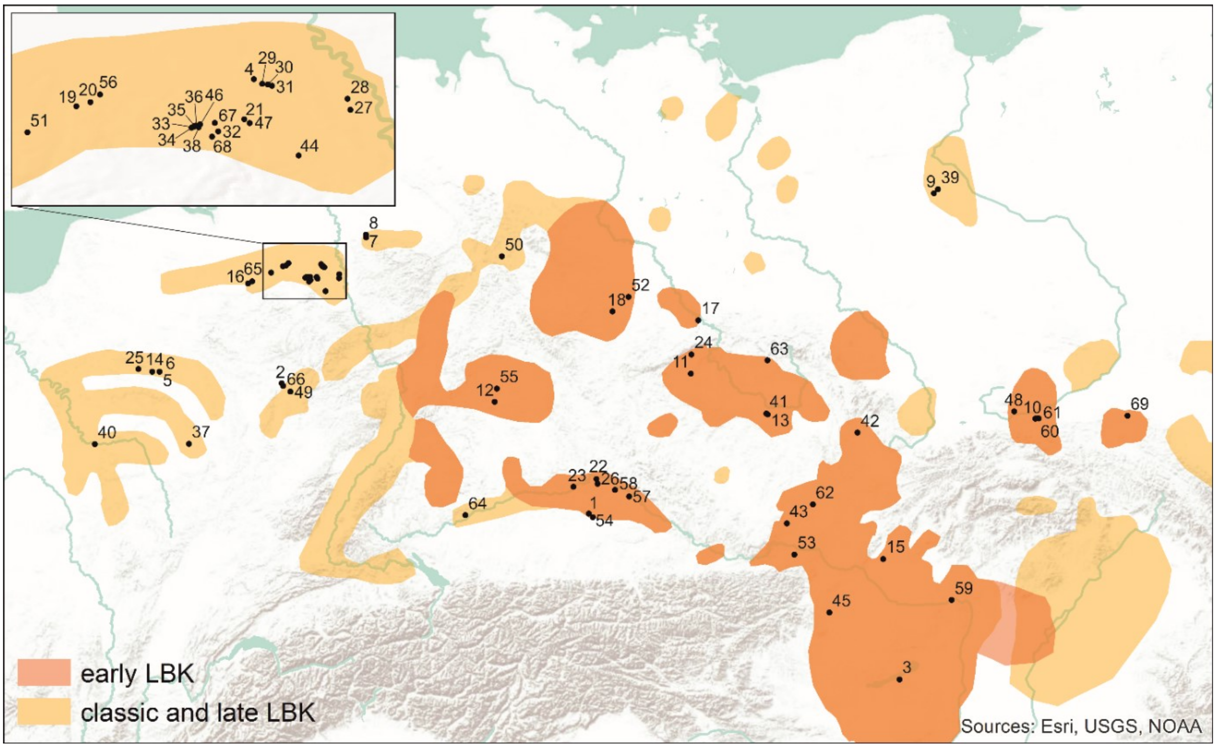

Fig. A. *Spread of the LBK and sites with analysed longhouse ground plans. For site names see Table B. (Map based on Buchvaldek et al., 2007).*

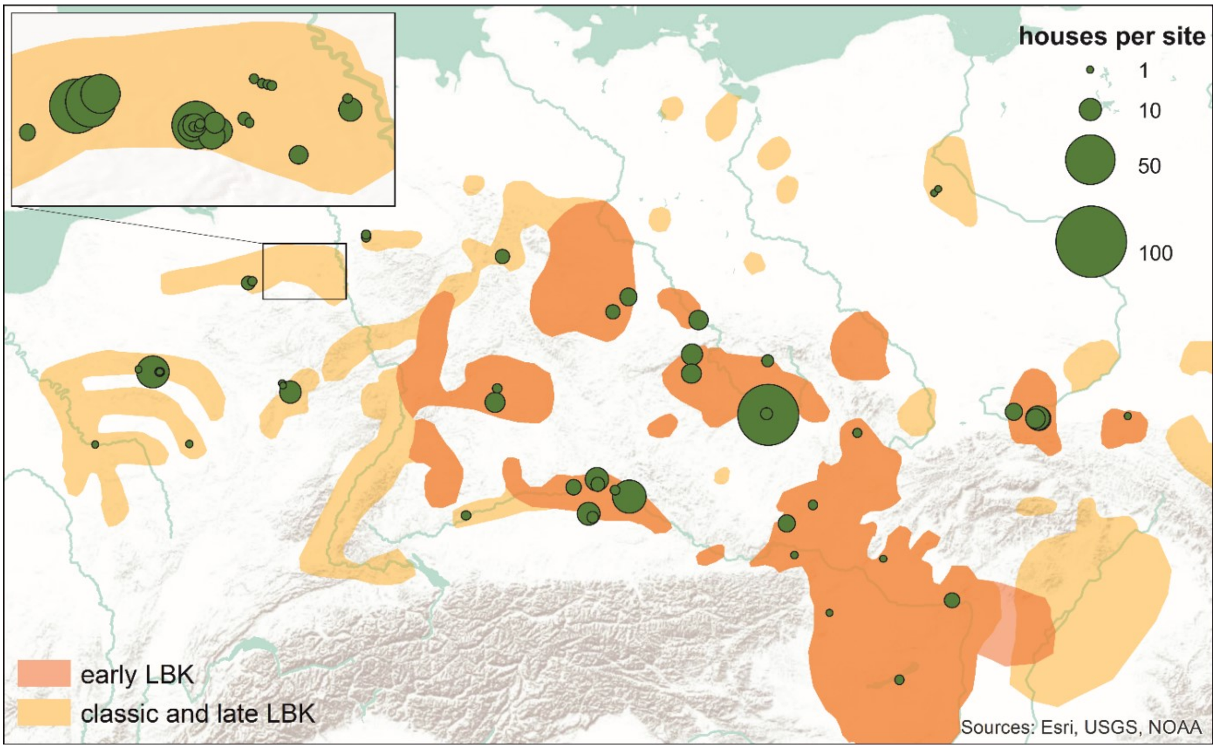

Fig. B. *Quantity of ground plans on individual sites.*

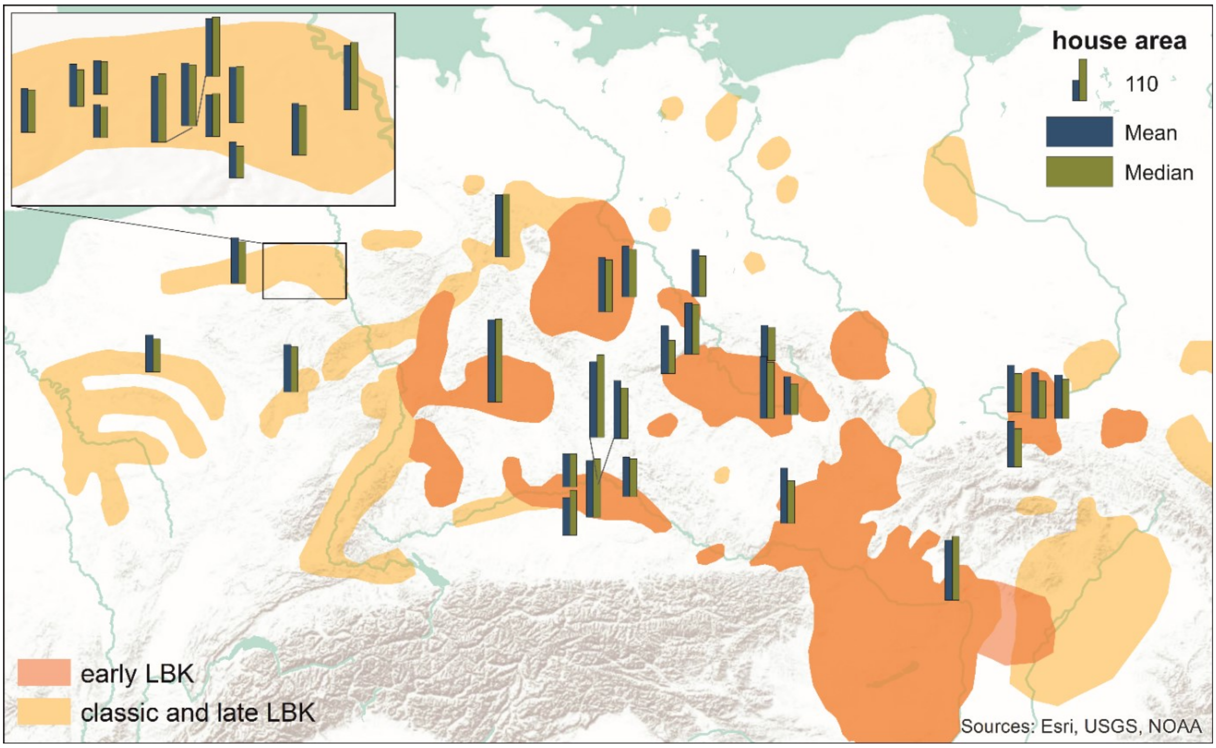

Fig. C. *Mean and median values for the floor areas at individual sites. Only sites with three or more longhouses are displayed.*

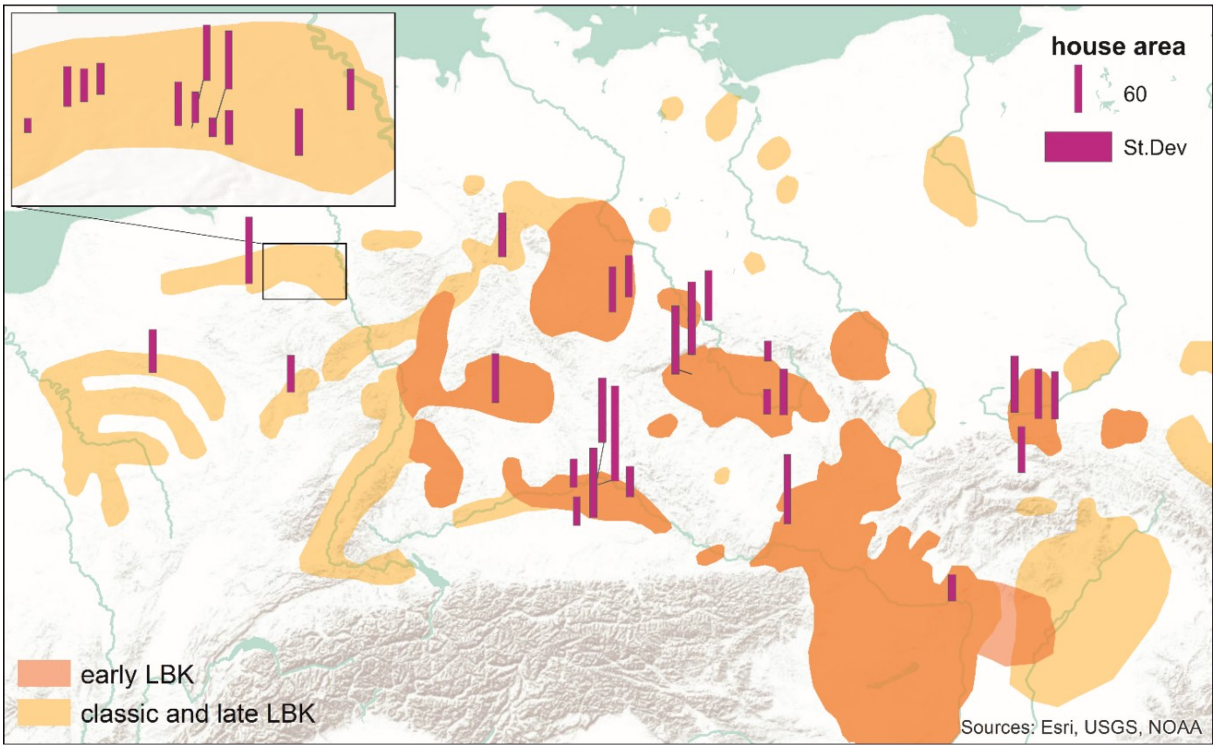

Fig. D. *Standard deviation value for the floor areas at individual sites. Only sites with three or more longhouses are displayed.*

Table B. *Analysed sites and parameters of house floor areas.*

No.	Site	Houses	Chronology	Mean	Median	St.Dev	Min	Max	Reference
1	Altdorf-Aich	11	classic	96.0	115.5	34.2	40.0	134.8	Euler (2011)
2	Alzingen-Grossfeld	1	late	114.6	114.6	0.0	114.6	114.6	Hauzeur (2006)
3	Balatonszárszó–Kis-erdei-dűlő	2	late	121.7	121.7	32.1	89.6	153.7	Oross (2010)
4	Bedburg-Garsdorf	1	_	72.8	72.8	0.0	72.8	72.8	Coudart (1998)
5	Berry-au-Bac-La Croix Maigret	1	late	179.2	179.2	0.0	179.2	179.2	Coudart (1998)
6	Berry-au-Bac-Le Chemin de la Pécherie	2	late	181.8	181.8	45.8	136.0	227.5	Coudart (1998)
7	Bochum-Altenbochum	2	late	81.1	81.1	10.0	71.1	91.1	Coudart (1998)
8	Bochum-Hiltrop/Berg. Zeche Constatntin	2	late	129.9	129.9	35.1	94.8	165.0	Coudart (1998)
9	Bożejewice 22/23	1	classic	302.4	302.4	0.0	302.4	302.4	Pyzel (2006)
10	Brzezie 17	8	classic	116.7	98.3	53.8	60.0	208.8	Czekaj-Zastawny (2014)
11	Březno	8	classic	121.9	85.9	79.4	48.0	289.0	Pleinerová and Pavlů (1979)
12	Buchbrunn	8	classic	211.0	212.3	56.6	137.8	320.4	Siller (2016)
13	Bylany	75	early-classic-late	96.2	78.0	57.0	37.7	282.1	Květina and Pavlů (2007)
14	Cuiry-lés-Chaudardes	21	late	94.1	84.0	51.3	40.0	260.4	Coudart (1998)
15	Čataj	1	classic	228.4	228.4	0.0	228.4	228.4	Pavúk (1986)
16	Darion	4	late	117.5	106.1	72.2	28.8	229.0	Bosquet and Golitko (2012)
17	Dresden-Prohlis	8	late	118.8	102.2	58.1	57.2	206.6	Link (2014)
18	Droßdorf	4	classic	138.1	131.3	48.3	87.2	202.6	Kretschmer et al. (2014)
19	Elsloo	33	classic-late	108.0	93.0	48.7	35.0	210.0	Modderman (1970)
20	Geleen	29	classic	84.2	78.0	41.0	34.0	187.2	van de Velde (2007)
21	Hambach	2	_	156.7	156.7	25.7	131.1	182.4	Coudart (1998)
22	Harting-Nord	11	classic-late	193.4	211.2	76.4	92.4	288.2	Herren (2003)
23	Hienheim-am Weinberg	5	late	84.0	84.5	31.4	44.0	132.8	Coudart (1998)
24	Hrdlovka	9	classic-late	131.7	128.0	85.8	52.4	348.0	Beneš et al. (2019)
25	Chassemy	1	late	112.5	112.5	0.0	112.5	112.5	Coudart (1998)
26	Köfering	4	classic	148.8	129.9	102.3	46.8	288.6	Brink-Kloke (1992)
27	Köln-Lindenthal	6	_	164.0	172.5	45.9	90.0	228.0	Coudart (1998)
28	Köln-Mengenich	1	late	72.9	72.9	0.0	72.9	72.9	Coudart (1998)
29	Königshoven 12	1	classic	157.8	157.8	0.0	157.8	157.8	Claßen (2011)
30	Königshoven 13	1	classic	120.6	120.6	0.0	120.6	120.6	Claßen (2011)
31	Königshoven 14	1	classic	147.3	147.3	0.0	147.3	147.3	Claßen (2011)
32	Lamersdorf 2	9	classic-late	91.9	81.8	40.4	44.0	187.6	Malcher (1992)
33	Langweiler 16	1	classic	177.6	177.6	0.0	177.6	177.6	Boelicke et al. (1994)
34	Langweiler 2	8	classic-late	167.7	173.5	65.0	55.4	254.6	Kuper (1973)

35	Langweiler 8	26	classic-late	147.0	151.7	53.4	58.2	245.3	von Brandt (1988)
36	Langweiler 9	6	classic-late	160.6	157.0	35.0	111.8	227.5	Kuper (1977)
37	Larzicourt	1	classic	229.4	229.4	0.0	229.4	229.4	Coudart (1998)
38	Laurenzberg 7	1	late	205.4	205.4	0.0	205.4	205.4	Boelicke et al. (1994)
39	Łojewo 35	1	classic	267.4	267.4	0.0	267.4	267.4	Pyzel (2006)
40	Marolles-sur-Seine	1	_	203.9	203.9	0.0	203.9	203.9	Coudart (1998)
41	Miskovice	3	early	156.4	142.1	24.9	135.7	191.4	Pavlů (1998)
42	Mohelnice	2	early	100.4	100.4	17.2	83.2	117.6	Tichý (1962)
43	Mold bei Horn	6	classic-late	142.0	109.0	79.3	49.9	256.2	Lenneis (2012)
44	Muddersheim	4	_	133.2	126.9	50.4	70.0	208.9	Coudart (1998)
45	Neckenmarkt	1	early	116.8	116.8	0.0	116.8	116.8	Lenneis and Lünning (2001)
46	Niedermerz 4	1	late	188.5	188.5	0.0	188.5	188.5	Boelicke et al. (1994)
47	Niederzier	1	_	168.0	168.0	0.0	168.0	168.0	Coudart (1998)
48	Olszanica	6	classic	119.2	96.5	63.8	60.0	249.0	Coudart (1998)
49	Remerschen-Schengerwis	10	classic-late	120.0	114.6	43.4	49.8	180.9	Hauzeur (2006)
50	Rosdorf	4	_	156.3	158.9	47.1	87.4	220.2	Coudart (1998)
51	Rosmeer	3	_	111.7	107.1	14.3	97.0	131.0	Coudart (1998)
52	Rötha	6	early-classic	130.4	121.5	47.6	75.4	217.8	Dalidowski et al. (2016)
53	Saladorf	1	classic	103.7	103.7	0.0	103.7	103.7	Lenneis (2012)
54	Sallmannsberg	3	late	144.0	149.5	70.5	55.0	227.5	Brink-Kloke (1992)
55	Schwanfeld	2	early	158.7	158.7	1.9	156.8	160.7	Lüning (2005)
56	Sittard	17	_	86.7	84.0	38.3	38.0	168.0	Coudart (1998)
57	Stephanspoching	23	classic-late	100.6	96.2	37.4	36.3	186.6	Pechtl (2009)
58	Straubing-Lerchenhaid	2	late	209.9	209.9	30.7	179.2	240.5	Brink-Kloke (1992)
59	Štúrovo	5	classic-late	152.7	162.5	28.9	98.0	182.0	Pavúk (1994)
60	Targowisko 12-13	12	late	111.2	100.8	55.9	45.2	261.3	Czerniak (2013)
61	Targowisko 16	12	classic-late	117.7	95.5	59.0	45.1	250.8	Czerniak (2013)
62	Těšetice	2	early-classic	101.4	101.4	12.0	89.4	113.4	Vostrovská and Prokeš (2012)
63	Turnov-Maškovy zahrady	3	early-classic	90.2	84.1	19.8	69.6	117.0	Bláhová-Sklenářová and Prostředník (2007)
64	Ulm-Eggingen	2	_	110.2	110.2	24.2	86.0	134.4	Coudart (1998)
65	Waremme-Longchamps	2	late	76.5	76.5	12.9	63.6	89.5	Bosquet and Golitko (2012)
66	Weiler-la-Tour-Holzdréich	1	classic	79.3	79.3	0.0	79.3	79.3	Hauzeur (2006)
67	Weisweiler 107	5	classic-late	142.0	143.8	64.8	33.2	210.9	Nockemann (2017)
68	Weisweiler 111	8	classic	107.4	110.1	21.9	58.7	133.9	Rück (2007)
69	Zwięczyca 3	1	classic	163.8	163.8	0.0	163.8	163.8	Dębiec (2014)
		466		**119.0**	**103.7**	**61.3**	**28.8**	**348.0**	

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