Community differentiation and kinship among Europe's first farmers

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Community differentiation is a fundamental topic of the social sciences, and its prehistoric origins in Europe are typically assumed to lie among the complex, densely populated societies that developed millennia after their Neolithic predecessors. Here we present the earliest, statistically significant evidence for such differentiation among the first farmers of Neolithic Europe. By using strontium isotopic data from more than 300 early Neolithic human skeletons, we find significantly less variance in geographic signatures among males than we find among females, and less variance among burials with ground stone adzes than burials without such adzes. From this, in context with other available evidence, we infer differential land use in early Neolithic central Europe within a patrilocal kinship system.

The dispersal of farming fundamentally altered social organization in Europe, providing the basis for millennia of population growth (1) and underlying the modern distribution of European languages, genotypes, and some communicable diseases (2–6). Farming spread within 5 centuries with the *Linearbandkeramik* (LBK) Neolithic cultural assemblage, from the Hungarian Plain, beginning at *ca.* 5500 cal B.C., through to the Paris Basin and the Ukraine, ending just after 5000 cal B.C. (7, 8).

These early farmers built their settlements of timber longhouses mostly on the low-lying loess soils along the river valleys of central Europe (8–10). Because they are easy to till and drain surface water well, while retaining adequate moisture, the areas of loess provided fertile and productive soils for the early crop species (e.g., barley, emmer, einkorn, pea, lentil, and flax), which were grown on small garden-like plots using intensive cultivation methods (10, 11).

Intensified agriculture may also have provided the basis for differentiation of resource access, transferred along kinship lines (8, 12, 13). Architecture, grave good assemblages, and the circulation of exotic goods, such as *Spondylus* shells from the North Aegean and Adriatic (14), suggest that social differentiation was present among LBK communities, but the models proposed for the social organization of these early farmers vary from egalitarian to highly stratified, often extrapolating from one specific case study. Wider studies of mortuary evidence have suggested the presence of a developing hierarchy throughout the 500- to 600-y span of the LBK, moving from a generally equalitarian, but gerontocratic, society toward greater differentiation within burial communities (8).

Status and wealth differences, which correlate with reproductive advantages (12, 13, 15, 16), could well be crucial for modeling and understanding the genetic consequences of prehistoric human dispersals (17). Because genetic modeling approaches also begin to incorporate sex-biased mobility differences (18, 19), there is increasing need for explicit evidence concerning these phenomena more directly.

Here, we present evidence concerning forms of social organization and differentiation at the population scale from across the LBK distribution. The evidence is derived from isotopic analysis of human skeletons, which provides indicators concerning diet, health, and place of origin that can be compared with the differing LBK burial contexts.

Among these indicators are strontium isotopes, which are conveyed from weathering rocks, waters, and soils into the food chain, and ultimately into the skeleton of local animals, where strontium substitutes for calcium, retaining the $^{87}Sr/^{86}Sr$ ratio of the mixed geologic source materials (20–26). The $^{87}Sr/^{86}Sr$ ratio in archaeological human tooth enamel thus serves as an averaged geographic signature from childhood (when the enamel mineral was mineralizing).

As part of a fresh wider study of more than 550 samples from eastern France to northern Hungary, we obtained $^{87}Sr/^{86}Sr$ ratios in new samples of tooth enamel from more than 300 human individuals interred in burial grounds, including the earliest known LBK cemetery of Vedrovice ($n = 64$; 5400–5250 cal B.C.) in the Czech Republic (27), as well as six additional LBK cemeteries (Fig. 1) of Aiterhofen ($n = 64$; 5300–5000 cal B.C.) and Schwetzingen ($n = 103$; 5100–5000 cal B.C.) in Germany; Nitra ($n = 62$; 5100–5000 cal B.C.) in Slovakia; Kleinhadersdorf ($n = 34$; 5300–4900 cal B.C.) in Austria; and Ensisheim ($n = 34$; 5200–5000 cal B.C.) and Souffelweyersheim ($n = 18$; 5200–5000 cal B.C.) in France. For convenience we refer to these latter six sites, all with similar dates and expected $^{87}Sr/^{86}Sr$ ranges, as SNAKES (Souffelweyersheim, Nitra, Aiterhofen, Kleinhadersdorf, Ensisheim, and Schwetzingen). To these data we took the opportunity to add an extra 18 individuals from Vedrovice analyzed by Richards et al. (28) and calibrated to the same Sr isotope reference standard (Dataset S1). Vedrovice has yielded the oldest radiocarbon dates so far from a cemetery context in the central European LBK (27).
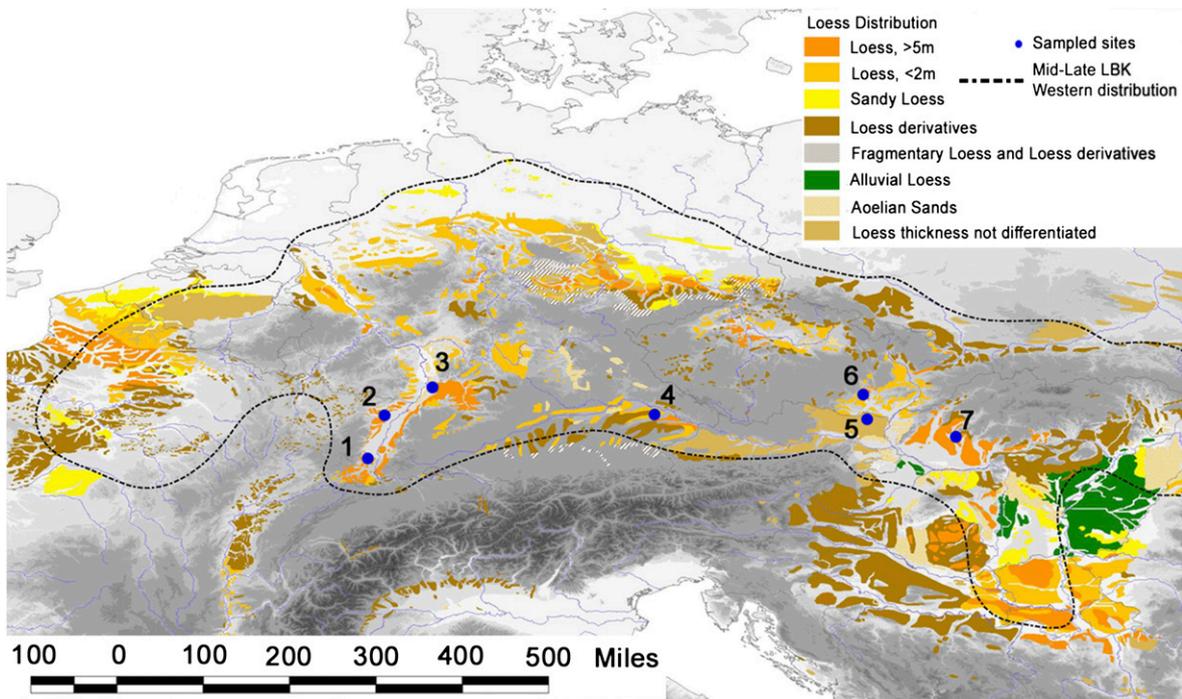
Fig. 1. Geographical distribution of loess soils in central and western Europe. Map indicates the mid to late western distribution of the LBK and the sampled cemeteries: 1, Ensisheim; 2, Souffelweyersheim; 3, Schweztingen; 4, Aiterhofen; 5, Kleinhadersdorf; 6, Vedrovice; 7, Nitra. After Loess distribution from Haase et al. (51).

As shown in Fig. 1, the SNAKES sites are all located within the belt of European loess, the widespread aeolian sediment favored by LBK farmers (2, 7, 9, 10). Certain uplands of central Europe are underlain by granitic formations of higher ^{87}Sr/^{86}Sr ratios than the more homogeneous lowlands often covered in loess (22–24, 29). Although measuring ^{87}Sr/^{86}Sr in loess deposits across this continental scale is not currently feasible (30, 31), it is known that the main sources of loess along the Danubian corridor are Alpine carbonates, with low ^{87}Sr/^{86}Sr ratios (29, 32, 33). For this reason, these similar loess soils are the basis for biologically available ^{87}Sr/^{86}Sr ratios, which range between 0.7085 and 0.7104, as characterized in LBK tooth enamel from loess-underlain sites of Alsace, Germany, Czech Republic, and Austria (22–24, 26, 29, 34–38). Situated slightly differently in this respect, Vedrovice lies at the base of the Bohemian Massif, where Precambrian contributions to the loess raise the resulting ^{87}Sr/^{86}Sr ratios in human skeletons to between 0.7108 and 0.7115 (28).

At each site, higher than expected biologically available ^{87}Sr/^{86}Sr ratios should generally indicate subsistence off the favored soils, such as (but not limited to) uplands underlain by high-^{87}Sr/^{86}Sr granitic rocks and sandstones derived from their erosion (22–24, 26, 34–38). These peripheral soils could be as close as several kilometers from the settlement (34); our inference is not that they were distant but that they were relegated to certain groups within the society.

Geology is only a coarse guide, however, to expected dietary ^{87}Sr/^{86}Sr ratios, and therefore not the crux of how we interpret our results. The ^{87}Sr/^{86}Sr ratios we measure in human enamel ultimately reflect a complex mixture of weathered sediments, streamwaters, and prehistoric anthropogenic inputs in agricultural soils (21). As a result, the ^{87}Sr/^{86}Sr in Neolithic human enamel will reflect cultural regularities of subsistence rather than an exact geologic location (20, 21, 26).

In fact, early agricultural communities often yield a range of ^{87}Sr/^{86}Sr ratios much narrower than their environmental surroundings. This is due to biopurification, whereby mammals average a variety of strontium inputs (39). Human agriculturalists typically reduce the ^{87}Sr/^{86}Sr variance even further through cultural practices altering those sources, such as the manuring and recycling of agricultural soils, and subsistence based on intergenerational cultivation of specific plots of land or favored soil types (11, 20, 25, 26).

The bio-averaging effect thus provides an opportunity for characterizing prehistoric social differentiation, by comparing the means and variances of ^{87}Sr/^{86}Sr between human groups (20, 21, 25, 26). By using the modal ^{87}Sr/^{86}Sr ratio among humans at each site as our reference points, we bypass much of the uncertainty in trying to connect geology with prehistoric behavior. By focusing on statistically significant differences in ^{87}Sr/^{86}Sr between human groups (20, 21, 26), we seek to determine whether some individuals or groups used different soils than others for their subsistence.

For this reason, in addition to the raw ^{87}Sr/^{86}Sr data, we also present these data normalized to maximize the visibility of group patterns (Dataset S1). This is done by normalizing the ^{87}Sr/^{86}Sr ratio, $R_{j,i}$ for each human individual j from site i, by subtracting mean ^{87}Sr/^{86}Sr ratio at the site, $\bar{R}_i$, and dividing by the site SD, σ_i. We refer to the normalized ^{87}Sr/^{86}Sr ratio for individual j as z_j:

$$z_j = \frac{R_{j,i} - \bar{R}_i}{\sigma_i}. \qquad [1]$$

By measuring, in units of SD, the distance of each individual's Sr isotope ratio from the site mean, we can then pool all seven sites together to examine patterns of variance among individuals across all of the sampled LBK sites.

With our interest in varied land use, and possible correlates to these differences in material culture, we focus on males buried with ground stone adzes. Found more often with males, this labor-intensive artifact is one of the most distinctive of the LBK. Fashioned from raw stone often exchanged over hundreds of

kilometers and requiring a long preparation process, LBK adzes seem to have conveyed social, or even status, differences (7, 8).

Sex is the other obvious potential differentiator: it has been suggested that early Neolithic society was patrilineal (6, 24, 40), but there are counter-suggestions (41) and compromises (42). As a result, and in context with previous archaeological studies (11, 43), our hypotheses are that the distributions of $^{87}Sr/^{86}Sr$ signatures will be (i) more variable among females than among males and (ii) less variable for males buried with a distinctive Neolithic ground stone adze.

Our main purpose is to present the strontium isotopic data set—the largest of its kind—and to demonstrate the remarkable patterns concerning sex and adzes. Results show the robust statistical support we find for these patterns in the data. Our aim lies in demonstrating the differences between groups (21, 26) and "to consider first and foremost the isotope data in a wider archaeological context, and be prepared to look for... something which is different rather than looking ab initio for a specific postcode of origin" (20). In Discussion and Conclusions, we therefore interpret the $^{87}Sr/^{86}Sr$ patterns in context with archeology (2, 3, 13), archaeobotany (11), and cross-cultural anthropology (12, 44–46), which generally support the premise that "as agricultural input intensifies, rights become more permanent and more exclusive" (13).

Results

Our results are given in Dataset S1 and summarized in Table 1 and Figs. 1 and 2. Among 382 individuals, 310 have determinations of sex, including 153 females and 147 males.

We begin by looking at differences between the sexes. When the normalized data from all seven sites are pooled together, the variance in $^{87}Sr/^{86}Sr$ is significantly larger for females ($n = 153$) than for males ($n = 147$), by an F test ($P < 0.001$ without outliers; $P < 0.01$ adding the four outliers) and by the more robust Levene's test ($P < 0.001$ with or without outliers).

In addition to measures of variance, we look at patterns above a certain threshold $^{87}Sr/^{86}Sr$ ratio. Pooling the data from SNAKES (Table 1 and Dataset S1), females and males show similar Gaussian distributions of $^{87}Sr/^{86}Sr$ ratios up to a cutoff of 0.711 (Fig. 3A), but above 0.711 there are 15 females and only three males, a significant difference ($P = 0.002$, $\chi^2 = 9.44$, df = 1).

This is evident also at five of the seven sites considered individually, where we find significantly ($P \leq 0.05$) greater variance in $^{87}Sr/^{86}Sr$ among females; the two exceptions were Aiterhofen, which showed the same pattern but not quite significantly ($P = 0.13$) and Ensisheim, the only site where the variance was not larger among females (Table 1). This statistical significance is clearest from the larger cemetery samples of Nitra, Schwetzingen, and Vedrovice (Table 1). At Vedrovice the pattern is the most significant, even with the more robust Levene's test ($P = 0.015$). At Vedrovice, adult females make up the majority

(14 of 16) of individuals with $^{87}Sr/^{86}Sr$ ratios above 0.712 or below 0.7104, which is significant even when accounting for the larger number of females in the overall sample ($P = 0.003$, $\chi^2 = 10.27$, df = 1). At Nitra, all six of the sampled individuals with $^{87}Sr/^{86}Sr$ above 0.7097 were females ($P = 0.008$, $\chi^2 = 7.10$, df = 1). At Schwetzingen, all eight individuals of identified sex with $^{87}Sr/^{86}Sr$ above 0.711 are female (one was of unidentified sex).

Taken together, these patterns indicate that women were more likely than men to have originated from, or obtained their subsistence from, areas outside the preferred loess of these LBK settlements.

We now turn to patterns regarding adzes. Among 311 sampled individuals pooled together from SNAKES, which included 62 adze burials from these six sites, only one of the 41 individuals with $^{87}Sr/^{86}Sr$ above 0.7103 is an adze burial ($P < 0.01$, $\chi^2 = 7.38$).

Because LBK adzes are disproportionately found with males, we test this also within the set of males. When the normalized data from all seven sites are pooled together, the variance in $^{87}Sr/^{86}Sr$ is significantly smaller for males with adzes ($n = 59$) than for males without adzes ($n = 88$), by an F test ($P < 0.001$, with or without outliers) and by the more robust Levene's test ($P = 0.014$ without outliers; $P = 0.037$ adding the three male outliers).

When the sex of a skeleton cannot be determined definitively but is suggested by certain skeletal traits, the individual is identified as a "probable" male or female (47). If we restrict ourselves just to the males sexed definitely ($n = 59$ with adzes, $n = 63$ without) the difference is still significant by Levene's test ($P < 0.01$ without outliers; $P = 0.024$ adding the three male outliers) and by F test ($P < 0.0001$, with or without outliers). Alternatively, if we look at just the raw $^{87}Sr/^{86}Sr$ data from 128 males sexed most definitely from the six sites of SNAKES, the $^{87}Sr/^{86}Sr$ from both males with adzes and males without adzes follow a similar normal distribution below 0.7103 (Fig. 3B), but above this value only one of the 15 definite males has an adze ($P < 0.005$, $\chi^2 = 7.71$).

With smaller sample size at the individual sites, the adze pattern is still significant among the larger samples from Vedrovice and Nitra. At Vedrovice, we find among the 19 identified males that the 10 adze burials had significantly smaller variance in $^{87}Sr/^{86}Sr$ than the nine without adzes ($P < 0.01$, F test; $P = 0.07$, Levene's test). Among five highest and five lowest $^{87}Sr/^{86}Sr$ ratios among Vedrovice males, only two are adze burials ($P = 0.04$, $\chi^2 = 4.27$, df = 1). At Nitra, seven of the 17 identified males had adzes, four of which make up the lowest four $^{87}Sr/^{86}Sr$ ratios of all Nitra males ($P = 0.02$, $\chi^2 = 5.71$, df = 1).

Discussion and Conclusions

The results confirm that $^{87}Sr/^{86}Sr$ signatures are more variable among females than among males and less variable for males buried with adzes. We interpret these results as consistent with

Table 1. Summary of results from each site

Site	Start cal B.C.	n (all, F, M)	Site median $^{87}Sr/^{86}Sr$	Females mean $^{87}Sr/^{86}Sr$	Females σ $^{87}Sr/^{86}Sr$	Males mean $^{87}Sr/^{86}Sr$	Males σ $^{87}Sr/^{86}Sr$	F test sex P value	F test adze P value
Vedrovice	5450	64, 32, 19	0.71111	0.71073	0.00102	0.71098	0.00070	0.05	<0.01
Aiterhofen	5300	65, 24, 35	0.70951	0.70958	0.00044	0.70947	0.00036	0.13	0.42
Ensisheim	5200	34, 12, 15	0.70925	0.70932	0.00067	0.70936	0.00075	0.36	<0.01
Souffelweyersheim	5200	18, 3, 9	0.70886	0.70969	0.00155	0.70890	0.00024	<0.01	0.13
Kleinhadersdorf	5200	33, 9, 11	0.70991	0.71011	0.00121	0.70980	0.00055	0.01	0.42
Schwetzingen	5100	103, 48, 41	0.70979	0.71014	0.00086	0.70987	0.00053	<0.01	0.04
Nitra	5100	63, 25, 17	0.70947	0.70953	0.00035	0.70946	0.00013	<0.01	0.18

The first F test column is a one-tailed test that the variance in $^{87}Sr/^{86}Sr$ ratios is greater among females than males; the second is the one-tailed test that variance in $^{87}Sr/^{86}Sr$ ratios among males without adze is greater than among males with adze. The symbol σ denotes SD, and the column showing sample size n shows all individuals, identified females (F), and identified males (M).
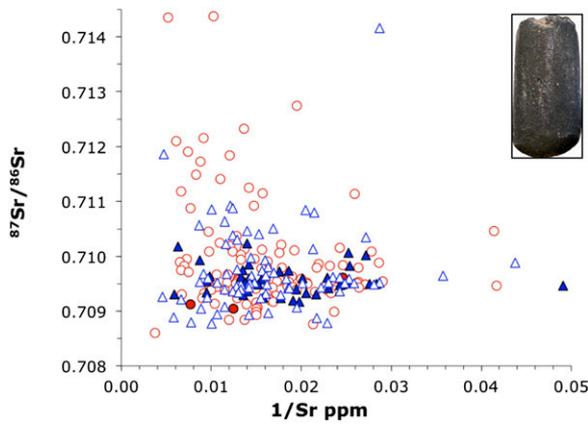
Fig. 2. The ^{87}Sr/^{86}Sr vs. 1/Sr from adult individuals of identifiable (definite or probable) sex. Circles show adult females, triangles show adult males, and filled symbols denote individuals buried with an adze. *Inset*: Typical LBK adze.

patrilocality, and with differential use of—or access to—preferred loess soils for males with adzes. Alternative interpretations for the patterns could be proposed—the former as indicating marginal land access for women, and the latter as indicating that males without adzes moved for marriage, whereas males with adzes did not—but such explanations are not well supported by archaeological or genetic evidence.

The difference in strontium isotope signatures between adze and nonadze burials is either due to different geographic origins of the food (plots of land), or possibly to different combination of foods (from a variety of locations) among the adze and non-adze groups. In either case, this demonstrates a difference of lifeways between the adze and non-adze groups.

The males buried with adzes, with their narrow range of ^{87}Sr/^{86}Sr signatures compared with others, apparently derived their subsistence from a remarkably consistent source material. This was the case across hundreds of kilometers of Central Europe and several different regional mortuary/cultural traditions. Loess soil, being widespread across central Europe, consistent with these ^{87}Sr/^{86}Sr ratios, and preferred for LBK settlement (2, 8–10), is by far the best candidate for these signatures, especially if cultivated for generations toward homogeneity.

For the SNAKES sites, considering that we expect loess areas not generally to yield ^{87}Sr/^{86}Sr above 0.7103, this indicates that males buried with adzes derived more of their subsistence from loess areas compared with those buried without an adze. The same is true at Vedrovice, with shift in the expected ^{87}Sr/^{86}Sr range for loess at the base of the Bohemian Massif.

This suggests that, by the developed phase of the LBK, males buried with adzes had the most consistent access to preferred loess soils (with ^{87}Sr/^{86}Sr ratios below 0.7103). This gains support from independent archaeological evidence from cereal husbandry practices that independently indicates the differential, intergenerational transfer of access to the most productive growing areas (11). Although these differences may reflect the colonization process, because the earliest groups control the best land, another possible explanation is that these differences took hold through transhumance, with male stockherders living much of the year outside the loess (and not needing adzes). In any case, these differences are reflected across the LBK distribution in time and space, which suggests they were foundational to more pronounced inequality later in prehistoric Europe.

The pattern among the sexes is quite consistent with marriage within a patrilocal kinship system, which is also consistent with independent archaeological (11, 43), genetic (6, 18, 19, 48), anthropological (16, 44–46), and even new linguistic (49) evidence concerning Neolithic Europe. These results have implications for genetic modeling of Neolithic expansion, for which sex-biased mobility patterns and status differences are increasingly seen as crucial (17–19, 40). Generally speaking, "male inheritance of land means that males tend to live where they were born, while females marry and move elsewhere" (40). Because patrilocality, intergenerational wealth transfer, and agriculture tend to correlate in small-scale societies (12, 13, 40, 44, 46), a simple explanation is that unequal and inherited land access developed in time among the early farmers in Central Europe (cf. ref. 50).

Two decades ago, Bogucki (9) considered it fairly likely that "individual residential units were responsible for the cultivation of particular plots" during the LBK, that "the household had exclusive rights to the crops produced by this plot," and that "fields were located as close to the houses of their cultivators as possible" (p. 119). Our evidence, along with archaeobotanical evidence (11), supports this, and suggests that the origins of differential access can be traced back to an early part of the Neolithic era (13) rather than only to later prehistory when

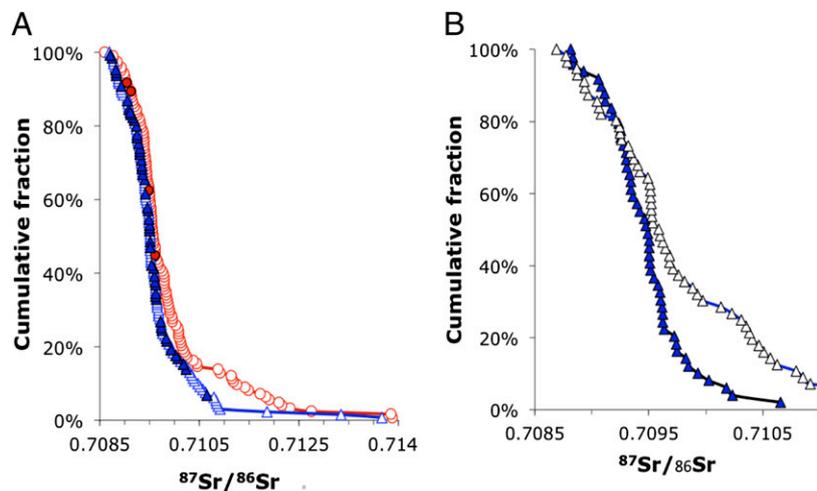**Fig. 3.** Cumulative distribution plots of ^{87}Sr/^{86}Sr in human enamel from sampled LBK individuals at SNAKES. (*A*) Individuals sexed either definitely or probably; (*B*) adze vs. no adze among males sexed definitely. Circles show adult females, triangles show adult males, and filled symbols denote individuals buried with an adze.

inequality and intergenerational wealth transfers are more clearly evidenced in burials and material culture (8, 50).

Materials and Methods

We analyzed samples of enamel from the molars or premolars of more than 300 LBK human skeletons. Based upon preservation and availability, the molar selected was typically M1 or M2, but occasionally M3, and premolars for Schwetzingen. Although these molars mineralize at different times of life, there is no statistical correlation between the molar sampled and the patterns of sex or adze described. Using an established procedure, approximately 5 mg of tooth enamel from each individual was mechanically cleaned and dentine removed with a surgical steel scalpel, and soaked for 1 h in weak [5% (vol/vol)] acetic acid. Each sample was then dissolved in 3 N HNO_3, purified by extraction chromatography in polyethelyne columns with Sr-spec Resin. With the purified Sr in 3% (vol/vol) HNO_3 acid, $^{87}Sr/^{86}Sr$ analyses were carried out

on a Thermo Electron Neptune Multi Collector Mass Spectrometer in the Department Earth Sciences, Durham University. Over all of the separate analytical sessions, the average composition and reproducibility of the 212 analyses of NBS 987 Sr isotope reference material (0.71024) was 0.710262 ± 0.000001 (1 SE). Blanks were typically below 10 pg Sr and always below 30 pg Sr for all runs.

From $^{87}Sr/^{86}Sr$ ratios in 311 LBK human individuals, five outliers were identified. One (Nitra burial 17/64) had 483 ppm Sr, which suggested possible postburial contamination. The four others (Schwetzingen female burial 54 and male burial 132, and Aiterhofen female burial 92 and male burial 57) had $^{87}Sr/^{86}Sr > 0.713$, several SDs from the means at their respective sites. These outliers were excluded in calculating the mean $^{87}Sr/^{86}Sr$ at each site.

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