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Sr isotopes in horn cores provide information on Early Modern cattle trade

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ABSTRACT: Stable strontium isotopes ($^{87}Sr/^{86}Sr$) were used to detect residence changes of apparently non-local long horned cattle. A find of horn cores from an Early Modern site near Enns (Austria) was investigated with regard to long-distance trade stock on the hoof during this period. Appositionally growing horn core was analysed in order to detect the geographical origin and the age of residence change in a selection of specimens. The results show that for parts of southern Germany and Austria, remains of long-horned cattle previously assumed to come from traded individuals of allochthonous origin because of their distinct morphology, in a number of cases represent animals of local origin.

KEY WORDS: TRADE, $^{87}Sr/^{86}Sr$, HORN CORE, ENNS, AUSTRIA, LONG-HORNED CATTLE

RESUMEN: Las relaciones de isótopos estables de estroncio ($^{87}Sr/^{86}Sr$) han sido utilizadas para detectar cambios de residencia de ganado cuernilargo, de aparente origen no local, en un yacimiento. A tal fin una serie de clavijas óseas del yacimiento de época moderna próximo a Enns (Austria) han sido estudiadas en relación con las hipótesis de desplazamientos a larga distancia del ganado vacuno que presumiblemente ocurrieron durante este periodo. Clavijas óseas de crecimiento aposicional han sido analizadas para determinar el origen geográfico y el momento de cambio de residencia en una serie de especímenes. Los resultados del estudio demuestran que en determinadas partes del sur de Alemania y de Austria, restos de vacuno cuernilargo que habían sido previamente asumidos como evidencia de individuos de origen alóctono debido a su peculiar morfología, puede que representen en algunos casos animales de origen local.

PALABRAS CLAVE: COMERCIO, RELACIONES $^{87}Sr/^{86}Sr$, CLAVIJAS ÓSEAS, ENNS, AUSTRIA, GANADO VACUNO CUERNILARGO

INTRODUCTION

A large amount of horn cores of domestic cattle were recovered during the excavations at the "horn core site" of Enns in the vicinity of the town of Linz in Austria (Knecht 1966, cf. fig. 1). The sample totalled 322 horn cores, with no admixtures of other skeletal elements. Based on its archaeological contents, the site can be roughly dated to the 14th till 18th century AD. Most probably, the site/area had been used for the retrieval of the keratin in the horn sheath, which was achieved by letting the horns rot in water in order to be able to separate the horn sheath from the bony horn core. In archaeological contexts, complete horn cores of cattle are quite rare, because taphonomic processes will result in a higher degree of fragmentation compared to horn cores from sheep or goat, which are more dense and robust (Driesch, 1976).

Some of the horn cores recovered at the site belonged to a long-horned type of cattle, which was uncommon in that area of NW-Austria at that time. Longhorns can be distinguished from shorthorns by the relation of the outer curvature to the base of the circumference. An index surpassing 180 is considered characteristic for long horn cattle, one between 100 and 180 for a middle horned specimen and an index below 100 is taken as a short horn (Armitage, 1982).

Horn core growth starts about two weeks after birth and ends, depending on the breed and sex, at an age of approximately six years. The tip grows

FIGURE 1

Geology and location of the site of Enns.

fast and up to 1cm per month between 18 and 21 months of age, and decreases to only 0,5 mm per month at the age of six years (Duerst, 1926). The base of the horn core grows in width by the formation of new bone layers at the periosteal side between the horn core and the horn sheath. The endosteal part or inner layers of the horn core will be re-absorbed progressively, leading to the cavity (lateral drift). The endosteal part of the horn core base will therefore represent the oldest part of a horn core, its youngest part being located at the tip. Following Armitage (1982), the surface texture of the horn cores was used to age individuals. These macroscopic stages are unfortunately highly variable with a precision of up to plus/minus three to four years.

In previous studies (e.g., Knecht, 1966), it was assumed that the horn core finds excavated represent long horn cattle that originated from the Pannonian Plain, where this breed was kept and raised until maturity to be sold later on in Austria and southern Germany. Early Modern times witnessed the establishment of extensive cattle trade networks across Europe as a result of a constantly growing urban population. Since local agriculture failed to provision cities, long-distance trade of animals on the hoof and of other agricultural products had to be intensified to compensate for this (Henning, 1979). Several historical records and toll registers mention so-called “Oxen Routes”, used for cattle drives (e.g., Braudel, 1985). Every year, for example, several thousands of “half-domesticated” oxen were traded from the Pannonian Plain via Vienna, Linz and Passau up to Regensburg (Pfeffer, 1949). It would, therefore, be of interest to verify whether the cattle found near Enns represent animals from such drives. Moreover, an identification of the age at which individual cattle began their journey would give clues to the mode of long-distance trade and inform us about the time elapsed between the animal’s arrival in the Linzer region and the moment of its slaughter.

The identification of non-local human remains at archaeological sites has been performed by comparing stable strontium isotope ratios in bone and tooth enamel taken from the same skeleton. Significant differences in the strontium isotope signature of these two tissues, which mineralise at different ontogenetic stages, are interpreted in terms of at least one residence change between childhood and adulthood (Grupe *et al*., 1997; Price *et al*., 2000). Strontium isotopic values reflect the local geological situation and thus serve as a marker of residence change in prehistoric and historical times. This approach has proved to be a valuable tool for the detection of geographical origin of humans, animals and also food items (Ericson, 1989; Price *et al*., 1994; Sealy *et al*., 1995; Sillen *et al*., 1995; Ezzo *et al*., 1997; Horn *et al*., 1998; Bentley *et al*., 2004; Schweissing, 2004). Unravelling the moment of residence change during the life of cattle should be possible by the investigation of appositionally grown tissue like horn core. For sampling this rather big and fast growing skeletal element, it is not appropriate to apply microsampling techniques. As such, bulk analysis suffices, since enough bone material is available for each of the major consecutive time periods. Since we do not know yet which part of the horn core enables one to reconstruct the whereabouts of a particular individual in detail, microsampling methods are useless, even at the risk of being put up with mixed isotopic ratios covering a larger, yet defined period of time.

MATERIAL AND METHODS

The areas of southern Germany, Austria and the Czech Republic are geologically different in terms of their strontium isotopic ratios. Between the Alps and the Danube river, soils are mostly characterised by carbonates with $^{87}Sr/^{86}Sr$ ratios between 0,708 and 0,709. The area northeast of the Danube is characterised by granitic substrates ($^{87}Sr/^{86}Sr$ >0,71) with small intrusions of gabbro and metagabbro ($^{87}Sr/^{86}Sr < 0,706$) (Figure 1). The Pannonian Plain in Hungary consists mainly of carbonates which have also, like the Bavarian soil, Sr isotopic values between 0,708 and 0,709. For this study, a preliminary cut-off value of 0,001 in $^{87}Sr/^{86}Sr$ between the horn core sample and the soil of the excavation site was used to discriminate between autochthonous and allochthonous individuals. These cut-off values discriminate very sharply between carbonate granitic and gabbro soils, but not within granitic soils, where the Sr-isotopic values vary between 0,71 and 0,72. The isotopic variation of granitic soils can exceed 0,001 within small regions and is therefore potentially helpful for a geographic discrimination on a much smaller scale. Unfortunately, no geological maps documenting this kind of small scale variability in isotopic signature of granitic soils are available for the area under study. The interpretation of local and non-local isotopic signatures can therefore only be done at the 0,001 level.

Horn cores of four long-horned (L2, L3/4, L5, L10/17) and two short-horned individuals (L4/13, L9/5) were selected for Sr analysis. All individuals appeared mature, with an approximate age of 3 to 10 years for L3/4, L5, L10/17 and L9/5, whereas L2 and L4/13 were estimated between 2 and 7 years old. For each individual, the horn core was sampled at the tip (from apical to basal) and at the base (from periosteal to endosteal), the analytical units thus representing different ontogenetic stages. Sampling at the tip, the youngest part of the horn core, was done at a 2 mm interval, whereas a 1.5 mm interval was chosen to sample the horn core basis from the periosteal to the endosteal surface. The minimum bone weight required for analysis was 50 mg. When available, a compact bone sample from the skull was analysed also, since the slowly remodelling skull bone should reflect the lifetime average of isotopic ratios of incorporated strontium. For specimen L 10/17, only the basal part of the horn core could be sampled because the tip of the horn core was missing.

Since the Hungarian Plain has been considered the region of origin of the long-horned cattle excavated at Enns (Knecht, 1966), it was considered useful to include material from that particular region in our analysis. L. Bartosiewicz (Institute of Archaeological Sciences, Budapest) kindly provided a faunal sample from the site of Székesfehévar, from which a first molar of an individual aged between 1 and 2 years was selected for analysis. Besides, two soil samples, one from Enns and one from Székesfehévar, were also analysed in order to obtain the isotopic signatures from these two sites.

Sample pre-treatment followed the protocol established by Grupe *et al.* (1997). The samples were cleaned under running tap water and then defatted with diethylether for 5 hours in a Soxhlet reflux device. Possible contaminations were removed by etching the samples ultrasonically for 5 minutes in concentrated formic acid. Leaching experiments proved that this etching time should suffice for a decontamination because of the identity of Sr isotope ratios in leachate and the remaining bone specimen achieved after that time. The organic matrix was removed by burning the samples to ashes for 12 hours at 500°C. The samples were then homogenised in a ZrO_2-coated mill (particle size approx. 5µm) and about 50 to 100mg of horn core powder was wet-ashed under pressure in 1ml concentrated HNO_3 for 6 hours at 160°C together with 30 mg of a ^{84}Sr-spike (NBS 988, National Bureau of Standards, Washington DC). Then 9 ml distilled water was added to complete the stock solution (10ml). The acid was evaporated at 120°C in a clean-air-bench and the sample solubilised for 24 hours in 3 ml 6N HCl, which was evaporated again and the sample solubilised in 3 ml 2,5N HCl. 2 ml of each sample was centrifuged to remove any remaining silica. The solution was then passed twice through a cation exchange column (Dowex AG 50Wx8, 200-400 mesh, using 2,5N HCl as mobile phase), to separate interfering Rb from Sr. All chemicals involved in this protocol were of suprapure quality.

Sr-isotope ratios were measured using a thermal ionisation mass spectrometer (MAT 261 Finnigan Corp. San Jose, CA) at the Institut für Allgemeine und Angewandte Geologie (IAAG), München. The samples were analysed on rhenium filaments by the double-filament-technique. Standard reference material SRM 987 (National Bureau of Standards, Washington DC) served for quality control. In addition, standard reference material SRM 1400 "bone ash" (National Bureau of Standards, Washington DC) was used to control the wet ashing and the column exchange procedure. Average measurement error of the mass spectrometer was 0,00002.

RESULTS

20 samples of NBS 1400 bone ash standard varied between 0,713091 and 0,713118. NBS 987 had a mean value of 0,710235 (sd: 0,000019), matching the value of 0,710230 which is internationally agreed upon (Steiger & Jäger, 1977).

The horn core samples analysed cover various stages of each individual's life, while the skull bone sample reflects the accumulated strontium during the course of a lifetime. Appositional growth at the tip of the horn core is faster than appositional growth by lateral drift at the base. For this reason samples from the base represent older ontogenetic stages. Measurement data for the cattle are presented relative to the individual's developmental stage (Table 1, Figures 2-5), based on the average values for horn core growth in long-horned breeds (Armitage, 1982). The measurement data for the latest growth phases of the horn cores are located on the left side of the x-axis, those for the growth of phases earlier in life on the right side.

Horn core L2 tip	$^{87}Sr/^{86}Sr$
L2 1	0,711142
L2 2	0,711095
L2 3	0,711092
L2 4	0,711040
L2 5	0,711019
L2 6	0,710931
L2 7	0,710982
Horn core L2 base	$^{87}Sr/^{86}Sr$
L2 a	0,710944
L2 b	0,710943
L2 c	0,711203
L2 d	0,711131
L2 e	0,711364
L2 f	0,711500
L2 g	0,711537
Bone L2	0,711346
Horn core L3/4 tip	$^{87}Sr/^{86}Sr$
L3/4 1	0,709956
L3/4 2	0,710043
L3/4 3	0,710420
L3/4 4	0,710435
L3/4 5	0,710529
L3/4 6	0,710642
L3/4 7	0,710698
L3/4 8	0,710841
Horn core L3/4 base	$^{87}Sr/^{86}Sr$
L3/4 a	0,710643
L3/4 b	0,710436
L3/4 c	0,710245
Horn core L4/13 tip	$^{87}Sr/^{86}Sr$
L4/13 1	0,709872
L4/13 2	0,709878
L4/13 3	0,709829
L4/13 4	0,709965
L4/13 5	0,709983
Horn core L4/13 base	$^{87}Sr/^{86}Sr$
L4/13 a	0,7104489
L4/13 b	0,7104706
L4/13 c	0,7103508
L4/13 d	0,710267
L4/13 e	0,710262
L4/13 f	0,710236

Horn core L10/17 base	$^{87}Sr/^{86}Sr$
L10/17 a	0,7058569
L10/17 b	0,7064324
L10/17 c	0,7064324
L10/17 d	0,7068292
L10/17 e	0,7074739
L10/17 f	0,7071652
Horn core L9/5 tip	$^{87}Sr/^{86}Sr$
L9/5 1	0,7102726
L9/5 2	0,7101916
L9/5 3	0,7102254
L9/5 4	0,7102644
L9/5 5	0,7102484
L9/5 6	0,7105484
Horn core L9/5 base	$^{87}Sr/^{86}Sr$
L9/5 a	0,715998
L9/5 b	0,716230
L9/5 c	0,717535
L9/5 d	0,716606
Horn core L5 tip	$^{87}Sr/^{86}Sr$
L5 1	0,710053
L5 2	0,710011
L5 3	0,710050
L5 4	0,710066
L5 5	0,710091
Horn core L5 base	$^{87}Sr/^{86}Sr$
L5 a	0,7096973
L5 b	0,7103737
L5 c	0,7105601
L5 d	0,7107814
L5 e	0,7107694
L5 f	0,7108248
L5 g	0,7115781
L5 h	0,7145845
Hungarian Cattle	$^{87}Sr/^{86}Sr$
tooth	0,710052
Soil sample	$^{87}Sr/^{86}Sr$
Enns (Austria)	0,71402
Székesfehévar (Hungary)	0,709482

TABLE 1

Sr-isotopic values ($^{87}Sr/^{86}Sr$) of the horn cores and soil samples.

From Figure 2 it becomes obvious that in horn core L2, slow isotopic change during the younger stages of life of the individual is followed by a faster change close to the death of the animal. The chronologically youngest layer of precipitated bone, which corresponds to an age shortly before death, matches the isotopic signature of the locality where the animal had been slaughtered. All isotopic ratios of this specimen exceed 0,71 and point therefore to an origin and feeding of the animal on "granitic" soils, but with considerable variation on a small scale.

Large variations in the isotopic values during their lifetime can be also seen in samples L5 (Figure 3) and L9/5 (Figure 4), again indicating that also these two individuals probably originated elsewhere. This is suggested by the fact that the consecutive ontogenetic stages exhibit different isotopic values which at no time correspond to the Sr signature obtained from the soil sample at the site. Both horn cores (L5, L9/5) show big differences between the tip of the horn core and the base. Whereas L5 shows only one value which differs from the others in terms of the cut-off value defined above, differences in the values between the samples of L 9/5 exceed 0,005. Nevertheless, all isotopic values are typical granitic signals, just like those measured in L2. This means that these presumed non-local specimens were all raised and kept in areas with granitic soils, isotopically very close to the geochemistry of the excavation site. The longhorn L10/17 shows no significant differences in isotopic signature between the consecutive ontogenetic stages, but clearly differs from the soil signature measured at the excavation site (Figure 5). It is therefore possible to specify the geographic origin of this individual: Its Sr isotopic values, which cluster around 0,706, are typical for the metagabbro and gabbro soil types, located in Bohemia (cf. Figure 1).

Horn core L3/4, another specimen pertaining to a long-horned breed, shows no geologically significant variations in the isotopic values of its basal and apical parts. All values, however, differ clearly from the one obtained from the soil of the site. The same applies to L4/13, a specimen representing a short-horned breed (Table 1).

The cattle molar from the site of Székesfehévar produced a Sr-isotopic value of 0,710052 (Table 1), which surprisingly does not match well with the one obtained from the local soil (0,7094482).

DISCUSSION AND CONCLUSIONS

According to the historical record, driven cattle were nourished on the spot during their journey. With the exception of individual L10/17, it beco-

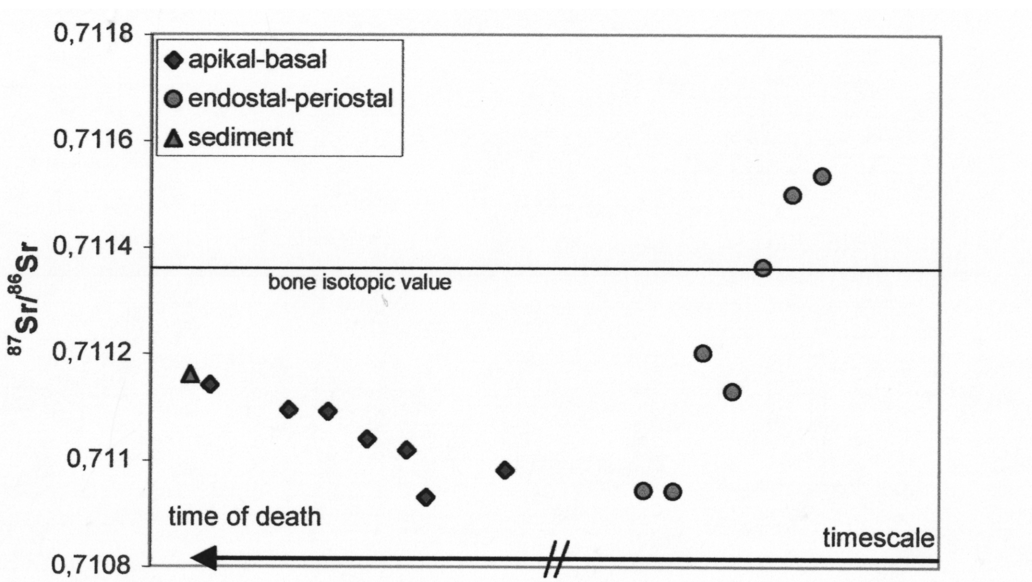

FIGURE 2

Change of isotopic values of horncore samples from L2 (longhorn) through time.

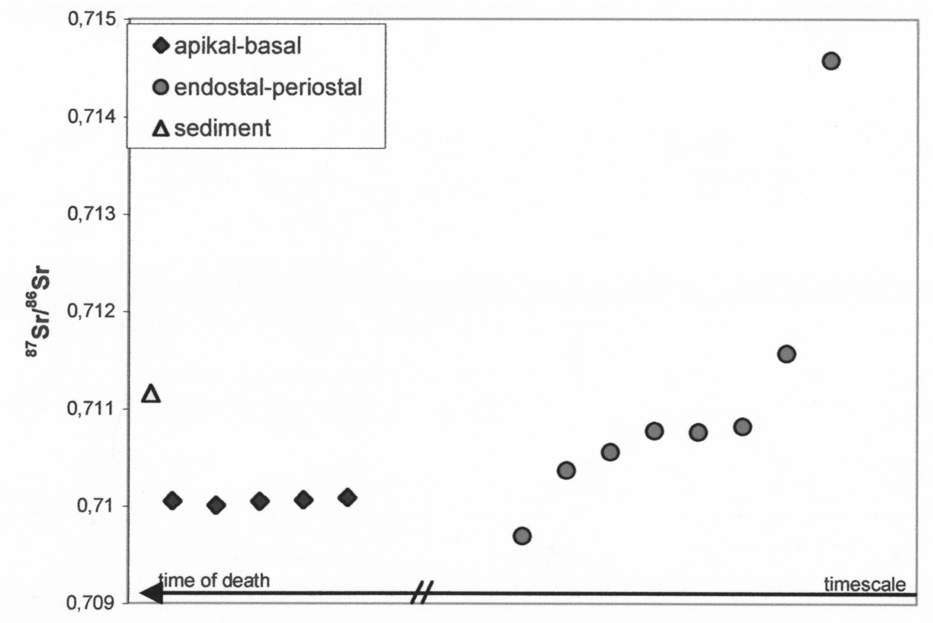

FIGURE 3
Change of isotopic values of horncore samples from L5 (longhorn) through time.

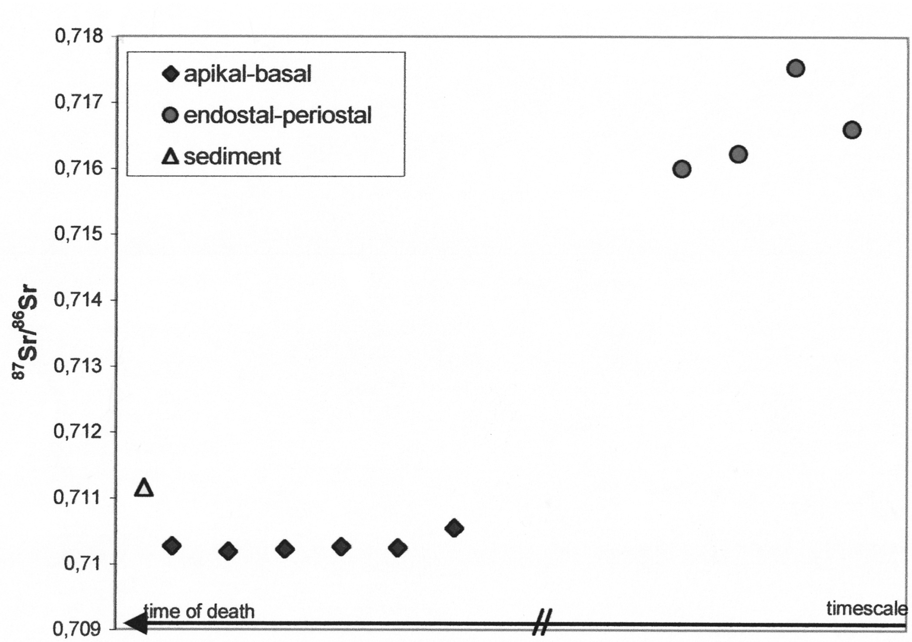

FIGURE 4
Change of isotopic values of horncore samples from L9/5 (shorthorn) through time.

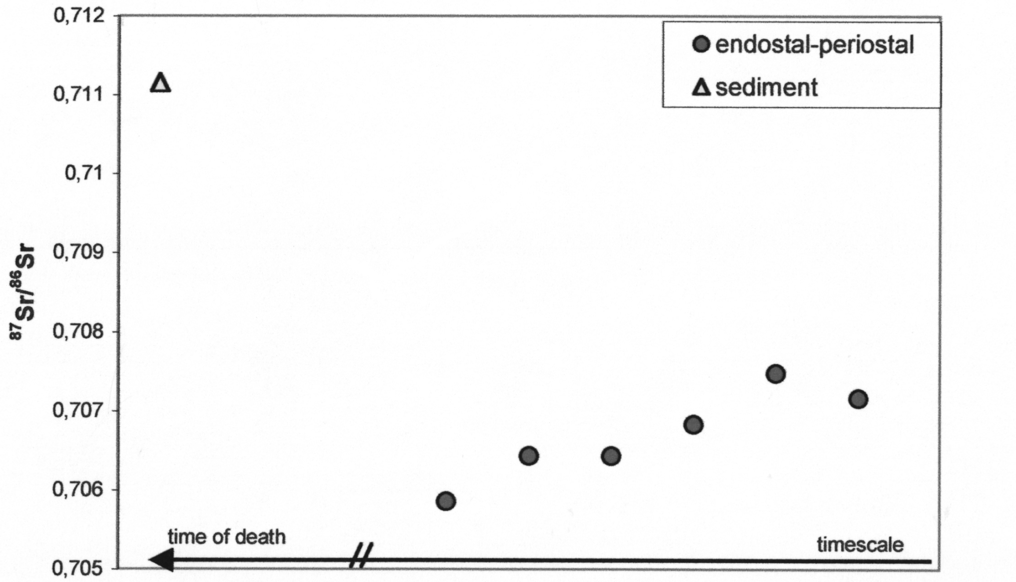

FIGURE 5
Change of isotopic values of horncore samples from L10/17 (longhorn) through time.

mes obvious that our analysis does not help much to specify the geographic origin of these animals. Of interest, however, is the fact that the youngest part of the horn core of L2 exactly matches the geochemistry of the slaughtering place, indicating that the individual was allowed to feed for at least some weeks at the place where its journey had ended. This has been a very common practice since the animals would put on weight and could be sold at a higher price (Schweissing & Grupe, 2003).

Two other individuals (L5, L9/5) do also show a proximity in their youngest isotopic values to the soil sample collected at Enns. While they do not exactly match the isotopic signature of the excavation site, they nevertheless are much closer to it than are the older parts of the horn cores, representing earlier ontogenetic stages. One possible explanation is that the animals originated from nearby places within the region, but that after the animals had been slaughtered, the horns (together with the skins?) were delivered at the site for further preparation. This hypothesis is supported by the lack of bones from meat-bearing body parts at the site and its vicinity.

Admittedly, the earlier assumption that the remains of long horn cattle excavated at Enns represent animals imported in large numbers from the Pannonian plain can neither be supported nor falsified by our analysis of only a small number of horn cores. However, the assumption should be adjusted in so far as the allochthonous cattle were obviously not slaughtered immediately upon arrival, and that longhorns were also kept in areas unknown as breeding centres for this type of cattle. The results obtained for individual L10/17 definitely show that longhorns also existed in Bohemia and that the animals had been traded over distances of more than 100 km to places like Enns. Specimen L3/4 as a local individual consolidates the assumption that long horn cattle was not only traded from distant places but that they were part of an indigenous cattle population. Our results also indicate that even shorthorns, the commonest type of cattle in the study area at that time, were traded since the isotopic values of L9/5 indicate an individual of non-local origin. Most surprising, however, is the fact that none of the allochthonous individuals exhibit isotopic values evidencing an origin on the Pannonian plain ($^{87}Sr/^{86}Sr$ = 0,708-0,709) where, based on historical sources, large herds of long horn cattle were raised and then driven to Austria and southern Germany. We have to stress that the single tooth from Hungarian cattle measured by us exhibited a Strontium isotopic ratio slightly different from the one obtained for local carbonate soils. Although no detailed geological maps of this region exist, minor variations in the geochemical composition of the different soils could account for this result. This, however, does not interfere with the results obtained on the horn cores from the site of Enns.

We conclude that the analysis of stable strontium isotope ratios of appositionally grown mineralised tissues like horn cores can serve as a proxy for trade and migration of livestock. The approach is likely to provide more insight into the long distance trade of stock on the hoof, and therefore into the energy flux through historical ecosystems, which constitutes an important parameter for evaluating periods of major ecocultural change, like those associated to the process of urbanisation.

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