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Strontium isotope analysis of Neolithic and Copper Age populations on the Great Hungarian Plain

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ABSTRACT

The strontium isotope ratio ($^{87}Sr/^{86}Sr$) is used in archaeological studies to identify major events of population movement in prehistory such as migration, conquest, and inter-marriage. This study shows that the strontium isotope method can be expanded to identify more subtle shifts in prehistoric human mobility. $^{87}Sr/^{86}Sr$ isotope ratios were analyzed in dental enamel from human and faunal specimens from the Late Neolithic and Copper Age on the Great Hungarian Plain. The archaeological record indicates that several aspects of life changed during the transition from the Late Neolithic to the Copper Age (ca. 4500 BC) in Hungary; evidence for increased interaction over a wide geographical area, less resource pooling and the use of secondary products has been used to support the idea that local populations became more mobile, perhaps due to the adoption of an agro-pastoral economy. Results from this study identify a change in the range of strontium isotope values from the Late Neolithic to the Copper Age from a very narrow range of values to a much broader range of values, which suggests that changes in how land and resources were utilized on the Great Hungarian Plain affected incorporation of strontium into the skeletal system. This study indicates that the strontium isotope ratio is a valuable tool for identifying more subtle changes in prehistoric behavior such as a shift to a more pastoral economy.

1. Introduction

This study uses the strontium isotope ratio ($^{87}Sr/^{86}Sr$) to examine changes in how human populations interacted with their environment on the Great Hungarian Plain during the Late Neolithic–Early Copper Age transition (ca. 4500 BC) by analyzing archaeological human and faunal enamel samples. Neolithic and Copper Age cultures in Hungary play a pivotal role in the dispersal of people and new ways of life in European prehistory. This region contains crucial archaeological information concerning the spread and use of domesticated plants and animals and the dynamics of tribal societies. From the Late Neolithic to the Early Copper Age a transformation in social organization, subsistence strategy and mobility has been inferred from the archaeological record. This transition is characterized by material changes in cultural distribution, settlement characteristics, ceramic assemblages, mortuary customs, and trade networks. Biogeochemical applications in anthropology, such as stable isotope analysis, provide new ways to directly and independently test patterns of prehistoric human behavior detected in archaeological evidence, and a foundation for this work is growing in Europe (e.g. Bentley, 2007; Bentley and Knipper, 2005; Bentley et al., 2003, 2004; Chiaradia et al., 2003; Grupe et al., 1997; Price et al., 1994, 1995, 2004; Whittle et al., 2002; Wormuth et al., 2000). The author builds on this work by exploring the applicability of strontium isotope analysis to identify changes in how land and resources were utilized on the Great Hungarian Plain during periods of socio-economic reorganization during the eneolithic.

2. Prehistoric setting

Over thirty years of systematic archaeological survey and excavation conducted in the Great Hungarian Plain has presented archaeologists with a dynamic picture of social transformations that were sparked by the arrival of Neolithic food producing communities and carried through the succeeding Copper and Bronze Ages (Bentley et al., 2003; Parkinson et al., 2004; Tringham, 2000; Visy, 2003; Zvelebil and Lille, 2000). While there is evidence for changes in mobility, trade networks, household organization, pottery styles, technology, distributions of cultural groups, and mortuary customs from the Neolithic to the Bronze Age, our knowledge of the region's prehistory would greatly benefit from biogeochemical analyses that directly reflect human behavior.

This study looks specifically at the Late Neolithic and Early Copper Age cultures who occupied the Great Hungarian Plain from ca. 5000 to 4000 BC (Parkinson, 2006b). The archaeological record suggests that a transition in sociopolitical organization, subsistence strategy and mobility occurred from the Late Neolithic to the Early

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Copper Age. Recent research has focused on detailing these changes (Gyucha et al., 2006; Parkinson, 2006a,b; Parkinson et al., 2004; Yerkes et al., 2007); however, questions about the level of mobility and cultural interaction that characterized Early Copper Age societies who shifted from the use of large permanent tell sites to small, impermanent single-component sites and maintained cultural homogeneity over a wider geographical area have not been resolved. Subsistence strategy is another aspect of Neolithic and Copper Age lifestyle that could be clarified with new lines of research. The extent of reliance on domesticated versus local wild species remains unclear, as well as when the shift to utilizing secondary animal products first occurred (Bogucki, 1987; Bökönyi, 1974; Greenfield, 1988; Sherratt, 1981, 1983). A majority of the evidence for the 'secondary products revolution' has relied on indirect sources such as ceramic vessels and iconography. It has also been suggested that an increase in mobility and increased reliance on cattle during the Neolithic and Copper Ages was due to an emerging agro-pastoral economy but this remains to be tested (Bognár-Kutzián, 1972; Bökönyi, 1974; Sherratt, 1983).

Many of these issues can be addressed using stable isotope analysis. Biogeochemical data of this sort often require extensive isotopic mapping to accurately test anthropological hypotheses; with this in mind, the aim of this study is to begin the accumulation of biogeochemical data in Hungary in order to test the applicability of the method under local conditions and add to the growing framework of biogeochemical data in Central Europe.

3. Geochemical application

The concentration and isotope ratio of strontium in human and faunal skeletal material can be used to identify movement throughout an individual's lifetime, residence and migration patterns based on the local geology, and dietary characteristics (Price et al., 1994). Several studies of this type have addressed questions of marriage, migration, conquest, and colonization in prehistoric Europe (e.g. Bentley, 2007; Bentley and Knipper, 2005; Bentley et al., 2003, 2004; Chiaradia et al., 2003; Grupe et al., 1997; Price et al., 1994, 1995, 2004; Wormuth et al., 2000); however, none of these studies have addressed the Late Neolithic and Copper Age transition in Hungary.

The $^{87}Sr/^{86}Sr$ isotope ratio is useful in the archaeological context because strontium is incorporated into the skeletal tissues of animals and humans through the food chain and remains there as a record of the diet of these individuals, and also of the geological area where the strontium was obtained. Unlike other isotope ratios used in anthropological contexts, there is no measurable fractionation in the $^{87}Sr/^{86}Sr$ ratio as it is carried through the food chain (Capo et al., 1998). As a trace element, strontium substitutes for calcium in the hydroxyapatite of teeth and bones. Because the skeletal tissue in teeth and bone represents different developmental periods in an individual's life, the strontium signature compared between these two tissues can be used to identify changes in behavior over time. The enamel in teeth forms in the first few years of an individual's life and is not replaced after formation, therefore the enamel functions as a permanent record of the individual's diet and geological habitat as a child (Grupe et al., 1997). Strontium levels in bone, which are continually being remodeled throughout life, are thought to reflect the individual's average strontium intake over the last 7–10 years of life (Jowsey, 1971). Comparisons of strontium isotope ratios between teeth and bone reflect whether there has been a significant change in diet and possibly geographical area within a lifetime. For full details of method, see Price et al. (2002).

Recent work has emphasized the importance of characterizing all potential sources of strontium in the human sample's local dietary range because the strontium value in humans is thought to be an average of all dietary sources. Bone may not always be the best indicator of the local range due to potential contamination in the burial environment that teeth are not generally susceptible to (Bentley and Knipper, 2005; Bentley et al., 2004; Hodell et al., 2004; Horn and Muller-Sohnius, 1999). Faunal teeth from contemporary archaeological contexts appear to be the best approximate of the local biologically available strontium in a particular environment and control for problems associated with using archaeological bone and modern water and soil samples (Blum et al., 2000; Ezzo et al., 1997; Hall-Martin et al., 1993; Koch et al., 1992; Price et al., 2000, 2002; Vogel et al., 1990). For this study several faunal species as well as a water sample were used to approximate the local biologically available strontium isotope range. The mean value of the faunal and water sample ±2 s.d. was used to define the boundaries of the estimated local human strontium isotope range according to the methods proposed by Price et al. (2002). More thorough isotopic mapping of the region will be done in future work by the author.

While it has been shown that the $^{87}Sr/^{86}Sr$ isotope ratio is a valuable tool for identifying major events of population movement based on underlying geological signatures, *variation* in the isotope ratio at the local level can also reflect changes in human behavior. Because the strontium in human skeletal systems is an average of strontium values acquired from all food and water resources, a change in the way an environment is utilized by a human population, without significant population movement, can also be expected to change the strontium isotope value recorded in their skeletal tissue. Recent publications that have utilized the $^{87}Sr/^{86}Sr$ isotope method in an expanded context include work by Tafuri et al. (2006) who were able to identify a shift from a sedentary to a pastoral economy by identifying changes in the variance of $^{87}Sr/^{86}Sr$ values over several time periods. The $^{87}Sr/^{86}Sr$ isotope method has also been used recently to study prehistoric hunter-gatherer adaptations (Haverkort et al., 2008). This study evaluates whether the $^{87}Sr/^{86}Sr$ values in human dental enamel from the Great Hungarian Plain can be used to identify changes in how humans interacted with their environment during a time of proposed social, political and economic transformation from the Late Neolithic to the Copper Age.

4. Geological setting

Prehistoric human populations living on the Great Hungarian Plain acquired the strontium measured in their skeletal system from food and water resources, which in turn reflects the strontium isotopic composition of the underlying geology. The isotope ratio may vary for different resources depending on the age of the source rock material so it is necessary to establish the geological setting in order to identify strontium isotope ranges within the scope of possible population movement.

Hungary is characterized by three distinct regions: the Great Hungarian Plain (east of the Danube River), Transdanubia (west of the Danube), and the Northern Mountains. The region to the north makes up a section of the Carpathian Mountains, a series of parallel mountain ranges that run from Vienna, Austria border the northern portion of Hungary, and end near Bucharest, Romania (Fig. 1). The study area is located on the southeastern portion of the Great Hungarian Plain (also known at the *Nagy Alföld*). The Plain should have a high strontium isotope composition because the average of sedimentary silts and clays that make up the soil is very old, allowing for a longer period of radioactive decay from ^{87}Rb. $^{87}Sr/^{86}Sr$ values of lowland loess from previous studies in Central Europe range from 0.7080 to 0.7100 (Bentley et al., 2003). The surrounding Carpathians are composed of a series of parallel mountain ranges formed at different time periods. The innermost mountain range in the Carpathians should have a lower strontium

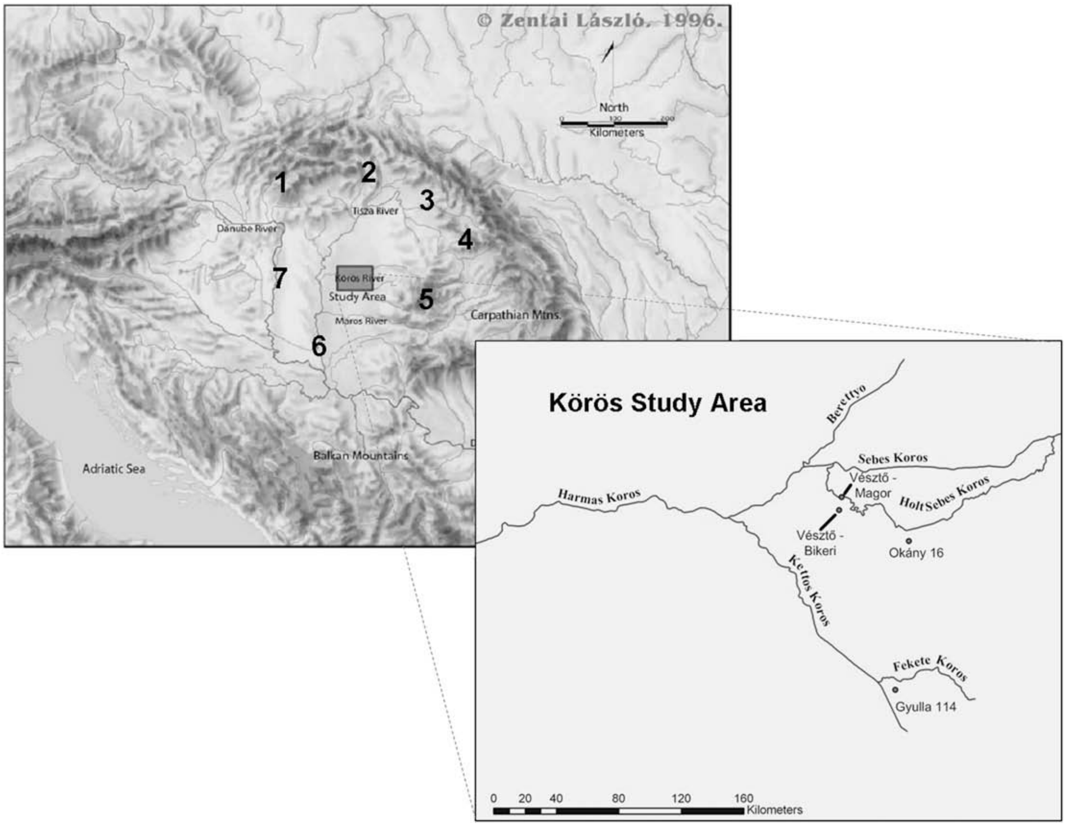

Fig. 1. Study area and the surrounding region. Numbers indicate average $^{87}Sr/^{86}Sr$ values recorded for rock and water sources throughout the region: 1 (Bukk Mountains; 0.7100), 2 (Tokaj Mountains; 0.7074), 3 (North Transcarpathian Basin; 0.7089), 4 (Gutai Mountains; 0.7090), 5 (Apuseni Mountains; 0.7051), 6 (Tisza River; 0.7096), and 7 (Danube River; 0.7096). Close up map of the study area identifies the archaeological sites sampled from in the Körös region. Regional map adapted from Parkinson et al. (2002; Fig. 1), based on a topographic map created by László (1996). Inset created by Margaret Morris.

isotope composition than the Plain because they are composed of younger geological units. The Apuseni Mountains located in Romania make up a portion of the Carpathians just east of the study area and $^{87}Sr/^{86}Sr$ values from bulk rock samples average at a much lower level of 0.7051 (Seghedi et al., 2004). In the Tokaj Mountains to the north, the rock $^{87}Sr/^{86}Sr$ value is also slightly lower than on the Plain (0.7074). $^{87}Sr/^{86}Sr$ measurements from the Danube River, its large tributary the Tisza, and various locations throughout the Carpathian–Pannonian region published in previous studies have been used to establish geological variability in strontium isotope ranges in the region surrounding the study area (Table 1). The average $^{87}Sr/^{86}Sr$ values for each locality are displayed in Fig. 1. These measurements are valuable in order to incorporate all of the factors that affect strontium isotope values in the human population; however, bedrock and water values cannot be used as the only reference of comparison with human values because they do not always directly reflect biologically available strontium. For this reason, several faunal samples were analyzed for comparison and used to establish the local biologically available strontium range for southeastern Hungary.

5. Archaeological sites

Enamel from human and several faunal species was sampled from five sites (three settlements and two cemeteries) located in the Körös River Valley in southeastern Hungary (the Körös River is a tributary of the Tisza) (Fig. 1). These include Vésztő-Mágor, Vésztő-Bikeri, Körösladány-Bikeri, Okány 6, and Gyula 114 (Giblin, 2004; Hegedűs and Makkay, 1987; Nicolim, 1983; Yerkes et al., 2007). Twenty-one burials were sampled for $^{87}Sr/^{86}Sr$ values from Vésztő-Mágor; 16 are from the Late Neolithic (ca. 5000–4500 BC) and five are from the Early Copper Age (ca. 4500–4000 BC). Vésztő-Mágor is a tell site that contains several occupation levels from the Neolithic, Copper, and Bronze Ages (Hegedűs and Makkay, 1987). Three burials and several faunal species (cattle, pig, sheep, goat, dog, rodent, clam, and snail) were sampled from Vésztő-Bikeri and Körösladány-Bikeri. These are single-component, Early Copper Age settlements from the Tiszapolgár culture. They are located just across from each other and are currently separated by a modern canal. These two sites are approximately 2 km from the tell site of Vésztő-Mágor and radiocarbon dates indicate that they may have been roughly contemporaneous Tiszapolgár settlements (Parkinson et al., 2004). Four burials were sampled from Okány 6. Okány 6 is a Tiszapolgár cemetery located on a poultry farm that was partially excavated due to the threat of disturbance in 1983 (Nicolim, 1983). The site is approximately 8 km southeast of the town of Vésztő where all of the above-mentioned sites are located. Ten burials were sampled for $^{87}Sr/^{86}Sr$ from the Middle Copper Age cemetery Gyula 114 in a previous study (Giblin, 2004). Gyula 114 is located approximately 43 km southeast of the town of Vésztő.

6. Samples and procedures

Enamel samples from 28 human and 12 faunal individuals were analyzed for strontium concentration and isotope ratio (10 human samples from Gyula 114 and 6 faunal samples from Vésztő-Bikeri and Vészto-Mágor were analyzed in a previous study) (Giblin, 2004). Human enamel was taken from the first molar, whenever possible, or the second molar if the first was not present. Molars were sampled whenever possible in faunal species. Enamel was

Table 1
$^{87}Sr/^{86}Sr$ values from bulk rock (BR) and water (W) samples in Hungary.

Sample	Material	Area	Age	$^{87}Sr/^{86}Sr$	Reference
B-4B	BR	Bukk Mountains	17	0.710327	Seghedi et al. (2004)
B-7-IE	BR	Bukk Mountains	17	0.711368	Seghedi et al. (2004)
B-14	BR	Bukk Mountains	17	0.710370	Seghedi et al. (2004)
B-28	BR	Bukk Mountains	15	0.707728	Seghedi et al. (2004)
B-29	BR	Bukk Mountains	18	0.710307	Seghedi et al. (2004)
TD-105	BR	N Transcarpathian Basin	15	0.708810	Seghedi et al. (2004)
TD-134	BR	N Transcarpathian Basin	15	0.708852	Seghedi et al. (2004)
TD-145-1A	BR	N Transcarpathian Basin	15	0.709104	Seghedi et al. (2004)
TD-145-4A	BR	N Transcarpathian Basin	15	0.708932	Seghedi et al. (2004)
SKH-25	BR	Tokaj Mountains	12	0.707424	Seghedi et al. (2004)
2G	BR	Gutai Mountains	10.8	0.708330	Seghedi et al. (2004)
3G	BR	Gutai Mountains	1.01	0.708940	Seghedi et al. (2004)
4G	BR	Gutai Mountains	10.7	0.710296	Seghedi et al. (2004)
6G	BR	Gutai Mountains	10.7	0.709200	Seghedi et al. (2004)
7G	BR	Gutai Mountains	11	0.708280	Seghedi et al. (2004)
363a	BR	Apuseni Mountains	8.6	0.704704	Seghedi et al. (2004)
394a	BR	Apuseni Mountains	11.2	0.704744	Seghedi et al. (2004)
400a	BR	Apuseni Mountains	12.6	0.703982	Seghedi et al. (2004)
401a	BR	Apuseni Mountains	11.4	0.705608	Seghedi et al. (2004)
767a	BR	Apuseni Mountains	11.7	0.704502	Seghedi et al. (2004)
776a	BR	Apuseni Mountains	10.5	0.704250	Seghedi et al. (2004)
788a	BR	Apuseni Mountains	7.4	0.704400	Seghedi et al. (2004)
790a	BR	Apuseni Mountains	14.6	0.708312	Seghedi et al. (2004)
2479a	BR	Apuseni Mountains	12.4	0.705713	Seghedi et al. (2004)
5199a	BR	Apuseni Mountains	12.8	0.704640	Seghedi et al. (2004)
6922a	BR	Apuseni Mountains	12.6	0.706252	Seghedi et al. (2004)
UR-3a	BR	Apuseni Mountains	1.6	0.704441	Seghedi et al. (2004)
n/a	W	Danube River	modern	0.709500	Price et al. (2004)
n/a	W	Danube River	modern	0.709600	Price et al. (2004)
n/a	W	Danube River	modern	0.708900	Palmer and Edmond (1989)
n/a	W	Tisza River	modern	0.709600	Palmer and Edmond (1989)

mechanically cleaned and isolated using a diamond drill bit attached to a Dremel tool. Duplicates were taken from three samples, and four samples were loaded and analyzed twice to test reproducibility (all samples were identical to the 4th decimal place). Samples were processed in the Radiogenic Isotopes Laboratory in the School of Earth Sciences at The Ohio State University. Chemical treatments were processed in a Class 100 clean lab.

Samples were reacted with acid according to the procedures described by Chiaradia et al. (2003) to remove the organic and post-depositional portion of the material. Once clean, all samples were weighed and spiked with 25 mg of ^{84}Sr spiked solution in a clean Teflon beaker. 1–2 ml of 2.5 N HCl plus 1 drop of $HClO_4$ was added to each beaker and put on the hot plate to dissolve. Once dissolved, the caps were removed and the samples were dried down. Samples were dissolved in 1 ml 2.5 N HCl and loaded onto a cation exchange chromatography column (Bio-rad AG50x8, 200–400 mesh) to separate the strontium from other elements. The strontium solution was collected, 1 drop of HNO_3 was added, and the samples were put on a hot plate overnight to dry down. The samples were dissolved in dilute HCl, loaded onto Re filaments and dried down. Isotopic measurements were performed using a Finnigan-MAT (model 261A) thermal ionization mass spectrometer (TIMS). Measured values were normalized assuming normal strontium with $^{86}Sr/^{88}Sr = 0.119400$. Mass spectrometry runs consisted of 100 ratio measurements with an ^{88}Sr ion beam intensity of approximately 6×10^{-11} A. Uncertainties refer to the last digit(s) and are two standard deviations of the mean within-run uncertainties. Reference value of $^{87}Sr/^{86}Sr$ for the SRM987 is 0.710242 ± 10 (one sigma external reproducibility). Mass spectrometry procedures and equipment are described in Foland and Allen (1991).

7. Results

Strontium concentration and $^{87}Sr/^{86}Sr$ ratio for all faunal samples are listed in Table 2; human results are listed in Table 3. The estimation of the local $^{87}Sr/^{86}Sr$ ratio was based on the mean value from seven faunal species ($n = 18$) and one water sample (Table 2). Fig. 2 shows the range for each species tested and the mean value (0.709736) ± 2 s.d. $^{87}Sr/^{86}Sr$ ratios ranged from 0.709331 (clam shell) to 0.710263 (pig). The faunal samples were taken from three sites (Vésztő-Mágor, Vésztő-Bikeri, and Körösladány-Bikeri) all located within approximately 2 km of each other. This estimate of the 'local' strontium value is displayed along with the human values in Fig. 3 to identify whether there are any non-local individuals.

The human $^{87}Sr/^{86}Sr$ values (Table 3) are presented in Fig. 3 according to chronology. Based on the local $^{87}Sr/^{86}Sr$ estimation from faunal and water samples only one individual falls outside the local range and can be considered a migrant. This individual happens to be one of the two Conquest Period (10th century) burials analyzed from Vésztő-Bikeri (Lichtenstein, 2001). Although this time period is not the focus of the current study, the data point shows that strontium will be a useful tool to study other periods in Hungarian history. Individuals from the Conquest Period are nomadic horsemen who represent the first native Hungarian inhabitants of the Great Hungarian Plain. While it is clear that one of the Conquest Period burials intrusive to the Vésztő-Bikeri settlement is not indigenous to the area, the other burial from that time period falls within the local range. The timing and pattern of their arrival on the Great Hungarian Plain may be an issue appropriately tested using strontium isotopes.

An interesting pattern emerges when the values are divided according to time period (Fig. 3). The Late Neolithic population displays a very narrow range in isotope values, while the Early and Middle Copper Age populations display much more variability. Fig. 4 displays the variance in $^{87}Sr/^{86}Sr$ values in the Neolithic and the Copper Age. A Monte Carlo test was used to evaluate whether the variance of these groups was statistically different at a 0.05 significance level (H_0: $\sigma^2 = \sigma^2$; H_1: $\sigma^2 \neq \sigma^2$). The Monte Carlo method was used because the sample size is small (less than 25 samples per time period), and the data do not conform to the assumption of normality needed to perform parametric analyses. According to the P-value (0.0699) generated by the Monte Carle test (simulation = 9999), the null hypothesis that the sample variances from the Late Neolithic and Copper Age are the same could not be

Table 2
$^{87}Sr/^{86}Sr$ values and concentration (ppm) for all faunal samples. EC = Early Copper Age; M = Modern. Standard error: ±2 s.d. of the mean within-run uncertainties.

Site	Sample	Sr (ppm)	$^{87}Sr/^{86}Sr$	Standard Error	Species	Time Period
Vésztõ-Mágor	283	167.6	0.709934	0.000009	cow	EC
Vésztõ-Mágor	299	248.4	0.709868	0.000015	cow	EC
Vésztõ-Bikeri	V20.F.1	226.2	0.709616	0.000008	pig	EC
Vésztõ-Bikeri	V20.F.2	154.8	0.709657	0.000009	pig	EC
Vésztõ-Bikeri	V20.F.3	158.8	0.709683	0.000007	pig	EC
Vésztõ-Bikeri	V20.F.4	224.0	0.710263	0.000006	pig	EC
Vésztõ-Bikeri	V20.F.5	192.6	0.709669	0.000008	pig	EC
Vésztõ-Bikeri	V20.F.6	215.1	0.710240	0.000008	pig	EC
Vésztõ-Bikeri	V20.F.7	205.9	0.709335	0.000007	pig	EC
Vésztõ-Bikeri	V20.F.8	207.5	0.710255	0.000009	pig	EC
Vésztõ-Bikeri	V20.F.9	181.5	0.709642	0.000009	pig	EC
Vésztõ-Bikeri	T1	n/a	0.710186	0.000008	Ovicaprine	EC
Vésztõ-Bikeri	T2	n/a	0.709704	0.000009	Sheep	EC
Vésztõ-Bikeri	T3	n/a	0.709640	0.000009	Dog	EC
Vésztõ-Bikeri	T4	n/a	0.709461	0.000006	Wild boar	EC
Vésztõ-Bikeri	V20-3	148	0.710018	0.000011	cow	EC
Körösladány-Bikeri	K14.F.2	364.1	0.709331	0.000007	clam shell	EC
Körösladány-Bikeri	K14.F.3	1369.0	0.709435	0.000007	snail shell	M

Table 3
$^{87}Sr/^{86}Sr$ values and concentration (ppm) for all human samples. N = Neolithic; EC = Early Copper; MC = Middle Copper; Conq = Conquest; Sarm = Sarmatian. F = female; M = male; ? = uncertainty; n/a = unable to determine; Ad = adult; Juv = juvenile.

Site	Sample	Sr (ppm)	$^{87}Sr/^{86}Sr$	Standard Error	Burial	Time Period	Sex	Age
Vésztõ-Mágor	VM.T.1	66.2	0.709601	0.000009	1	N	F	Ad
Vésztõ-Mágor	VM.T.2	80.0	0.709621	0.000007	2	N	M	Ad
Vésztõ-Mágor	VM.T.3	198.8	0.709871	0.000007	4	N	F	Ad
Vésztõ-Mágor	VM.T.4	90.6	0.709548	0.000007	6	N	F	Ad
Vésztõ-Mágor	VM.T.5	117.2	0.709606	0.000007	7	N	M	Ad
Vésztõ-Mágor	VM.T.6	85.0	0.709605	0.000009	13	N	M	Ad
Vésztõ-Mágor	VM.T.7	75.4	0.709619	0.000008	15	N	n/a	Ad?
Vésztõ-Mágor	VM.T.8	68.3	0.709683	0.000006	27	EC	F?	Juv
Vésztõ-Mágor	VM.T.9	92.8	0.709734	0.000009	28b	EC	n/a	Juv
Vésztõ-Mágor	VM.T.10	77.9	0.709537	0.000009	30	N	M	Ad
Vésztõ-Mágor	VM.T.11	76.2	0.709606	0.000009	31	N	n/a	Juv
Vésztõ-Mágor	VM.T.12	85.3	0.709592	0.000008	32	N	M	Ad
Vésztõ-Mágor	VM.T.13	147.8	0.709556	0.000008	33	N	M?	Juv
Vésztõ-Mágor	VM.T.14	65.6	0.709728	0.000008	36	N	M	Ad
Vésztõ-Mágor	VM.T.15	113.3	0.709726	0.000008	37	EC	F	Ad
Vésztõ-Mágor	VM.T.16a	72.4	0.709659	0.000008	39	N	M	Ad
Vésztõ-Mágor	VM.T.17	95.7	0.709626	0.000008	40	EC	M	Ad
Vésztõ-Mágor	VM.T.18	157.8	0.709632	0.000008	41	EC	M?	n/a
Vésztõ-Mágor	VM.T.19	83.0	0.709494	0.000009	42	N	F	Ad
Vésztõ-Mágor	VM.T.20	124.2	0.709643	0.000008	43	N	F	Ad
Vésztõ-Mágor	VM.T.21	80.0	0.710085	0.000009	44	N	M	Ad
Vésztõ-Bikeri	V20.T.1	37.9	0.709929	0.000007	1	Conq	M	Ad
Vésztõ-Bikeri	V20.T.2	68.2	0.709517	0.000008	2	EC	M	Ad
Vésztõ-Bikeri	V20.T.3	87.2	0.712180	0.000008	4	Conq	M	Ad
Okány 6	OK.T.1a	126.1	0.709921	0.000012	1	EC	M	Ad
Okány 6	OK.T.2	121.3	0.709111	0.000012	2	EC	M	Ad
Okány 6	OK.T.3	95.5	0.709909	0.000009	4	EC	n/a	n/a
Okány 6	OK.T.4	139.3	0.709669	0.000007	7	Sarm	F	Ad
Gyula 114	Gy 4.1	78.8	0.709635	0.000009	4	MC	M	Ad
Gyula 114	Gy 6.1	66.0	0.709872	0.000008	6	MC	M	Ad
Gyula 114	Gy 8.1	97.9	0.709364	0.000009	8	MC	M	Ad
Gyula 114	Gy 10.1	130.0	0.709149	0.000007	10	MC	F	Ad
Gyula 114	Gy 11.1	67.7	0.709585	0.000007	11	MC	F	Ad
Gyula 114	Gy 12.1	90.7	0.709659	0.000007	12	MC	F	Ad
Gyula 114	Gy 13.2	100.9	0.709160	0.000007	13	MC	M	Ad
Gyula 114	Gy 14.1	95.3	0.709526	0.000023	14	MC	M	Ad
Gyula 114	Gy 16.1	99.6	0.709458	0.000009	16	MC	M	Ad
Gyula 114	Gy 17.5	117.8	0.709232	0.000007	17	MC	F	Ad

rejected at a 0.05 significance level; however, the low *P*-value supports the idea that the $^{87}Sr/^{86}Sr$ values from the Late Neolithic and Copper Age display differences in variance. While these results are not statistically significant they indicate that the Copper Age sample is less uniform in strontium isotope values than the Late Neolithic. This lays the groundwork for future isotope work in the region and helps to identify two major areas that require attention: 1) a greater sample size of strontium isotope values from Neolithic and Copper Age populations is needed and 2) stable carbon, nitrogen, and oxygen isotope values would greatly add to the interpretive power of the strontium isotope results.

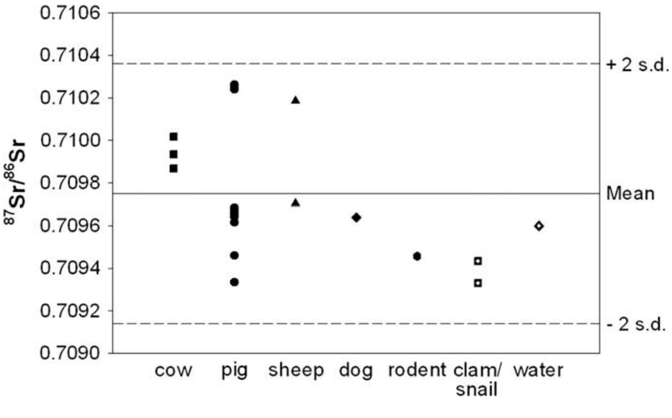

Fig. 2. Local $^{87}Sr/^{86}Sr$ estimate based on faunal ranges and water.

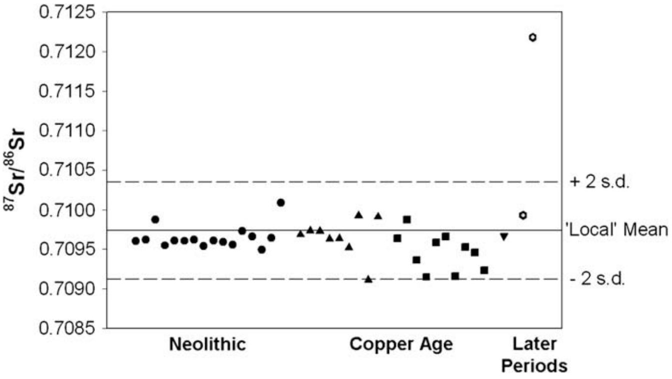

Fig. 3. $^{87}Sr/^{86}Sr$ variation in human teeth over time. Circles = Late Neolithic; upward triangles = Early Copper Age; squares = Middle Copper Age; downward triangles = Sarmatian; open hexagons = Conquest Period.

8. Discussion

The results from this study indicate that strontium isotopes may prove to be a useful measure of internal change in mobility, diet, and social organization during the Neolithic and post-Neolithic. While there is no evidence for significant population movement such as migration (with the exception of the Conquest Period burial), there is a noteworthy change in the range of strontium isotope values between Late Neolithic individuals and Copper Age individuals on the Great Hungarian Plain. Recent work has highlighted the "transformation" that occurred in many aspects of life from the Late Neolithic to the Early Copper Age (Gyucha et al., 2006; Parkinson, 2006a,b; Parkinson et al., 2004; Yerkes et al., 2007). During the Late Neolithic, settlements consisted of large, nucleated tell sites that were occupied over long periods of time. Starting in the Early Copper Age, sites increased in number, became much smaller, and spread out in the landscape. This has been assumed to indicate an increased level of mobility by Copper Age populations.

How could these slight changes in mobility affect the range of a group's $^{87}Sr/^{86}Sr$ value? Nicodemus (2003) suggests that increased mobility and reduced social complexity in the Early Copper Age led to subsequent changes in subsistence strategy.

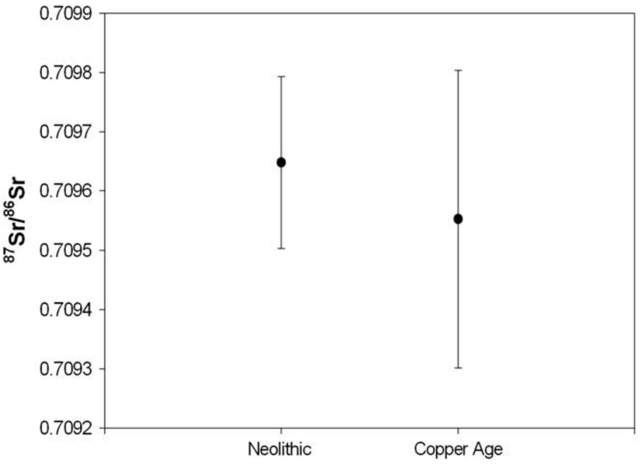

Fig. 4. Mean and standard deviation distribution of $^{87}Sr/^{86}Sr$ in human tooth enamel in the Neolithic and Copper Age.

Changes in subsistence strategy, even if the population is still living in the Great Hungarian Plain, may change the $^{87}Sr/^{86}Sr$ ratio recorded in enamel because the relative contribution of each dietary source and the concentration of strontium in those sources will have an effect on the composite human value. Analyses of faunal remains from Neolithic and Early Copper Age sites in this region have shown that the Early Neolithic (6000–5000 BC cal.) colonizers focused on protecting the sheep and goats that they had brought up from the southwest and did not exploit the abundant local wild game and potential domesticates (cattle and pigs) (Bartosiewicz, 2005; Nicodemus, 2003; Vörös, 1980). During the Middle and Late Neolithic periods large game hunting increases dramatically and "local" domestic cattle are more abundant than the "imported" sheep and goats. However, during the Early Copper Age, hunting declines and a more balanced system of stock raising develops as the numbers of domestic pigs, sheep and goats increase. The $^{87}Sr/^{86}Sr$ values for pigs analyzed from Vésztő-Bikeri show a relatively wide range of values (0.7093–0.7103). Increased use of pigs, an expansion of swineherd territory, and trade of pigs in the Copper Age may have resulted in more variable $^{87}Sr/^{86}Sr$ values.

The use of secondary products such as milk may have also had an important effect on the $^{87}Sr/^{86}Sr$ values in Copper Age populations. Because of its high calcium content, milk contains more strontium than other food sources such as meat. Consequently, if milk products make up a part of the human diet, they will contribute a greater amount to their $^{87}Sr/^{86}Sr$ value. It has been suggested that there was an increase in pastoralism during the Copper Age. If herds of cattle, sheep, and goat were being kept longer for secondary products (instead of primarily meat production) and grazed over larger geographic ranges, this increase in grazing lands might be reflected in the $^{87}Sr/^{86}Sr$ values found in the animals. In turn, if there was an increase in secondary products exploitation during the Copper Age, coupled with an intensified agro-pastoral subsistence strategy (Bartosiewicz, 1999, 2005; Bökönyi, 1974; Craig et al., 2005; Greenfield, 1988; Sherratt, 1997), then there would be a subsequent change in the $^{87}Sr/^{86}Sr$ value in humans. Preliminary data from this study may express that change as increased variability in the $^{87}Sr/^{86}Sr$ values.

Changes in social structure may also have affected the variability in $^{87}Sr/^{86}Sr$ values. Parkinson (2003) suggests that there was a shift in social organization and consequently social processes from the Late Neolithic to the Early Copper Age. For example, in the Late Neolithic, he suggests that society was complexly structured as integrated units that interacted intensively within well-defined geographical units, such as tells. In contrast, during the Early Copper Age, society was less complexly structured, units were less integrated, and those units interacted less intently but over a much larger geographical area. It is very possible that variability in $^{87}Sr/^{86}Sr$ values reflects these changes of less resource pooling and greater interaction over a wide geological range.

9. Conclusions

This study shows that strontium isotopes can be used along with other lines of evidence to characterize changes in mobility, subsistence strategy, and social organization during the Neolithic and Copper Age on the Great Hungarian Plain. While there was no evidence for non-local individuals in the Neolithic and Copper Age groups tested, there did exist a difference in the range of $^{87}Sr/^{86}Sr$ values between the Late Neolithic and Copper Age, indicating that changes in how local populations interacted with each other and the local environment can be identified using strontium isotopes.

Several areas of future research that will further test the applicability of biogeochemical analysis for understanding the eneolithization process in Hungary may be identified. First, more baseline data are required to clearly discern the meaning of the broadening of $^{87}Sr/^{86}Sr$ values. Mobility, subsistence strategy and social organization are interrelated factors; however, a better understanding of the causes of variation in $^{87}Sr/^{86}Sr$ values is needed before conclusive statements on prehistoric behavior can be made using strontium isotopes. This will require extensive isotopic mapping of environmental and dietary variables that contribute to the prehistoric human strontium value in the region. Second, the use of other stable isotopes such as carbon, nitrogen, and oxygen will be a valuable supplement to strontium data. Carbon and nitrogen will be useful for approximating the relative contribution of plant and animal sources in Neolithic and Copper Age prehistoric diets and how they changed over time. Oxygen isotopes are increasingly used along with strontium to better characterize levels of mobility (e.g. Budd et al., 2004; Knudson and Price, 2007).

The most important conclusion that may be drawn from this study is the great potential for future chemical analysis of prehistoric humans in the Great Hungarian Plain. It has been shown in studies over the past few decades that stable isotopes and trace elements are an emerging tool for understanding human behavior in an anthropological context, but in order for the data to be relevant, a large baseline database for human and animal material, as well as all aspects of the environment, needs to be established. With an expanded database of stable isotope values for the Great Hungarian Plain and surrounding regions, it will be possible to directly investigate proposed changes in prehistoric human mobility, diet, and social organization during a time of intense transformations in Central Europe.

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References

Bartosiewicz, L., 1999. The role of sheep versus goats in meat consumption at archaeological sites. In: Bartosiewicz, L., Greenfield, H. (Eds.), Transhumant Pastoralism in Southern Europe. Archaeolingua Kiadó, Budapest, pp. 47–60.

Bartosiewicz, L., 2005. Plain talk: animals, environment and culture in the Neolithic of the Carpathian Basin and adjacent areas. In: Bailey, D., Whittle, A., Cummings, V. (Eds.), (Un)settling the Neolithic. Oxbow, Oxford, pp. 51–63.

Bentley, R.A., 2007. Mobility, specialization and community diversity in the Linearbandkeramik: isotopic evidence from skeletons. In: Whittle, A., Cummings, V. (Eds.), Going Over: the Mesolithic–Neolithic Transition in North-West Europe. Oxford University Press, New York, pp. 117–140.

Bentley, R.A., Knipper, C., 2005. Geographical patterns in biologically available strontium, carbon and oxygen isotope signatures in prehistoric SW Germany. Archaeometry 47, 629–644.

Bentley, R.A., Krause, R., Price, T.D., Kaufmann, B., 2003. Human mobility at the early Neolithic settlement of Vaihingen, Germany: evidence from strontium isotope analysis. Archaeometry 45, 471–486.

Bentley, R.A., Price, T.D., Stephen, E., 2004. Determining the 'local' $^{87}Sr/^{86}Sr$ range for archaeological skeletons: a case study from Neolithic Europe. Journal of Archaeological Science 31, 365–375.

Blum, J.D., Taliaferro, E.H., Weisse, M.T., Holmes, A., 2000. Changes in Sr/Ca, Ba/Ca and $^{87}Sr/^{86}Sr$ ratios between two forest ecosystems in the northeastern USA. Biochemistry 49, 87–101.

Bognár-Kutzián, I., 1972. The Early Copper Age Tiszapolgar Culture in the Carpathian Basin. Akademiai Kiado, Budapest.

Bogucki, P., 1987. The establishment of agrarian communities on the North European Plain. Current Anthropology 28, 1–24.

Bökönyi, S., 1974. History of Domestic Mammals in Central and Eastern Europe. Akadémiai Kiadó, Budapest.

Budd, P., Millard, A., Chenery, C., Lucy, S., Roberts, C., 2004. Investigating population movement by stable isotope analysis: a report from Britain. Antiquity 78, 127–141.

Capo, R.C., Stewart, B.W., Chadwick, O.A., 1998. Strontium isotopes as tracers of ecosystem processes: theory and methods. Geoderma 83, 197–225.

Chiaradia, M., Gallay, A., Todt, W., 2003. Different contamination styles of prehistoric human teeth at a Swiss necropolis (Sion, Valais) inferred from lead and strontium isotopes. Applied Geochemistry 18, 353–370.

Craig, O.E., Chapman, J., Heron, C., Willis, L.H., Bartosiewicz, L., Taylor, G., Whittle, A., Collins, M., 2005. Did the first farmers of central and eastern Europe produce dairy foods? Antiquity 79, 882–894.

Ezzo, J.A., Johnson, C.M., Price, T.D., 1997. Analytical perspectives on prehistoric migration: a case study from east-central Arizona. Journal of Archaeological Science 24, 447–466.

Foland, K.A., Allen, J.C., 1991. Magma sources for Mesozoic anorogenic granites of the White Mountain magma series, New England, USA. Contributions to Mineralogy and Petrology 109, 195–211.

Giblin, J., 2004. Strontium Isotope and Trace Element Analysis of Copper Age Human Skeletal Material from the Great Hungarian Plain. Unpublished undergraduate honor's thesis. Department of Anthropology, Florida State University, Tallahassee.

Greenfield, H.J., 1988. The origins of milk and wool production in the Old World: a zooarchaeological perspective from the Central Balkans. Current Anthropology 29, 573–593.

Grupe, G., Price, T.D., Schroter, P., Sollner, F., Johnson, C.M., Beard, B.L., 1997. Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains. Applied Geochemistry 12, 517–525.

Gyucha, A., Bácsmegi, G., Fogas, O., Parkinson, W.A., 2006. House construction and settlement patterns on an Early Copper Age site in the Great Hungarian Plain. Communicationes Archaeologicae Hungariae 2006, 5–28.

Hall-Martin, A.J., van der Merwe, N.J., Lee-Thorp, J.A., Armstrong, R.A., Mehl, C.H., Struben, S., Tykot, R., 1993. Determination of species and geographic origin of rhino horn by isotopic analysis and its possible application to trade control. In: Ryder, O. (Ed.), Rhinoceros Biology and Conservation. Zoological Society of San Diego, San Diego.

Haverkort, C.M., Weber, A., Katzenberg, M.A., Goriunova, O.I., Simonetti, A., Creaser, R.A., 2008. Hunter-gatherer mobility strategies and resource use based on strontium isotope (^{87}Sr/^{86}Sr) analysis: a case study from Middle Holocene Lake Baikal, Siberia. Journal of Archaeological Science 35, 1265–1280.

Hegedűs, K., Makkay, J., 1987. Véstző-Mágor: a settlement of the Tisza culture. In: Raczky, P. (Ed.), The Late Neolithic of the Tisza Region: a Survey of Recent Excavations and Their Findings. Szolnok County Museums, Budapest, Szolnok, pp. 85–104.

Hodell, D.A., Quinn, R.L., Brenner, M., Kamenov, G., 2004. Spatial variation of strontium isotopes (^{87}Sr/^{86}Sr) in the Maya region: a toll for tracking ancient human migration. Journal of Archaeological Science 31, 585–601.

Horn, P., Muller-Sohnius, D., 1999. Comment on "Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains" by Gisela Grupe, T. Douglas Price, Peter Schroter, Frank Sollner, Clark M. Johnson and Brian L. Beard. Applied Geochemistry 14, 263–269.

Jowsey, J., 1971. The internal remodeling of bones. In: Bourne, G.H. (Ed.), The Biochemistry and Physiology of Bone III: Development and Growth. Academic Press, New York, pp. 201–238.

Knudson, K.J., Price, T.D., 2007. Utility of multiple chemical techniques in archaeological residential mobility studies: case studies from Tiwanaku- and Chiribaya-affiliated sites in the Andes. American Journal of Physical Anthropology 132, 25–39.

Koch, P.L., Halliday, A.N., Walter, L.N., Stearley, R.F., Huston, T.J., Smith, G.R., 1992. Sr isotopic composition of hydroxyapatite from recent and fossil salmon: the record of lifetime migration and diagenesis. Earth and Planetary Science Letters 108, 277–287.

László, Z., 1996. Relief of Carpathian-Basin. Electronic document. <http://lazarus.elte.hu/hun/summer.jpg> (accessed 01.06. 08).

Lichtenstein, L., 2001. Honfoglalás kori sír Vésztõ határában – a Grave from the Hungarian Conquest Period at Vésztõ. Régészeti kutatások Magyarországon, pp. 87–97.

Nicodemus, A., 2003. Animal Economy and Social Change during the Neolithic–Copper Age Transition on the Great Hungarian Plain. Unpublished Master's thesis. Department of Anthropology, Florida State University, Tallahassee.

Nicolim, E., 1983. Okány 6 régészeti adattára. Munkácsy Mihály Múzeum, Békéscsaba.

Palmer, M.R., Edmond, J.M., 1989. The strontium isotope budget of the modern ocean. Earth and Planetary Science Letters 92, 11–26.

Parkinson, W.A., 2003. Integration, interaction, and tribal 'cycling'. In: Parkinson, W.A. (Ed.), The Archaeology of Tribal Societies. International Monographs in Prehistory, U.S., pp. 391–438.

Parkinson, W.A., 2006a. Tribal boundaries: stylistic variability and social boundary maintenance during the transition to the Copper Age on the Great Hungarian Plain. Journal of Anthropological Archaeology 25, 33–58.

Parkinson, W.A., 2006b. The social organization of Early Copper Age tribes on the Great Hungarian Plain. In: BAR International Series, vol. 1573 Oxford.

Parkinson, W.A., Gyucha, A., Yerkes, R.W., 2002. The Neolithic-Copper Age transition on the Great Hungarian Plain: recent excavations at the Tiszapolgár Culture settlement of Vésztö-Bikeri. Antiquity 76, 619–620.

Parkinson, W.A., Yerkes, R.W., Gyucha, A., 2004. The transition from the Neolithic to the Copper Age: excavations at Vésztö-Bikeri 2000–2002, Hungary. Journal of Field Archaeology 29, 101–121.

Price, T.D., Grupe, G., Schroter, P., 1994. Reconstruction of migration patterns in the Bell Beaker period by stable strontium isotope analysis. Applied Geochemistry 9, 413–417.

Price, T.D., Gebauer, A.B., Keeley, L.H., 1995. The spread of farming into Europe north of the Alps. In: Price, T.D., Gebauer, A.B. (Eds.), Last Hunters–First Farmers: New Perspectives on the Prehistoric Transition to Agriculture. School of American Research Advanced Seminar Series, Santa Fe, pp. 95–126.

Price, T.D., Manzanilla, L., Middleton, W.H., 2000. Residential mobility at Teotihuacan: a preliminary study using strontium isotopes. Journal of Archaeological Science 27, 903–913.

Price, T.D., Burton, J.H., Bentley, R.A., 2002. The characterization of biologically available strontium ratios for the study of prehistoric migration. Archaeometry 44, 117–135.

Price, T.D., Knipper, C., Grupe, G., Smrcka, V., 2004. Strontium isotopes and prehistoric human migration: the Bell Beaker period in Central Europe. European Journal of Archaeology 7, 940.

Seghedi, I., Downes, H., Szakacs, A., Mason, P., Thirlwall, M., Rosu, E., Zoltan, P., Marton, E., Panaiotu, C., 2004. Neogene–Quaternary magmatism and geodynamics in the Carpathian–Pannonian region: a synthesis. Lithos 72, 117–146.

Sherratt, A., 1981. Plough and pastoralism: aspects of the secondary products revolution. In: Hodder, I., Isaac, G., Hammond, N. (Eds.), Pattern of the Past: Studies in Honour of David Clarke. Cambridge University Press, Cambridge, pp. 261–305.

Sherratt, A., 1983. The secondary exploitation of animals in the Old World. World Archaeology 15, 90–104.

Sherratt, A., 1997. Economy and Society in Prehistoric Europe: Changing Perspectives. Princeton University Press, Princeton.

Tafuri, M.A., Bentley, R.A., Manzi, G., di Lernia, S., 2006. Mobility and kinship in the prehistoric Sahara: strontium isotope analysis of Holocene human skeletons from the Acacus Mts. (southwestern Libya). Journal of Anthropological Archaeology 25, 390–402.

Tringham, R., 2000. Southeastern Europe in the transition to agriculture in Europe: bridge, buffer or mosaic. In: Price, T.D. (Ed.), Europe's First Farmers. University Press, Cambridge, pp. 19–56.

Visy, S., 2003. Hungarian Archaeology at the Turn of the Millennium. Ministry of National Cultural Heritage, Teleki LászlóFoundation, Budapest.

Vogel, J.C., Eglington, B., Auret, J.M., 1990. Isotope fingerprints in elephant bone and ivory. Nature 346, 747–749.

Vörös, I., 1980. Zoological and paleoeconomical investigations on the archaeological material of the early Neolithic Körös Culture. Folia Archaeologica 31, 35–61.

Whittle, A., Bartosiewicz, L., Boric, D., Pettitt, P., Richards, M., 2002. In the beginning: new radiocarbon dates for the Early Neolithic in Northern Serbia and Southeast Hungary. Anteus 25, 72–117.

Wormuth, M., Hansen, B.T., Schutkowski, H., 2000. ^{87}Sr/^{86}Sr ratios in human bone and tooth enamel indicate residential mobility at lifetime. European Journal of Mineralogy (Suppl. 12), 238.

Yerkes, R.W., Parkinson, W., Sarris, A., Gyucha, A., Hardy, M., Catanoso, L., 2007. Geophysical and Geochemical Investigations at two Early Copper Age settlements in the Körös River Valley, Southeastern Hungary. Geoarchaeology 22, 845–871.

Zvelebil, M., Lille, M., 2000. Transition to agriculture in Eastern Europe. In: Price, T.D. (Ed.), Europe's First Farmers. University Press, Cambridge, pp. 57–92.