Strontium Isotope Analysis of Archaeological Fauna from the Wadian Site

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Abstract:
The Wadian site is located at Yuzhou City, Henan Province. It is a large settlement site of the Longshan culture and it is dated to 4225-3755 BP. According to an archaeozoological study four domestic animals such as dog, pig, sheep and cattle were found on the site. The purpose of our study is to discuss the problem of how strontium isotope analysis can be used to identify non-local individuals at the Wadian site. Tooth Enamel and bone samples from 11 animal individuals were analysed for strontium isotope ratio (87Sr/86Sr), by the thermal ionization mass spectrometry, including five pigs, four mice, one sheep and one cow. Molars were sampled whenever possible in faunal species. According to the local strontium isotopes ratio range two pigs, one sheep and one cow from the Wadian site fell well outside the local strontium isotopes ratio range and were considered to be non-local.

Key Words: *Wadian Site, Fauna, Strontium Isotopes*

Introduction

In recent years, isotopic tracers have been employed in many studies to map the geographical movement of certain materials and species (Towers et al. 2010, 509; Copeland et al. 2010,1 437; Kennedy et al. 1997, 766; Blum et al. 2000, 87; Aberg, 1995, 309). Similar methods were introduced in archaeology two decades ago for the investigation of residential changes among prehistoric humans (Ericson 1985, 503). Of all the isotopes that are currently analysed in archaeological skeletal tissues, strontium isotopes are among the most effective for characterizing prehistoric human and animal mobility and their study is a hotspot in the international archaeometric field. Strontium isotope analysis of dental tissues can be used to reveal patterns of movement in animals (Bentley 2006, 135).

In principle, the method is quite simple. Strontium has a geological origin and four naturally occurring isotopes: non-radiogenic ^{84}Sr, ^{86}Sr and ^{88}Sr, and the radiogenic ^{87}Sr. ^{87}Sr is formed through the radioactive decay of rubidium (^{87}Rb—$^{87}Sr+\beta^{-}$—$\upsilon+Q$). It may be demonstrated theoretically that the ^{87}Sr content of a rock is dependent on the ^{87}Rb content and the age of the rock. Different rocks are characterized by distinct ratios of two isotopes of strontium, ^{87}Sr and ^{86}Sr. As rocks are weathered into soils, the plants growing in those soils acquire the $^{87}Sr/^{86}Sr$ ratio. Animals that eat the plants incorporate strontium into their skeletons; animal skeletal tissues, however, often display a remarkable homogeneity in values within a given region, suggesting that they acquire strontium from a range of local sources and thus provide a “regional average” of bioavailability strontium (Evans et al. 2006, 309; Price et al. 1994, 503; Sealy et al. 1991, 399; Sealy et al. 1995, 290).

Strontium isotope ratio analysis of tooth enamel has become an established technique for investigating the mobility and origins of human populations (Bentley et al. 2007, 645—656; Grupe et al. 1997, 517; Haverkort et al. 2008, 1265; Montgomery et al. 2000, 370; Nehlich et al. 2009, 1791; Price et al. 1994, 503; Price and Gestsdóttir 2006, 130) and, to a lesser extent, animal populations (Balasse et al. 2002, 917; Britton et al. 2009, 1163; Hedman et al. 2009, 64; Hoppe 2004, 129). In China the strontium isotope analysis technology applied to archaeological research has just begun (Yin et al. 2008, 50; Zhao et al. 2011, 42). So far the use of strontium isotope analysis of ancient animal domestication and migration activities at the Wadian site has not been reported yet.

The Wadian site is located in Yuzhou City, Henan Province. It is a large settlement site of the Longshan culture, and it is dated to 4255-3755 BP. Four species found through archaeological excavations at the site are domestic animals raised by ancient settlers of the Wadian site. They are dogs, pigs, sheep and cattle. The faunal assemblage is heavily dominated by pigs whilst cattle and sheep are relatively rare compared to pigs and are present in levels postdating 4000 BP (Institute of Cultural Relics and Archaeology of Henan Province 2004). Why was such a small number of cattle and sheep unearthed? Were they locally and self-produced or did they come from other places?

Two problems have emerged in studies involving the estimation of local isotope levels and the distinction of migrants from natives. In this paper we address these problems and suggest some solutions.

Materials and Methods

Selection of samples

The faunal remains of Wadian site are unearthed from Longshan cultural layers, which are Wadian I, Wadian II, Wadian III. In this study, Tooth Enamel samples from 7 animal individuals and bone samples from 4 mice were analysed for strontium isotope ratios through thermal ionization mass spectrometry. These samples came from the excavated pits within the Wadian settlement. Tooth samples were taken from the first molar whenever possible. The tooth enamel sample is not random, because samples were taken from those skeletons with adequate tooth preservation.

Sample preparation and analysis

Samples for this study were prepared at the Institute of Archaeology, Chinese Academy of Social Sciences. The surface of each sample was cleaned with a carbide burr fitted to a dental drill. The pulp and dentine were removed from each tooth, leaving only the intact enamel. Tooth enamel samples were then placed in 5% acetic acid for seven hours, rinsed three times and then ashed at 850°C for eight hours in open porcelain crucibles. These ashed samples were then transferred to the Beijing Geological Research Institute, CNNC, where about 0.1-0.2g (as much as could be obtained) of powdered sample was dissolved in $HF+HNO_3+HClO_4$ in a Savillex® capsule, dried down on a hotplate and then redissolved in 6mol/L HCL. This sample solution was then dried down again, redissolved in 0.5 mol/L HCL. These purified samples were analysed using an ISOPROBE-T thermal ionization mass spectrometer. $^{87}Sr/^{86}Sr$ ratios were corrected for mass fractionation in the instrument, using the exponential mass fractionation law and $^{86}Sr/^{88}Sr = 0.1194$. Measured values for the NBS 987 standard were $^{87}Sr/^{86}Sr = 0.710250 \pm 0.000007$.

Sample ID	Unit	Species	Tooth	87Sr / 86Sr	2σ
1	YHW97IVT4H24	pig	M1	0.712583	0.000015
2	YHW97IVT3(4)	pig	M1	0.712776	0.000015
3	YHW97IVT3(3)	pig	M1	0.712705	0.000007
4	YHW97IVT5(3)	pig	M1	0.712548	0.000012
5	YHW97IVT4H17	pig	M1	0.712701	0.000012
6	YHW97IVT4(3)	mouse	limb	0.712698	0.000015
7	YHW97IVT3(4)	mouse	limb	0.712778	0.000016
8	YHW97IVT4H37	mouse	limb	0.712723	0.000012
9	YHW97IVT2(3)	mouse	limb	0.712750	0.000012
10	YHW97IVT3H19	sheep	M1	0.711978	0.000013
11	YHW97IVT5H3	cattle	M1	0.712142	0.000013

Table 1. Strontium isotope ratios from Wadian faunal samples.

Results and Discussion

The results from the domestic animal teeth are presented in Table 1. There is a clear difference in $^{87}Sr/^{86}Sr$ values for the different species.

Determination of local range of strontium isotope ratios

Currently the measurement of strontium isotopes ratios in archaeological skeletons has matured into a main method for characterizing prehistoric animal origins in the international archaeometric field. Because of the survival of animals in the same area, the strontium isotope ratios in their body have the appropriate consistency. The survival of animals in different regions, with the changes in the environment brought about by the different geological conditions, results in the different strontium isotope ratios in their bodies. Strontium isotope analysis provides the opportunity to compare $^{87}Sr/^{86}Sr$ values set within enamel during tooth development (and derived from the food and liquid ingested) with those found in the area of the archaeological site, thus allowing for the investigation of animal movement in the past. Biologically available strontium is influenced strongly by the signature of the underlying geology that erodes and is passed along the food chain. Therefore, the strontium values of underlying rocks should be reflected in the tooth enamel of animals that grazed on them and as such the information pertaining to the geographical origin of individual animals can be gathered (Viner et al. 2010, 2812). Based on the above principle, in order to assess whether the animals from Wadian site were born locally or were from diverse geographical origins the local range of strontium isotope ratios must be estimated.

In the past two decades a number of researchers have made many significant and valuable explorations to estimate a range of local strontium isotope ratios (Grupe et al. 1997, 517; Price et al. 2000, 903; Price et al. 2002, 117). In South Africa, Sillen et al. (1998) found that whole soils have higher $^{87}Sr/^{86}Sr$ than the plants growing on them. Given the variation in the soil samples the relative consistency in the $^{87}Sr/^{86}Sr$ ratios in plants for each geologic terrain is striking, and animals eat mainly local plants, resulting in their body having the average level of $^{87}Sr/^{86}Sr$ further than that of plants.

In their study of human migration, Bentley et al. (2004) analysed $^{87}Sr/^{86}Sr$ in the enamels of pigs, cattle, dogs, deer, mice and other animals to help map the biologically-available $^{87}Sr/^{86}Sr$ in Vaihingen. At the Neolithic village of Vaihingen (ca. 5450-5000 BC), $^{87}Sr/^{86}Sr$ ratios in enamel samples from domestic animals revealed that the standard deviation for pigs was less than half that of caprines or cattle and even less than the variance from the human bones. If the pigs were not fed some restricted diet this implies that the pigs' diet came from a smaller (or more homogeneous) area than that of the humans. On the basis of the Vaihingen study, pig enamel samples may provide good indicators of local biologically available Sr isotope ratio signatures.

All these issues considered, it appears that the best way to characterize the local strontium isotope signature at an archaeological site would be to measure the archaeological teeth and bone of animal species that lived locally (Bentley et al. 2007, 645; Giblin 2009, 491; Hedman et al. 2009, 64; Knudson et al. 2005, 903; Nehlich et al. 2009, 1791; Sillen et al. 1998, 24). Since different species occupy different regions with varying home ranges, the choice of local animals has to be tailored to the particular site, using both archaeological evidence and, if possible, measuring $^{87}Sr/^{86}Sr$ in enamel samples from different species. Depending on the prehistoric period and location of each site, other possible 'local' species include domestic animals. Once a suitable local species is identified, prehistoric enamel samples from different locations can then be used to map $^{87}Sr/^{86}Sr$ ratio of the prehistoric site (Bentley et al. 2004, 365).

In this study, we selected samples of mouse limb to determine the range of local strontium isotope ratios in the Wadian site for the reasons described below.

The results from the domestic animals are presented in Table 1. There is a clear difference in $^{87}Sr/^{86}Sr$ values for the different species, not so much in their average values, but in the variation between them. The average $^{87}Sr/^{86}Sr$ value in enamel from pig teeth is 0.712663 ±0.000250 and from mouse bone is 0.712737±0.000058. The standard deviation in the mouse bone values is thus less than that of pigs (Table 2). This suggests that mice were kept more locally than pigs.

Species	Mean 87Sr/86Sr	σ
pig	0.712663	0.000250
mouse	0.712737	0.000058

Table 2. Mean and Standard Deviation (σ) of $^{87}Sr/^{86}Sr$ Levels in fauna teeth from the Wadian site.

Based on the Strontium isotope ratio determination results, obtained by calculating the 4 mouse strontium isotope ratios of the average of 0.712737, defined as within 2σ of the mean $^{87}Sr/^{86}Sr$ in the archaeological mouse bone, the local range at the Wadian site is 0.712679 - 0.712795.

Investigation of the diversity of sheep and cattle origins at the Wadian site

The results from seven domestic animal teeth and four mouse bones are presented in figure 1. There is a clear difference in $^{87}Sr/^{86}Sr$ values for the different species. As figure 1 shows, the pig enamel values are highly varied and fall into two groups: 1) the first two have values for enamel that are lower than the local Wadian ratio, suggesting that they were not local, and 2) the next three individuals in the graph have the same enamel values with the local Wadian ratio. It is entirely possible that these individuals were born locally.

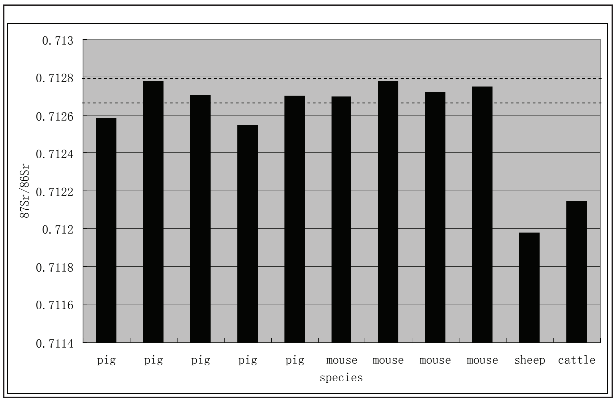

Figure 1. Bar graph of strontium isotope ratios in tooth enamels from the Wadian site.

The results for the first molar enamel, which formed within a few months of the animal's birth, indicate that sheep and cattle from the Wadian site fell well outside the local strontium isotopes ratio range and can be considered to be not local.

Conclusions

Tooth enamel and bone samples from 11 animal individuals were analysed for strontium isotope ratio ($^{87}Sr/^{86}Sr$), through thermal ionization mass spectrometry, including five pigs, four mice, one sheep and one cow. Molars were sampled whenever possible in faunal species. As the results show, $^{87}Sr/^{86}Sr$ ratios from animals revealed that the standard deviation for the mice (±0.000058) was less than half that of pigs (±0.000250). This implies that the mouse diet came from a more homogeneous area than the other animals.

The mean $^{87}Sr/^{86}Sr$ ratios of four mouse samples were 0.712737. Based on the local strontium isotopes ratio range determined by the mean $^{87}Sr/^{86}Sr$ ratios $\pm 2\sigma$ of four mouse samples (0.712679 - 0.712795**)**, we found that two pigs, one sheep and one cow from the Wadian site fell well outside the local strontium isotopes ratio range and were considered to be not local.

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Bibliography

Aberg, G. 1995. "The use of natural strontium isotopes as tracers in environmental studies." *Water, Air and Soil Pollution* 79:309-322.

Balasse, M., Ambrose, S. H., Smith, A. B., and Price, T. D. 2002. "The seasonal mobility model for prehistoric herders in the south-western cape of South Africa assessed by isotopic analysis of sheep tooth enamel." *Journal of Archaeological Science* 29**:**917-932.

Bentley, R. A. 2006. "Strontium isotopes from the earth to the archaeological skeleton: a review." *Journal of Archaeological Method and Theory* 13:135-187.

Bentley, R. A., Buckley, H. R., Spriggs, M., Bedford, S., Ottley, C. J., Nowell, G. M., Macpherson, C. G., and Pearson, D. G. 2007. " Lapita migrants in the Pacific's oldest cemetery: isotope analysis at Teouma, Vanuatu." *American Antiquity* 72:645 -656.

Bentley, R. A., Price, T. D., and Stephan, E. 2004. "Determining the "local"$^{87}Sr/^{86}Sr$ rang for Archaeological skeletons: a case study from Neolithic Europe." *Journal of Archaeological Science* 31:365 -375.

Blum, J. D., Dasch, A. A., Hamburg, S. P., Yanai, R. D., and Arthur, M. A. 2000. "Changes in Sr/Ca, Ba/Ca and $^{87}Sr/^{86}Sr$ ratios between two forest ecosystems in the northeastern USA." *Biogeochemistry* 49:87 -101.

Britton, K., Grimes, V., Dau, J., and Richards M. P. 2009. "Reconstructing faunal migration using intra-tooth sampling and strontium and oxygen isotope analyses: a case study of modern caribou (Rangifer tarandus granti)." *Journal of Archaeological Science* 36:1163-1172.

Chunyan, Z., Jing Y., and Nu, H. 2011. "Strontium isotope analysis of archaeological fauna from the Taosi site (in Chinese)." *Quaternary Sciences* 1:42 -47.

Copeland, S. R., Sponheimer, M., Lee-Thorp, J. A., Le Roux, P. J., De Ruiter, D. J., and Richards, M. P. 2010. "Strontium isotope ratios in fossil teeth from South Africa: Assessing laser ablation MC-ICP-MS analysis and the extent of digenesis." *Journal of Archaeological Science* 37:1437-1446.

Ericson, J. E. 1985. "Strontium isotope characterization in the study of prehistoric human ecology." *Journal of Human Evolution* 14:503-514.

Evans, J. A., and Chenery, C. A. 2006. "Bronze age childhood migration of individuals near stonehenge, revealed by strontium and oxygen isotope tooth Enamel analysis." *Archaeometry* 48:309-321.

Giblin, J. I. 2009. "Strontium isotope analysis of Neolithic and Copper age population on the Great Hungarian Plain." *Journal of Archaeological Science* 36:491-497.

Grupe, G., Price, T. D., Schriiter, P., Siillner, F., Johnson, C. M., and 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.

Haverkort, C. M., Weber, A., Katzenberg, M. A., Goriunova, O., Simonetti, I. A., and 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.

Hedman, K. M., Curry, B. B., Johnson, T. M., Fullagar, P. D., and Emerson, T. E. 2009. "Variation in Strontium isotope ratios of Archaeological fauna in the Midwestern United States: A preliminary study." *Journal of Archaeological Science* 36:64-73.

Hoppe, K. A. 2004. "Late Pleistocene mammoth herd structure, migration patterns, and Clovis hunting strategies inferred from isotopic analyses of multiple death assemblages." *Paleobiology* 30:129 -145.

Institute of Cultural Relics and Archaeology of Henan Province. 2004. *Yuzhou Wadian*. Beijing: World Publishing Company.

Kennedy, B. P., Folt, C. L., Blum, J. D., Chamberlain, C. P. 1997. "Natural isotope markers in salmon." *Nature* 387:766-767.

Knudson, K. J., Tung, T. A., Nystrom, K. C., Price, T. D., and Fullagar, P. D. 2005. "The origin of the Juch'uypampa cave mummies: Strontium isotope analysis of Archaeological human remains from Bolivia." *Journal of Archaeological Science* 32:903 -913.

Montgomery, J. P., Budd, P., and Evans, J. 2000. "Reconstructing the lifetime movements of ancient people: a Neolithic case study from Southern England." *European Journal of Archaeology* 3:370 -385.

Nehlich, O., Montgomery, J., Evans, J., Schade-Lindig, S., Pichler, S. L., Richards, M. P., and Alt, K. W. 2009. "Mobility or migration: a case study from the Neolithic settlement of Nieder-Mörlen (Hessen, Germany)." *Journal of Archaeological Science* 36:1791-1799.

Price, T. D., and Gestsdóttir, H. 2006. "The first settlers of Iceland: An isotopic approach to colonization." *Antiquity* 80:130-144.

Price, T D., Johnson, C. M., Ezzo, J. A., Ericson, J., and Burton, J. H. 1994. " Residential mobility in the prehistoric Southwest United States: A preliminary study using strontium isotope analysis." *Journal of Archaeological Science* 21:315-330.

Price, T. D., Manzanilla, L., and Middleton, W. D. 2000. "Immigration and the ancient city of Teotihuacán in Mexico: A study using Strontium isotope ratios in human bone and teeth." *Journal of Archaeological Science* 27:903-913.

Price, T. D., Burton, J. H., and Bentley, R. A. 2002. "The characterization of biologically-available strontium isotope ratios for investigation of prehistoric migration." *Archaeometry* 44:117-135.

Ruochun, Y., Juzhong Z., and Xiaoyong Y. 2008. "Preliminary study of prehistoric human migration based on Sr isotope analysis from Jiahu relics." *Quaternary Sciences* 28:50-57.

Sealy, J. C., Van Der Merwe, N. J., Sillen, A., Kruger, F. J., and Krueger, H. W. 1991. "$^{87}Sr/^{86}Sr$ as a dietary indicator in modern and archaeological bone." *Journal of Archaeological Science* 18:399-416.

Sealy, J., Armstrong, R., Schrire, C. 1995. "Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons." *Antiquity* 69:290–300.

Sillen, A., Hall, G., Richardson, S., and Armstrong, R. 1998. "$^{87}Sr/^{86}Sr$ ratio in modern and fossil food-webs in sterkfontein valley: implications for early hominid habitat preference." *Geochimica et Cosmochimica Acta* 62:2463-2473.

Towers, J., Montgomery, J., Evans, J., Jay, M., and Pearson M. P. 2010. "An investigation of the origins of cattle and aurochs deposited in the early Bronze Age barrows at Gayhurst and Irthlingborough." *Journal of Archaeological Science* 37:508-515.

Viner, S., Evans, J., Albarella, U., and Pearson, M. P. 2010. "Cattle mobility in prehistoric Britain: strontium isotope analysis of cattle teeth from Durrington Walls (Wiltshire, Britain)." *Journal of Archaeological Science* 37:2812-2820.