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Variation in strontium isotope ratios of archaeological fauna in the Midwestern United States: a preliminary study

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Strontium isotope values ($^{87}Sr/^{86}Sr$) in bone and tooth enamel have been used increasingly to identify non-local individuals within prehistoric human populations worldwide. Archaeological research in the Midwestern United States has increasingly highlighted the role of population movement in affecting interregional cultural change. However, the comparatively low level of geologic variation in the Midwestern United States might suggest a corresponding low level of strontium variation, and calls into question the sensitivity of strontium isotopes to identify non-local individuals in this region. Using strontium isotopes of archaeological fauna, we explore the degree of variability in strontium ratios across this region. Our results demonstrate measurable variation in strontium ratios and indicate the potential of strontium analysis for addressing questions of origin and population movement in the Midwestern United States.

1. Introduction

The analysis of strontium isotope ratios of human bone and tooth enamel has been used to assess migration and population movement in prehistoric populations in many parts of the world, including the American Southwest (Ezzo and Price, 2002; Ezzo et al., 1997; Price et al., 1994), Mexico (Price et al., 2006), Mesoamerica (Hodell et al., 2004), South America (Knudson et al., 2004; Wright, 2005), South Africa, Europe (Bentley, 2006; Bentley et al., 2004), and most recently, the American Midwest (Hedman, 2006a,b; Price et al., 2007; Widga, 2006).

In the Midwest, researchers have identified potential population movements beginning as early as 10,000 BC as essential to understanding the region's prehistory (e.g., Emerson, 1991; Emerson and Brown, 1992; Emerson and McElrath, 2001; Fortier, 2001; McElrath and Emerson, in press; McElrath et al., 2000; Price et al., 2007; Steadman 1998, 2001; Stoltman 1983, 1986, 1991, 2000). The scale of human population movement projected by archaeologists varied tremendously through time. Prior to about AD 200 such movements are thought to have occurred on a pan-regional scale with populations entering the area from as far away as the mid-south, the upper Ohio River Valley, and the eastern Plains. After AD 200, migrations are thought to have occurred at a more intraregional level within the Midwest (Emerson et al., in press; Emerson and McElrath, 2001; Fortier, 2001; Stoltman, 1983, 1986). Archaeological evidence for population movement in the Midwest is particularly clear in the post-AD 1000 period at which time the rise of the large Mississippian center of Cahokia, increased regional conflict, and climatic shifts appear to result in a demographically fluid landscape. During the eleventh to fourteenth centuries Cahokia acts both as an attracting force, possibly drawing in populations from the Missouri Ozarks, northern and central Illinois, southern Wisconsin, and the Ohio River drainage, and as a disperser of elite emissaries, traders, war parties, and dissatisfied residents (Pauketat, 2004). The late prehistoric era (post-AD 1400) was characterized by large-scale shifts of population as part of a general westward movement that continues through the European contact period. The scale of population movement (in terms of numbers and distance) is sufficiently great at this time that, if intraregional strontium variation can be identified, it should be reflected in the human skeletal populations.

Strontium provenience techniques have been used primarily in areas characterized by significant regional variation in geological substrate and strontium isotope values. Little research has been carried out in the Midwest using $^{87}Sr/^{86}Sr$ values (however, see Price et al., 2002, 2007). Can strontium analysis be used to identify non-local individuals at different sites in the Midwest, and perhaps

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more importantly, can it be used to identify possible places of origin of non-local individuals?

Before this methodology can be applied with confidence in the Midwest, spatial variability in strontium values in this region must be demonstrated and these differences must be great enough to distinguish between particular areas, yet small enough within these subregions to provide a unique isotopic signature (Hodell et al., 2004). In this paper we summarize the results of a preliminary study aimed at assessing the degree of variation in strontium isotope ratios in the Midwest, focusing on Illinois. In this study we use tooth enamel values from archaeological faunal specimens as a basis for defining the local strontium signatures for archaeologically, geographically, and geologically significant subregions in the Midwest.

2. Strontium isotopes

Variation in strontium isotope composition is expressed as the ratio of ^{87}Sr to ^{86}Sr. ^{87}Sr is a radiogenic isotope of strontium derived from the decay of rubidium (^{87}Rb). Relative to non-radiogenic ^{86}Sr, the abundance of ^{87}Sr is determined by the age and original rubidium content of the parent materials (Hodell et al., 2004). Rubidium is enriched in the earth's crust and depleted in the mantle. Thus, many old igneous and metamorphic rocks from the earth's crust have high strontium values (0.715 and higher), and recent volcanic rocks have low strontium values (typically 0.703–0.707). Marine limestones and dolomites have ratios between 0.707 and 0.710, generally indicating the strontium ratio of seawater at the time they were formed (Wright, 2005:555). Marine shales, on the other hand, have much higher ^{87}Sr/^{86}Sr values (e.g., 0.726–0.754 for the New Albany Shale of Illinois; Steuber et al., 1993) because they contain older and more Rb-rich detrital minerals. High-precision isotope ratio mass spectrometry (e.g., TIMS, ICP-MS) produces measurements with very small uncertainties (e.g., $\pm$0.003% of the measured ^{87}Sr/^{86}Sr) and thus very small variations in this ratio can be significant and reflect important discernible differences in the material being analyzed.

Strontium enters the ecosystem through the formation of soils derived from the combined impacts of accreted material (primarily from eolian deposition or settling of small particles from floodwaters) or through weathering of the underlying geologic material such as bedrock or till. The effects of the two processes are often blurred in the upper soil horizons through bioturbation. Rivers and groundwater tend to reflect the strontium values of the materials through which they flow, while strontium in plant and animal tissues is derived respectively from the water they take up and/or the food they consume. Although there is no discernible isotopic fractionation of strontium as it makes its way up the food chain, Price et al. (2002) demonstrated that there can be significant heterogeneity in the strontium isotope ratios of rocks, soils, and plants within a local area (see also Bentley et al., 2004; Blum et al., 2000; Sillen et al., 1998). 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 bioavailable strontium (Price et al., 2002:124). Humans consuming primarily local plant and animal resources should, therefore, have strontium values comparable to those of local fauna (Hodell et al., 2004; Price et al., 2002; Sillen et al., 1998).

3. The geology

The bedrock of the study region consists of sedimentary rock layers of various types and ages (Fig. 1). The bedrock mapping units range in age from Lower Paleozoic to Middle Cenozoic, but for this study the ages of the rock units are much less important than their lithology, or composition, which includes beds of limestone, dolomite, siltstone, and shale (Fig. 2). ^{87}Sr/^{86}Sr values reported by Steuber et al. (1987) for carbonate rocks (limestones and dolomites) in this sequence range from 0.7076 to 0.7098, those for shales range from 0.7279 to 0.7547, and those for sandstones range from 0.7106 to 0.7276. Bedrock is expected to contribute significantly to the ^{87}Sr/^{86}Sr values in areas with little or no glacial overburden (e.g., glacial deposits, loess) such as the Driftless region of southwestern Wisconsin, northeastern Illinois and northeastern Iowa, the Missouri Ozark region, and the American Bottom in southwestern Illinois.

Glacial deposits and loess characterize surface deposits over much of the research area (Fig. 2). Glacial deposits are comprised of sediment picked up and carried by the glacier along its flow path from its origin to the place of final deposition. Local sediment (i.e., sediments derived from an area near the final deposition spot) comprises proportionately more of the mixed glacial deposits than do transported sediments. In Illinois, the glacial debris fines consist primarily of comminuted Paleozoic bedrock and are composed of both carbonate rock and shale. Hence, the expected strontium value of glacial deposits in Illinois would be intermediate to that of the high values characteristic of shales and low values of carbonates. However, because parent materials can vary, and because strontium is leached unequally from different minerals, we cannot predict strontium isotope ratios of soils in glacial settings *a priori*. Rather, variability in strontium values is expected as the result of variations in the mixture of transported and local rock fragments present in glacial materials at any given locale.

Late glacial wind-blown silt (loess) blankets much of the Midwestern landscape. The winds were primarily easterly resulting in thickest loess accumulation (as much as 30 m) on the eastern uplands of north-to-south trending valleys. The source of the sediment was the alluvium that was deposited seasonally by meltwater. After glaciation ceased in the Midwest, loess deposition ceased, and subsequent soil forming processes modified the upland loess mantle. Loess thins rapidly away from the source valleys, and is less than 1 m thick in central Illinois between the valleys of the Illinois and Wabash Rivers (Fig. 2). In general, the landscape in this region has remained fairly stable for the past several thousand years. Although loess thickness has varied through time due to topographic change and erosion, this should not be a significant issue of concern for the time period addressed in this particular study.

In most of Illinois, Wisconsin, eastern Iowa, Indiana, and Michigan the mineralogy of loess is more smectite-rich than the underlying illite and chlorite-rich glacial deposits. In areas where loess is thickest and, consequently, is likely the primary soil parent material, the ^{87}Sr/^{86}Sr range of underlying Illinois Basin shales of the bedrock are not a reliable predictor of ^{87}Sr/^{86}Sr values of the overlying loess. Still, where shales, which have higher ^{87}Sr/^{86}Sr values than loess, comprise the bedrock, the ^{87}Sr/^{86}Sr of the loess mantle should be elevated relative to areas underlain by carbonates, which have lower ^{87}Sr/^{86}Sr values, more similar to those of overlying loess.

4. The samples

Archaeological sites were selected for sampling based on availability of appropriate faunal specimens with an attempt to include sites from a wide geographical area and reflecting varied geology (Fig. 1). The American Bottom, Upper Mississippi River Valley, Illinois River Valley, and the southern Great Lakes region of Illinois are represented, as well as northwestern Iowa, central and southwestern Indiana, and the Ozark region of Missouri. These regions figure prominently in questions of late prehistoric human population movement within the Midwestern United States