MIGRATION PATTERNS IN THE PREHISTORIC CALIFORNIA DELTA: ANALYSIS OF STRONTIUM ISOTOPES

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New opportunities for extensive research on Windmiller sites in California have been scarce in the last few decades. In addition, new methods are available for analyzing human remains which have yet to be applied to available collections. This paper presents new information on both fronts with an analysis of strontium isotope ratios ($^{86}Sr/^{87}Sr$) in human teeth and bone samples from the recently excavated population at CA-CCO-548. The data represent a snapshot of the composition of a Windmiller population and provide information for reconstructing migration and residence patterns as well as specific analyses of migration and group composition.

The development of sedentism is of particular interest to anthropologists because it has been a recurring theme throughout prehistory and has occurred in many areas of the world (Marshall 2006). Typically, there is a range of social changes that accompany such a shift, including changes in social organization and complexity, diet, health, and landscape use. California is of particular interest because restricted residential mobility was not followed by the development of agriculture. The Early period (ca. 5500-2500 B.P.) in central California provides a context in which to examine the processes of resource intensification and sedentism, since archaeological evidence indicates the process of sedentarization was beginning around this time.

Of particular interest is how social organizations, such as postmarital residence patterns, are related to or affected by changes in subsistence and settlement strategies over time. This study hinges on a developing methodology in archaeometry that examines strontium (Sr) isotope ratios as a way to estimate short-term (over the course of a lifespan) migration. Comparison of Sr isotope ratios ($^{87}Sr/^{86}Sr$) between the teeth of an individual, which form early in life and do not remodel, and bones, which are constantly remodeled throughout life, provides information useful for the reconstruction of migration and residence patterns over a single lifetime. This information then allows for detailed and specific analysis of migration, social organization, and group composition (Bentley et al. 2003; Ezzo et al. 1997; Price et al. 1994; Prohaska et al. 2002).

Changing subsistence strategies, such as those seen during California's prehistory, may have an impact on the relative importance of males and females in a society and thus on marriage patterns. In an economy focused on traditionally female-acquired resources, it would be beneficial for females to remain in their natal area where they have become familiar with their landscape by learning from their mothers and female kin. Archaeological evidence indicates intensive use of small seeds and acorns was beginning during the Early period (Basgall 1987). The work related to such plant processing was primarily done by

the women in the group. Thus as acorns and small seeds gained importance relative to hunting, a shift in social organization from patrilocality to matrilocality would be expected in order for related women to stay together as a work unit. If marriage patterns and other factors of social organization can be deduced, which is possible with certain biological indicators (discussed below), we can examine relationships and timing between processes such as sedentism, plant resource intensification, and certain aspects of social organization, such as postmarital residence patterns.

BACKGROUND

The Early period in California dates to between 5,500 and 2,500 years ago and displays an economy emphasizing hunting, fishing, and plant resource procurement (Bennyhoff and Fredrickson 1994; Moratto 1984; Milliken et al. 2007; Rosenthal et al. 2007). We also see the beginnings of group-oriented exchange and status-oriented social organization. The technological addition to the material culture of this period was the mortar and pestle. By the end of the Early period, populations were substantially larger than they had been at the end of the Middle Holocene. Numerous sites from this time period in central California are classified into the Windmiller tradition, which is characterized by having predominantly extended burials and a specific assemblage of materials associated with them (Bennyhoff and Fredrickson 1994; Heizer 1949; Lillard et al. 1939). The Marsh Creek site is peculiar because it has a variety of burial styles, including those classically defined as Windmiller.

In the Delta region of California, there has been a gap of several decades in research with newly excavated bioarchaeological collections. This has resulted in a significant lag in the use of newly developed techniques and a gap in the information available for this period, particularly with respect to questions that can be addressed through the analysis of human remains. The availability of the new burial population from CCO-548 and the permission to do minimally destructive analyses have created an excellent opportunity to explore new techniques and questions for this area.

The Site: CCO-548 (The Marsh Creek Site)

The Marsh Creek site is located in Contra Costa County on a tributary to the San Joaquin River, in what would have been the fringes of the marshy delta area during prehistoric times. During the fieldwork, approximately 500 individuals were excavated from multiple localities scattered across the site (the report is pending, but see Wiberg and Clark 2004 for preliminary information). The remains represent a mixed pattern, with some classic Windmiller burials based on orientation, position, and artifact types present, and others uncharacteristic of the classic Windmiller pattern. Within the clusters of burials were multiple styles of interment, including both flexed and extended burials and single- and multiple-individual interments. The majority of these burials were found the upper component of the site. There was also variation in the cardinal orientation of the extended burials and relatively few interments with grave goods. Preliminary radiocarbon dating on the site indicates a relatively short period of occupation, between about 4500 and 3500 B.P., for the upper, Early period component. There is also a lower Middle Holocene component that returned dates between 7000 and 5500 B.P. This lower component has had minimal archaeological attention compared to the rest of the site.

The Sample

The subset of individuals being analyzed as part of a dissertation project was chosen based on burial preservation, completeness, and factors related to the variation seen across the population, such as age, sex, interment style, and associated artifacts. The first priority went to those burials that were most complete and apparently best preserved. Such burials are most likely to yield uncontaminated teeth and bones, and have good collagen preservation, maximizing the interpretive value of the proposed archaeometric analyses. However, an attempt was also made to adequately represent all of the variation at the site. Analyses will focus on the Early period component; however, samples will also be taken from the

few burials associated with the lower, Middle Holocene component. For this preliminary paper, results from 14 individuals from the Early period component are discussed.

Strontium isotope analysis and migration

Analysis of $^{87}Sr/^{86}Sr$ stable isotope ratios in human burial populations has had limited exploration in archaeology, especially in California, but has great potential to open up new avenues of research. The isotope ratios of Sr vary as a function of age in geologic formations. Strontium has chemical properties similar to calcium, such that it is easily substituted for calcium in organic molecules. It is incorporated into the human body through food consumed by the individual. Plants take up the Sr available in the soil of their immediate surroundings, and thus humans receive their Sr from those plants and the animals feeding on those plants. Fractionation (preferential uptake of one isotope over another) does not occur for Sr because the relative difference in mass between the two isotopes is minimal. Thus, there is no enrichment of one strontium isotope over another at different trophic levels, as is seen, for example, in carbon and nitrogen stable isotope ratios (e.g., DeNiro and Epstein 1981). The $^{87}Sr/^{86}Sr$ present in tissues in the body reflects the strontium ratio available in the diet from local environment (Price et al. 2002).

Comparing Sr isotope ratios between the teeth and bones of an individual allows for reconstruction of migration and residence patterns, in particular the changes in residence between childhood and adulthood. Teeth in the human body are formed early in life (variably depending on the tooth) and do not change their chemical composition later, so that $^{87}Sr/^{86}Sr$ values obtained from enamel in teeth reflect the strontium available when an individual was young and their teeth were developing (Hillson 2005). On the other hand, bone is continuously remodeled throughout life, and $^{87}Sr/^{86}Sr$ values from bone reflect the last four to 20 years of the individual's life (depending on the skeletal element; for example, the femur represents 12-20 years of life). These properties of strontium and its relationship to the human body provide the opportunity to study changes in the geological source of food resources consumed over time in one individual.

The $^{87}Sr/^{86}Sr$ values for bone and enamel can also be compared to the local signatures and the surrounding geological regions, which can determine the location and migration pattern of groups, including the areas from and to which they were moving (Bentley et al. 2003; Ezzo et al. 1997; Prohaska et al. 2002). These data will allow for an investigation into the composition of the population in terms of local and nonlocal inhabitants, making it possible to identify marriage patterns (e.g., patrilocal, where men do not move after marriage; matrilocal, where women do not move; or other patterns). Examination of the $^{87}Sr/^{86}Sr$ ratio between individuals, and comparison to attributes such as interment style, spatial location within the site, sex, and health, among others, will be of particular interest because these traits demonstrate substantial variation across the site. In similar studies, there has been significant patterning between such attributes and $^{87}Sr/^{86}Sr$, which is related to an individual's origin (see Bentley et al. 2002, 2003; Ezzo et al. 1997; Price et al. 1994; Prohaska et al. 2002).

For the CCO-548 population, it is expected that a consistent osteological strontium isotope signature in bone will emerge, representing a "local" signature due to cohabitation and local consumption of foods. If the individuals represent a cohesive population, then any nonlocal individuals would provide information about marriage patterns, showing which individuals are joining or marrying into the population and thus elucidating some aspects of social organization at that time. For example, if the nonlocal signature were represented predominately by women, it would indicate a pattern of patrilocal residence. If nonlocals were predominately men, it would indicate a system of postmarital residence in which women stay in their natal area with their female kin (e.g., matrilocality).

METHODS

For these analyses, the samples were dissolved, and Sr was isolated by routine Sr separation techniques and analyzed by Multi Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS). This method removes all isotopes of rubidium (Rb), one of which (^{87}Rb) can interfere with the Sr

Table 1: Burial data.

Individual Number	Burial #	$^{87}Sr/^{86}Sr$: Bone	$^{87}Sr/^{86}Sr$: Enamel	Status	Sex	Age	Burial Position
1	4	0.707296	0.707304	local	male	35-45	flexed
2	107	0.707346	0.707319	local	male	35-45	extended
3	116	0.707331	0.707303	local	?	20-25	extended
4	123	0.707263	0.707285	local	female	40-50	semiextended
5	132	0.707165	0.707377		male	20-25	extended
6	164	0.707287	0.707182		male	30-40	semiextended
7	185	0.707265	0.707299	local	male	17-25	extended
8	231	0.707274	0.707204		female	18-24	extended
9	262	0.707259	0.707159		female	40-50	extended
10	292	0.707277	0.707356		female	33-46	semiflexed
11	413	0.707280	0.707333	local	male	43-55	flexed
12	439	0.707258	0.707436		male	20-30	extended
13	451	0.707307	0.707311	local	female	45-55+	flexed
14	465	0.707471	0.707345		female	43-55	extended

isotope system. Prior to dissolution, bone (~0.1 g of powder) and enamel (~0.05 g of powder) were treated with 15 percent hydrogen peroxide (H_2O_2) for 24 hours to remove organic material. Samples were then rinsed in distilled water and dried down followed by treatment with 0.1 N acetic acid for 24 hours to remove carbonates. Complete dissolution (i.e., no residual solids remained) in 2.5 N hydrochloric acid (HCl) was obtained by placing the samples under lids on a hotplate for 24 hours. Samples were then dried down and brought up in 8 N nitric acid (HNO_3). The supernatant was loaded onto super-cleaned ion exchange columns containing Eichrom Sr Spec resin and rubidium (Rb), barium (Ba), lead (Pb), and most other elements removed by rinses of 3 N HNO_3. Sr was eluted by 0.5 N HNO_3, dried down, and reloaded onto the columns a second time (in 8 N HNO_3) to ensure complete purification of Sr from Rb. All acids used were distilled to ensure their purity and titrated to ensure the correct elutions.

Sr isotope ratios were determined by Nu Plasma MC-ICP-MS at the UC Davis Interdisciplinary Center for Plasma Mass Spectrometry. In the period from October 2006 to August 2009, the mean $^{87}Sr/^{86}Sr$ value for the SRM 987 standard for the Nu Plasma has been 0.710226 ±26 (2 σ; n = 97). Isotope analyses were mass-fractionation corrected to $^{86}Sr/^{88}Sr = 0.1194$. $^{87}Sr/^{86}Sr$ isotope measurements for the samples were normalized to an accepted value of 0.710248 for the SRM 987 standard.

RESULTS AND DISCUSSION

The data obtained suggest that differences between $^{87}Sr/^{86}Sr$ ratios in bone and enamel can be seen both for individuals and within the population as a whole (Table 1; Figure 1). The mean for bone $^{87}Sr/^{86}Sr$ is 0.707282 (sd = 0.000066). The mean for enamel $^{87}Sr/^{86}Sr$ is 0.707291 (sd = 0.000075). The bone $^{87}Sr/^{86}Sr$ signatures indicate that most individuals in this sample population were eating similar diets and were therefore probably living as a cohesive unit. Only two of the 14 individuals fall outside of the standard deviation for the bone ratios of this population. The enamel $^{87}Sr/^{86}Sr$ ratio data show more variation overall, with five of the 14 individuals outside of the standard deviation for enamel. This indicates that there are likely to be more enamel $^{87}Sr/^{86}Sr$ signatures outside of the local signature for the

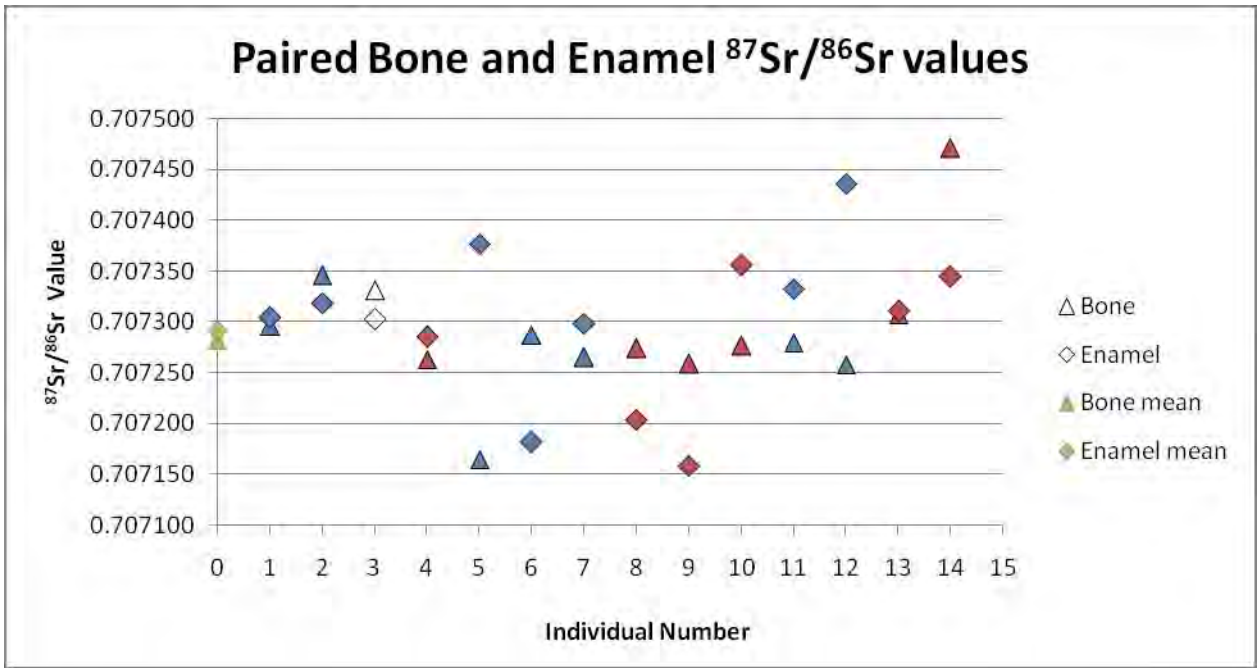

Figure 1. Paired bone and enamel values.

population, and it will be possible to determine the local/nonlocal status of the individuals in the population.

The "local/nonlocal" status for individuals is determined based on the difference between bone and enamel signatures. For this preliminary analysis, individuals with an $^{87}Sr/^{86}Sr$ signature difference greater than 0.00006 are considered to be "nonlocal" individuals. For this sample population, there appear to be seven local and seven nonlocal individuals. All of the $^{87}Sr/^{86}Sr$ values that fall outside of a standard deviation for their respective sample types belong to nonlocal individuals. Three of the individuals have an $^{87}Sr/^{86}Sr$ enamel value higher than that of their bone, while the other four have higher bone values than enamel. Of the local individuals, four are male, two are female, and one is of unknown sex. Three were buried flexed, and three were buried extended, and one semiextended. Two of the males were aged 35-45, one was 17-25, and one was 45-55. Both females are estimated to be older than 40. Of the nonlocal individuals, three of them are male and four are female; five were buried in the extended position, one semiextended, and one semiflexed. The nonlocal males were estimated to be 20-40 years old, whereas, of the nonlocal females one was estimated to be 18-24, while the rest were estimated to be older than 35.

Based on the composition of this sample from the population, females are slightly more likely to be nonlocal, indicating a possible patrilocal marriage pattern; however, an increased sample size will help to clarify the pattern. In addition, nonlocal individuals were buried predominately in the extended position, while local individuals do not seem to have a dominant burial style preference.

CONCLUSION

The recent excavation of the Marsh Creek site from the Delta region of California allows for new methods of investigation into recurring questions raised about the archaeological record as well as the opportunity to explore innovative ways of addressing archaeological questions using new archaeometric techniques. With the development of new analytical techniques, archaeologists can ask increasingly detailed and varied questions of the archaeological record. At the same time, federal laws, such as the Native American Graves Protection and Repatriation Act (NAGPRA), are removing certain parts of

archaeological collections, in particular skeletal remains and associated funerary remains, for reburial, thus taking them out of the realm of archaeological analysis. The skeletal and funerary remains from the Marsh Creek site will ultimately be repatriated and reburied, and collaboration, negotiation, and a close working relationship with the most likely descendants (MLDs) has allowed for the opportunity to apply new archaeometric techniques to a sample of the skeletal remains before they are reburied. The ultimate goal of the study is to add to our knowledge of Native American mobility, marriage patterns, and weaning behavior in the Delta region. These topics are relevant to the conditions in prehistoric California and to the development of complex hunter-gatherer behavior throughout the world.

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