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Tracing the mobility of individuals using stable isotope signatures in biological tissues: “locals” and “non-locals” in an ancient case of violent death from Central California

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ABSTRACT

Stable isotope analyses of biological tissues that grow during different phases of life can be used to trace the geographic location of individuals during different windows of time. We apply this principle and reexamine three prehistoric skeletons excavated in 1964 from archaeological site CA-YOL-117 in Central California. Field evidence suggests they were killed as part of a single violent event. We report new radiocarbon dates and Strontium, Oxygen, Carbon, and Nitrogen isotopic data from first molars, third molars, and bone to examine circumstances surrounding their death. Data suggest two of the three individuals were born, and all three lived their teenage years, near the site they were buried in. However, as adults they lived elsewhere, likely to the north along the Sacramento River. Around AD 1450, upon returning to the territory of their childhood years, they were killed and placed in a mass grave. The data invite a more nuanced interpretation of how we view “local” and “non-local” individuals archaeologically. Overall, the analysis provides an interesting glimpse into the nature of warfare and violence among pre-contact hunter–gatherers of Northern California.

In 1964 a local farmer working his field called the University of California at Davis Anthropology Department to examine skeletal remains he had inadvertently disturbed and exposed on the edge of a small elevated mound, CA-YOL-117, in eastern Yolo County, California (see Fig. 1). Professor Martin Baumhoff went to investigate the skeletons. He determined that the remains were those of four late prehistoric Native Californians. One was highly disturbed and not deemed worthy of further excavation, but three interred in a single pit were less disturbed and were excavated and brought back to the university. Skeletal remains were curated in the UC Davis Anthropology Museum, and remained largely unanalyzed until recently. To the best of our knowledge, the site is still mostly in-tact, but has not been further excavated or studied.

CA-YOL-117 is located within the Yolo Basin, a major spillway of the Sacramento River in Central California. This landscape was frequently flooded during prehistoric times, especially in winter and spring. Even with modern levee construction, the area is still occasionally flooded during periods of high discharge in the Sacramento River, though this is now intentional to relieve pressure on levees. For example, Fig. 2 shows photographs of the site, among the trees in the center of each image, in the summer and winter of 2011. The site lies within the traditionally recognized territory of the Patwin tribe (Bennyhoff, 1977; Kroeber, 1932). However, no known ethnographic villages were recorded in the area (Johnson, 1978), and given seasonal flooding and its marshy nature, the Yolo Basin may have been somewhat of a “no man’s land” between the territories of the Patwin tribe to the north and east, and the Plains Miwok tribe to the east.

In 2002, the three individuals were inventoried, and age, sex and evidence of pathological conditions and nutritional stress indicators were assessed (Self, 2003). Here, we present new radiocarbon dates on the burials to help determine when these individuals lived, and Strontium isotopes from first and third molars and bone to track their positions on the landscape over time. Oxygen and carbon isotope ratios of the bone and tooth enamel, and nitrogen and carbon isotopes from bone collagen, confirm our reconstruction of the life histories of these individuals. In the sections below we report on these studies and re-evaluate the circumstances regarding their death.

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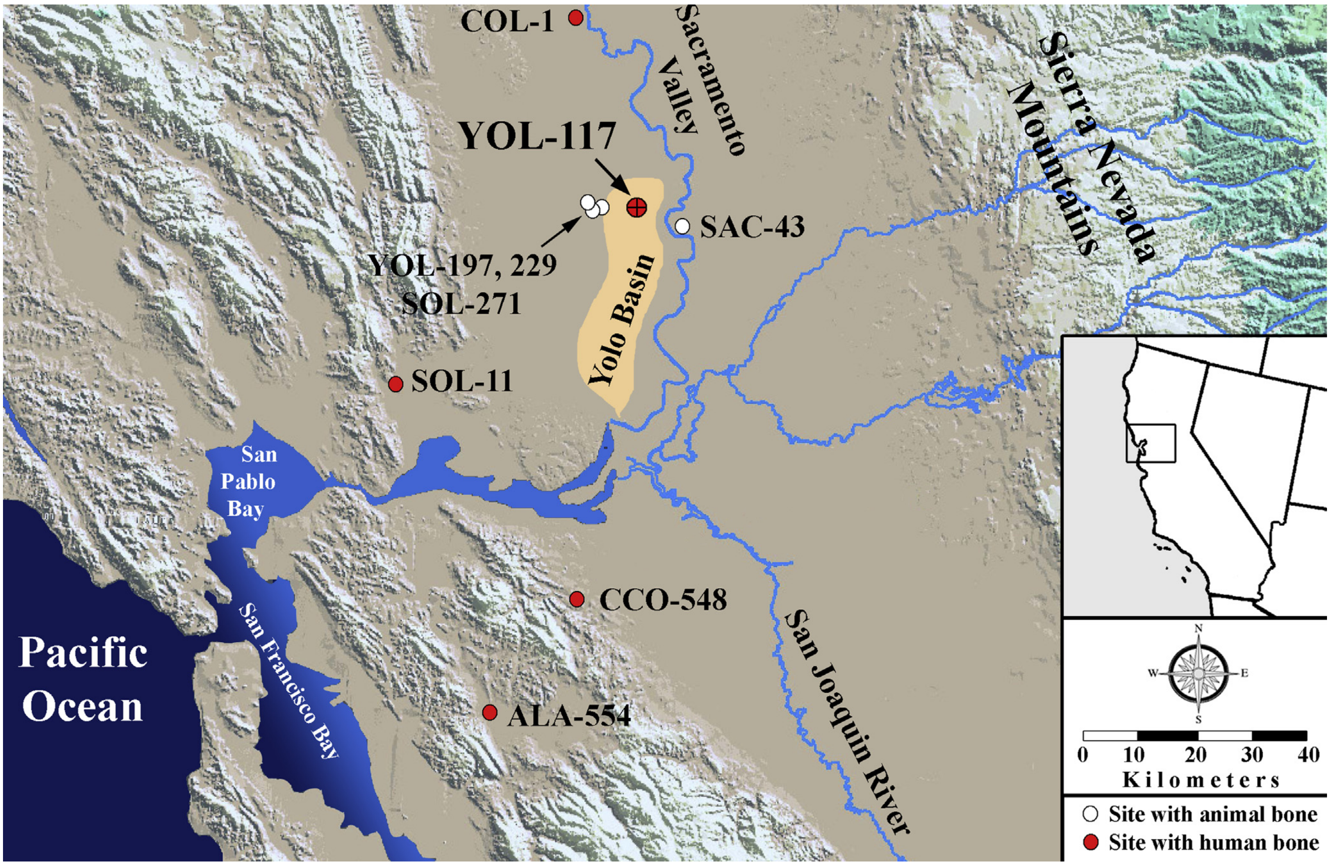

Fig. 1. Map of Central California showing location of YOL-117, other archaeological sites mentioned in the text, and important geographic features.

1. Individuals from CA-YOL-117

The burials from CA-YOL-117 were interred in what appears to be a single pit. Unfortunately, no photographs were taken during the original field excavations in 1964. Only a quick sketch of the burial pit was made. We have taken this drawing and superimposed images of the proper skeletal elements to reconstruct the orientation and placement of the burials (see Fig. 3). Examination of the burial style reveals they are not buried in a traditional position (typically, this would be tightly flexed), but are more haphazardly placed next to and partially on top of one another in semi-extended positions.

Summary demographic data on the burials are given in Table 1. There is little evidence of pathology or indicators of nutritional stress. However, all three contain evidence of violent trauma. Loose projectile points (i.e., non-embedded arrowheads) were found near and in the rib cages of all three individuals. Burial #2 had seven arrow points in this area, Burial #3 three, and Burial #4 five. As well, Burial #3 had cut marks and a fragments of two obsidian points still embedded in the vertebral column, and Burial #4 had cut marks on the vertebral column consistent with perimortem wounds caused by an arrow and what appears to be a fragment of an obsidian point embedded in a thorasic vertebra.

Together with the style of burial, the data strongly suggest all three individuals were killed as part of a single violent event and were disposed in a pit. Our initial hypothesis was that these males were killed during a raid, with the bodies buried locally. Ethnohistoric and ethnographic records from central California indicate that warfare was endemic and not uncommon between groups (Estudillo, 1809; Font, [1776] 1930; Lambert, 2007), with raiding and defending villages a common theme (James and Graziani, 1975; Jorgensen, 1980; Kroeber, 1925). Interviews with informants indicate that raids were most commonly undertaken as payback for murder or to punish poachers of resources, and more rarely associated with territorial expansion or to acquire marriage partners (Bettinger, n.d.). As well, evidence for warfare and violent events are not uncommon in the archaeological record, including embedded projectiles, perimortem craniofacial fractures, forearm "parry" fractures, and peri- or post-mortem trophy-taking of various body parts (Allen, 2012; Andrushko et al., 2005, 2010; Bartelink et al., 2013; Jones and Schwitalla, 2008; Jurmain, 2001; Jurmain and Bellifemine, 1997; Jurmain et al., 2009; Schwitalla, 2013).

2. Isotopic tracers of geography

To determine whether the three CA-YOL-117 individuals were local to the region, we use two main isotope systems, $^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$, as tracers of the geographic location of individuals at certain points in their lives. We supplement this with N and C isotopic analyses of bone.

The $^{87}Sr/^{86}Sr$ signature of a region varies primarily as a function of age and geochemistry of geological formations (e.g. Capo et al., 1998; Faure, 1986). The isotope ^{86}Sr is stable, whereas the radioactive isotope ^{87}Rb decays to form radiogenic ^{87}Sr, leading to relatively higher $^{87}Sr/^{86}Sr$ ratios with increasing geological age. Strontium has an atomic ratio similar to calcium and can easily substitute for Ca into biomolecules, including hydroxylapatite, in the mammalian body (Bronner et al., 1963). Plants take up Sr in small amounts from local soils and pass it up the food chain to humans and other animals. Fractionation of Sr up the food chain is negligible due to the minimal difference in mass between the two

Fig. 2. Image of CA-YOL-117 in summer (top) and winter (bottom), 2011.

isotopes. In this manner, the $^{87}Sr/^{86}Sr$ ratio has been shown to be a good tracer of the geological age and geochemical origin of the parent bedrock from which soils are formed (Capo et al., 1998; DeNiro and Epstein, 1981; Edmond, 1992). For pre-industrial hunter–gatherers, who acquire nearly all of their food within a short radius (ca. 25 km) of their residential base (Kelly, 1995), this Sr isotopic signature becomes incorporated into bone and teeth. In pre-industrial societies, archaeologists have shown that $^{87}Sr/^{86}Sr$ generally traces the geographic location of the residential base and local environment (Beard and Johnson, 2000; Bentley et al., 2003; Price et al., 2002).

Unfortunately, $^{87}Sr/^{86}Sr$ in bedrock has not been extensively mapped in California. While some regions have been studied by geologists and other scientists (Barnett-Johnson et al., 2008; Hobbs et al., 2005, 2010; Ingram and Lin, 2002; Ingram and Weber, 1999), and the age of some rock formations has been determined by Sr/Rb dating (Chen and Tilton, 1991; Cole and Basu, 1995; Kistler and Peterman, 1973), a state-wide map of Sr isotope ratios does not, to the best of our knowledge, exist. Existing data suggest there is a N–S gradient in Sr isotopes across the Sierra Nevada, with ^{87}Sr increasing to the North due to slightly older surface geology. In the Central Valley of California, this N–S gradient generates enough contrast that different regions can be characterized. To date, this approach to trace the geographic positions of individuals has seen only limited application in California (Jorgenson et al., 2009). To assist this study, we also measured $^{87}Sr/^{86}Sr$ on bones from rodents that were found in nearby archaeological middens. We assume these small-bodied animals did not migrate large distances and represent a "local" Sr signature for the region in which they were deposited.

Similarly, $^{18}O/^{16}O$ (expressed as $\delta^{18}O$) can also trace geography. Oxygen incorporated into hydroxylapatite in humans is derived mainly from imbibed water (Bryant et al., 1996; Longinelli, 1984; Kohn, 1996; Sponheimer and Lee-Thorp, 1999). Water, however, is fractionated through physical processes, especially evaporation and precipitation, with lighter water molecules evaporating first and precipitating last (Kendall and Coplen, 2001). Because the source of rainfall is relatively constant for many regions in North America, especially California, certain ranges of $\delta^{18}O$ are characteristic of waters in a given region. By extension, people drinking local water will incorporate that $\delta^{18}O$ signature in their biological tissues. The distribution of $^{18}O/^{16}O$ in waters across California is much better established than Sr. Using large samples of water from modern contexts, and quantitative models, a $\delta^{18}O$ map has been generated (Kendall and Coplen, 2001; Unnikrishna et al., 2002). Due to the effects of elevation on precipitation, California has a steep E–W gradient in $\delta^{18}O$ in surface waters. This high contrast assists in bracketing different geographic regions for $\delta^{18}O$. Breastfeeding can

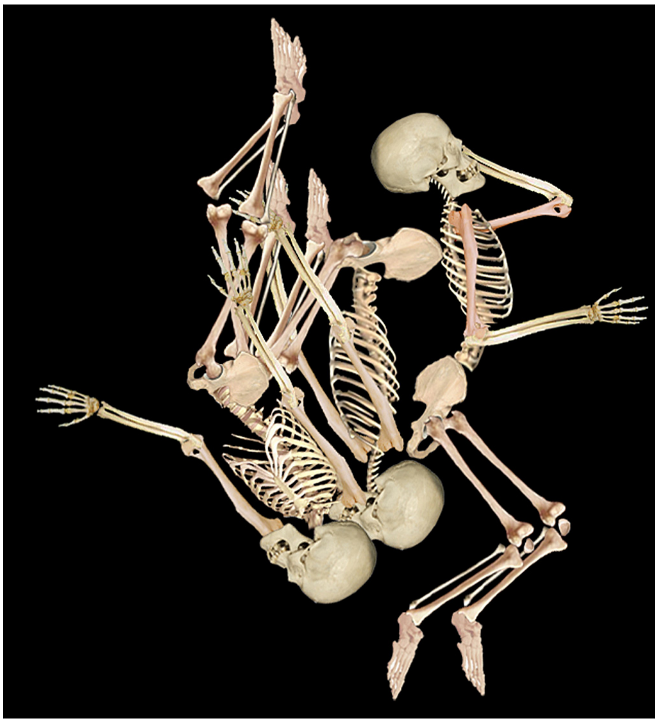

Fig. 3. Reconstruction of burial positioning in the pit from CA-YOL-117, based on field sketch.

enrich $\delta^{18}O$ by up to 3.0‰ (Wright and Schwarcz, 1998). This result is particularly important for interpreting oxygen isotope data from the enamel of first molars, formed between ages 0–3, possibly before the age of weaning. Taking enamel samples from the buccal or lingual surfaces near the cementum–enamel junction, which forms closer to age 3 when breastmilk is typically a minor source of water, ensures that breastfeeding effects on isotopic composition are minimized. Our enamel samples were taken from these parts of the teeth. Note further that heavy occlusal wear on first molars often forces such a sampling strategy anyway.

C and N isotopes are typically used to study paleodiet of individuals, however, because different foods vary in their spatial distribution, they can also inform on paleo-geography. In paleodietary studies around the world, $^{13}C/^{12}C$ (expressed as $\delta^{13}C$) often provides an estimate of the consumption of C3 vs. C4 plants (e.g., maize, sorghum, millet). In Central California, there are few C4 plants of economic importance to human foragers (Bartelink, 2006), and instead $\delta^{13}C$ provides a signature of the consumption of marine foods, which are, of course, most abundant near the coast. Previous studies in California show a strong pattern discriminating coastal and estuarine vs. terrestrial foragers (Bartelink, 2009; Eerkens et al., 2013), and we use $\delta^{13}C$ as a discriminator of terrestrial vs. marine environments. Nitrogen isotopes ($^{15}N/^{14}N$, expressed as $\delta^{15}N$) reflect the general trophic level of consumed foods. Nitrogen fractionates during the synthesis of biological tissues, favoring the retention of the heavier ^{15}N. As a result, $\delta^{15}N$ increases by about 2–4‰ with each trophic level. In terrestrial systems in Central California, there are essentially three trophic levels, plants, herbivores, and carnivores. By contrast, in aquatic environments, including both fresh, brackish, and marine systems, there are more trophic levels, resulting in greater enrichment of $\delta^{15}N$ at the top of the food chain (typically large fish, predatory birds, and aquatic mammals). Thus, $\delta^{15}N$ can help discriminate the spatial location of individuals living near large aquatic systems. In Central California such systems include the brackish-water Suisun Marsh, California Delta, and Sacramento River (Eerkens et al., 2013).

Table 1
Demographic and radiocarbon dates for three individuals from CA-YOL-117.

Individual	Sex	Age at death	Stature (cm)	^{14}C date	Calibrated yrs BP
Burial 2	Male	20–35	169	460 ± 25	AD 1420–1455
Burial 3	Male	25–40	166	395 ± 25	AD 1440–1620
Burial 4	Male	45–60	173	480 ± 25	AD 1415–1450

Notes: Calibrated dates represent 95% confidence intervals.

Thus, between Sr, which shows a N–S gradient in Central California, and O, which displays an E–W gradient, we can generate a rough geographic approximation of where an individual was living during the time of tissue synthesis. As well, we can determine the role of marine protein in the diet, and the general trophic level of protein, which varies across different ecosystems in California, particularly aquatic vs. terrestrial, to provide further context on geographic location. We exploit these findings below.

3. Analytical methods

Teeth and bone samples were washed with deionized water and the surface cleaned of any adhering soil or other material. The outer layers of each sample were removed using a Fordham microdrill and disposed. The same drill was then used to remove an additional ~200 μg sample of powdered material, enamel in the case of teeth, cortical material from bone. This powdered sample was then divided for Sr, C and O isotope analysis. Organics were removed by adding a 1.5% sodium hypochlorite at a ratio of 0.04 ml solution/mg sample (Koch et al., 1997). After 24 h the sample was centrifuged and the solution replaced. After a second 24 h the solution was discarded and the sample was washed three times with dH_2O. For the next 8–12 h the sample was placed in a diagenetic wash composed of a 1 M acetic acid solution (at the same ratio of .04 ml solution/mg sample) which was replaced after 12 h. The sample was then rinsed three times with dH_2O and any remaining water pipetted off. The sample was left in the container with no cap until completely dry.

While enamel appears to be relatively conservative, bone is more susceptible to diagenetic change (Budd et al., 2000), though recent studies suggest some parts of bone are also more resistant (Scharlotta et al., 2013). To minimize the potential effects of diagenesis, we mechanically removed the outer layers of bone and tooth samples, and subjected them to chemical cleaning. As well, our study focuses on interior sections of well-preserved cortical bone, and enamel, minimizing the potential effects of diagenetic changes to isotopic values (Knudson et al., 2005).

For strontium isotope analyses, about 0.05 g bone or teeth powder was weighed out, digested in closed Savillex® PFA containers in a concentrated $HF–HNO_3$ mixture and loaded in 8 N HNO_3 on Teflon micro-columns containing Eichrom Sr Spec resin. Strontium was eluted by 0.1 N HNO_3 following rinses by 3 N HNO_3 to remove matrix and interfering elements, particularly Rb, but also Ba and Pb. The procedure was repeated to ensure complete purification of Sr from Rb. The Nu Plasma (Nu032) MC-ICPMS at UC Davis Interdisciplinary Center for Plasma Mass Spectrometry uses a desolvating nebulizer (DSN-100) and ratios are corrected for mass fractionation to $^{86}Sr/^{88}Sr = 0.1194$. ^{87}Rb is monitored to correct for the interference of ^{86}Rb on ^{86}Sr. $^{87}Sr/^{86}Sr$ isotope ratios for the samples were normalized to an accepted value of 0.710248 for the SRM 987 standard. Since the Nu Plasma arrived in November 2003, the mean $^{87}Sr/^{86}Sr$ value for the SRM987 standard has been 0.710229 ± 0.000050 (2 σ; $n = 78$). For samples of standard BCR-2, which were processed with the samples, a normalized $^{87}Sr/^{86}Sr$ ratio of 0.705041 ± 0.000013 was obtained.

Apatite preparation started with the same cleaned bone, which was powdered in an agate mortar and pestle. Approximately .04 g of bone powder was placed in a weighed centrifuge vial. Organics were removed by adding a 1.5% sodium hypochlorite at a ratio of 0.04 ml solution/mg sample. After 24 h the sample was centrifuged and the solution replaced. After a second 24 h the solution was discarded and the sample was washed three times with dH_2O. For the next 8–12 h the sample was placed in a diagenetic wash composed of a 1 M acetic acid solution (at the same ratio of .04 ml solution/mg sample) which was replaced after 12 h. The sample was then rinsed three times with dH_2O and any remaining water pipetted off. The sample was left in the container with no cap until completely dry. Apatite samples were analyzed on a GVI Optima Stable Isotope Ratio Mass Spectrometer at the Stable Isotope Lab in the Geology Department at University of California, Davis. External precision for $\delta^{18}O$ and $\delta^{13}C_{apa}$ values is ±0.07 and ±0.04 (1σ), respectively, based on multiple ($N = 177$) analyses of the calcite standards NBS-19 and UCD-SM92. Oxygen isotope ratios are expressed as $\delta^{18}O$ representing a ratio of the abundance of ^{18}O relative to the abundance of ^{16}O, which is compared to a standard and expressed in permil units.

To isolate collagen, 1–2 g of cortical bone was cleaned of any surface contamination by first drill exposed surfaces with a diamond bit and then sonicating the sample in deionized water. The sample was then weighed and demineralized with a solution of 0.5 M hydrochloric acid (HCl). Bone was then washed three times with dH2O and soaked in 0.125 M NaOH (sodium hydroxide) for 24 h to remove humic acids and rinsed again deionized water. Slightly acidic pH3 water was added to the vial and the sample placed in a 70°–90 °C oven for approximately 24 h to solubilize collagen. After centrifuging the sample, the pH3 solution was pipetted into a clean vial and freeze-dried, isolating the collagen fraction. $\delta^{13}C_{col}$ and $\delta^{15}N$ were measured by continuous-flow mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20–20 isotope ratio mass spectrometer) at the Stable Isotope Facility, University of California Davis. Carbon isotopes ratios, $\delta^{13}C_{col}$, are reported expressed in permil notation (parts per thousand) relative to the PeeDee Belemnite standard (arbitrarily set at 0‰), while N isotope ratios, $\delta^{15}N$, are expressed against N_2 in modern atmospheric air (also arbitrarily set to 0‰). The long-term standard deviation for samples in the lab is 0.2‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$.

4. Results

Radiocarbon dates were obtained on all three of the burials from collagen extracted from bone. The dates were calibrated using the on-line version of Calib 5.1 (Stuiver et al., 2005) and are nearly identical in absolute age. If we assume these individuals lived contemporaneously, as suggested by the burial context, and supported by the radiocarbon dates, then overlap in the calibrated radiocarbon dates should provide the most likely intervals during which the violent deaths took place. The three calibrated radiocarbon dates overlap in their 95% confidence intervals between AD 1440 and AD 1450, suggesting they were killed somewhere close to this window of time.

Data collected from rodent samples near CA-YOL-117 suggest a narrow range of $^{87}Sr/^{86}Sr$ values Table 2. Samples from the edge and just west of the site vary between 0.70663 and 0.70679. A single sample from CA-SAC-43, further east along the Sacramento River (see Fig. 1), produced a similar but slightly larger value at 0.70691, suggesting that $^{87}Sr/^{86}Sr$ of sediment in the Sacramento River carries a slightly different signature.

Table 2
Sr and O isotope values for prehistoric rodent bones from sites near CA-YOL-117.

Site	Sample name	Element	$^{87}Sr/^{86}Sr$	$\delta^{18}O$
CA-YOL-229	Rodent	Vertebrae	0.706632 ± 0.000005	−5.51
CA-YOL-197	Rodent	Femur	0.706706 ± 0.000006	−7.13
CA-SOL-271	Rodent 1	Incisor	0.706763 ± 0.000005	−6.41
CA-SOL-271	Rodent 2	Incisor	0.706707 ± 0.000006	−6.88
CA-SOL-271	Rodent 2	Mandible	0.706755 ± 0.000005	−5.71
CA-SOL-271	Rodent 3	Pelvis	0.706789 ± 0.000005	−6.26
CA-SAC-43	Rodent	Mandible	0.706910 ± 0.000007	−6.13

Note: Sites arranged west to east.

Additional human samples that we have analyzed from areas to the south and north of CA-SAC-43 (Jorgenson, 2012; Jorgenson et al., 2009; unpublished data) indicate that $^{87}Sr/^{86}Sr$ follows a north-south gradient across the Sacramento and San Joaquin Valleys, with the lowest values in the north and the highest in the south. These patterns mirror results produced by researchers in biology and geology studying Sr dissolved in water, incorporated into fishbone, and in geological formations (Barnett-Johnson et al., 2008; Cole and Basu, 1995; DePaolo, 1981; Hobbs et al., 2010; Ingram and Weber, 1999; Kistler and Peterman, 1973; Masi et al., 1981; Nelson, 1995). Fig. 4 plots $^{87}Sr/^{86}Sr$ vs. $\delta^{18}O$ for the CA-YOL-117 samples against other human bone samples from Central California, with the region expected for "local" values for CA-YOL-117 circled.

Note, in particular, that while the majority of the CA-YOL-117 teeth (five of six) fall into the local isotopic range for the site, the three bone samples do not. This is significant because some studies suggest that post-depositional remodeling of bone can cause changes to biogenic Sr (e.g., Dunn et al., 2000; Hoppe et al., 2003), while enamel is typically resilient to such alteration. That the bone values here are quite unlike the local faunal signature, yet were sitting in local sediment for hundreds of years, suggests that either the original biogenic Sr has been little- or un-altered or that the original bone $^{87}Sr/^{86}Sr$ values were even more unlike the local range to begin with (i.e., even more non-local). That is, post-depositional alteration of the Sr isotope ratios should cause convergence *towards* the local value, not away from it. While we suspect the former (i.e., little-altered Sr isotope ratios in bone), our general interpretations of the results are in either case the same. The bone values do not overlap the local range, and even if they are

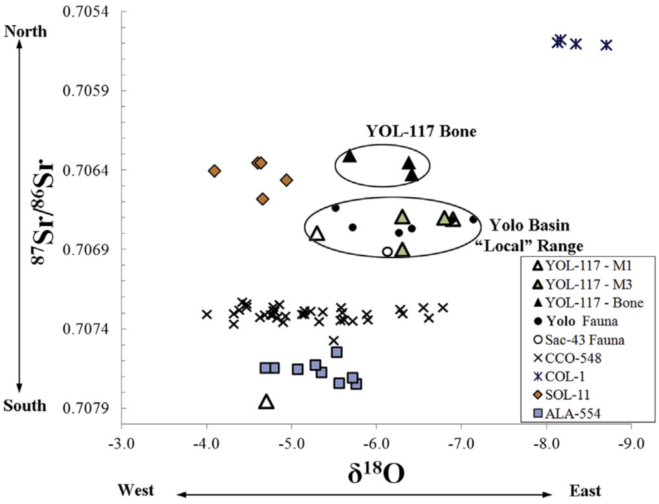

Fig. 4. $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values for CA-YOL-117 males and regional Central California human skeletal samples showing separation by site.

Table 3
Sr, O and C isotope results from CA-YOL-117.

Individual	$^{87}Sr/^{86}Sr$ M1	$^{87}Sr/^{86}Sr$ M3	$^{87}Sr/^{86}Sr$ bone	$\delta^{18}O$ M1	$\delta^{18}O$ M3	$\delta^{18}O$ bone Apa	$\delta^{13}C$ M1	$\delta^{13}C$ M3	$\delta^{13}C$ bone Apa	$\delta^{15}N$ bone Coll.	$\delta^{13}C$ bone Coll.
Burial 2	0.706705	0.706898	0.706423	−6.9	−6.3	−6.4	−14.6	−14.9	−15.7	11.6	−19.9
Burial 3	0.707852	0.706699	0.706348	−4.7	−6.8	−6.4	−13.2	−13.4	−15.2	10.5	−19.6
Burial 4	0.706792	0.706690	0.706304	−5.8	−6.3	−5.7	−15.9	−14.1	−15.8	9.9	−19.9

Notes: Coll. = Collagen; Apa. = Apatite.

affected by diagenesis (i.e., are converging on the local value), they have not changed enough to bring them into the local range. These males were living the final years of their lives in a location at some distance from CA-YOL-117.

Bone collagen values give additional information on the possible adult homeland for the three men. Table 3 indicates enriched $\delta^{15}N$ but depleted $\delta^{13}C_{col}$ for the CA-YOL-117 males. This is consistent with a diet where the majority of protein came from higher trophic levels, but from non-estuarine and non-marine sources. We do not have other humans from CA-YOL-117 to compare to (nor are rodents good models for humans for dietary isotopes). Instead, Fig. 5 plots $\delta^{13}C_{col}$ vs. $\delta^{15}N$ values of the CA-YOL-117 against values recorded for other Late Holocene (ca. 2500–250 BP) humans in Central California (see Bartelink, 2009; Beasley et al., 2013; Eerkens et al., 2013), grouped by ecological zone. As shown, the three males plot within the range of other Sacramento River foragers.

5. Discussion

The isotopic data presented above provide context for interpreting the mobility patterns, and hence, local or non-local status of the CA-YOL-117 males. First, relative to the total range for individuals across Central California, there is much greater within-site variation for $\delta^{18}O$ than for $^{87}Sr/^{86}Sr$. Indeed, $^{87}Sr/^{86}Sr$ is surprisingly consistent within sites, but shows high inter-site variation, making it the most useful isotope ratio for tracing mobility in the region. Further, the relatively narrow range of variation among bone $\delta^{18}O$, $^{87}Sr/^{86}Sr$, $\delta^{13}C$, and $\delta^{15}N$ values for the three CA-YOL-117 males is consistent with the interpretation that they were living in the same general location during the final adult years of their lives, likely the same village.

Second, the first and third molar data in Table 3 and Fig. 4 suggest that two of the three individuals from CA-YOL-117 (Burial #2 and #4) have Sr and O isotopic values that are different than local Yolo Basin values. Although there may be other regions in California with identical isotopic values, this result is entirely consistent with the interpretation that two of the men were born and raised near the site, through at least age 12. Burial #3 appears to have been born elsewhere, likely to the south, based on $^{87}Sr/^{86}Sr$ values in his first molar, but moved to the vicinity around CA-YOL-117 by at least age 10–12 based on isotopic measurements made on his third molar. Thus, all three individuals appear to have been living near the site during their late childhood years, the place they were ultimately buried.

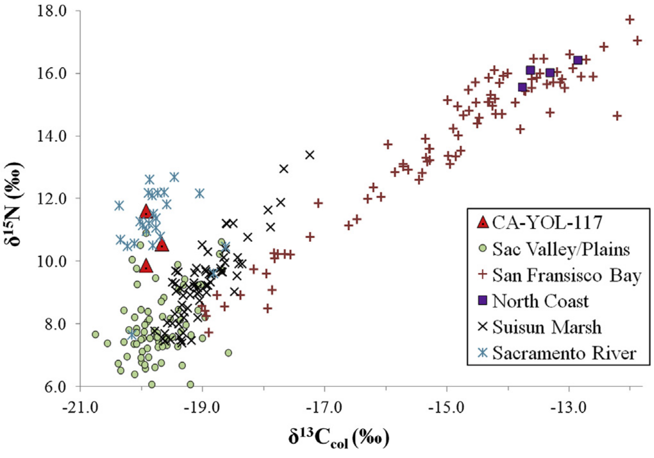

Fig. 5. $\delta^{13}C$ and $\delta^{15}N$ values for CA-YOL-117 males and regional Central California human bone collagen samples, showing separation by ecological zone.

Isotopic values recorded in bone are consistent with the interpretation that all three men moved away from the site during early adulthood. Strontium isotope values suggest this location was slightly to the north, while $\delta^{18}O$ values indicate an area approximately equal in longitude to CA-YOL-117. This suggests a location in the Sacramento Valley.

As seen in the bone collagen values presented in Fig. 5, the CA-YOL-117 individuals had similar diets to one another. The depleted $\delta^{13}C_{col}$ and enriched $\delta^{15}N$ suggest habitation near an aquatic environment with an extended food web and minimal input of marine-derived carbon. As seen the three males fall comfortably within the range of other foragers living along the Sacramento River. At the same time, they are distinctly outside the range of foragers from the Pacific Coast, San Francisco Bay, and Suisun Marsh, and for the most part, different than foragers living in the plains of the Sacramento Valley (i.e., along minor creeks and sloughs). Together, as with the Sr and O isotopes, the C and N isotopes are consistent with an adult homeland to the north of the Yolo Basin, in the Sacramento Valley and along the Sacramento River.

6. Conclusions

The new isotopic data add important context surrounding the circumstances of this ancient violent event. We had expected a simple dichotomous result; either the individuals would be “local” to the site (born, raised, and living at the site throughout their lives), or “non-local” (born, raised, and living elsewhere). In such a case, interpretation of the isotopic data may have been more straightforward: either they had died defending their village (local) or they were crossing or invading a foreign territory and had been killed (non-local). Initially, we had hypothesized the latter, given the non-traditional burial posture. However, the isotopic data suggest a much more nuanced scenario. We now believe these individuals were locals to the site at one point in their lives, but migrated away and lived elsewhere as adults. Hence, ultimately they became isotopic non-locals.

That they were killed and buried at the site, of course, opens a new set of questions surrounding the circumstances of their death. Given their non-traditional burial style and evidence for projectile wounds as the cause of death, we argue that these individuals were not welcome to CA-YOL-117, and were treated as enemies. As mentioned above, poaching and avenging a murder were the most common reasons given for raiding in the ethnographic period (Begginer, n.d.). Were these men caught poaching? If so, why did they lack rights in lands they had apparently lived in or near as children and teenagers? It is possible they married out of their native community (i.e., through a matrilocal system), losing land-rights in the process? On the other hand, patrilocal post-marital residence was generally considered the norm in this region of Central California (Johnson, 1978). Were the men raiding to avenge a previous murder, and were killed in the process? If so, why were they avenging a murder in their native homeland, where they presumably had kin relations?

It is also possible the men lost contact with, and land rights in, the Yolo Basin. Perhaps they and their kin were forced to leave the Yolo Basin after their teenage years. For example, paleoecological data indicate that the Little Ice Age, between AD 1500 and 1850, produced cooler and wetter conditions in Central California (Byrne et al., 2001; Jones and Kennett, 1999; Malamud-Roam and Ingram, 2001, 2003). Such environmental conditions could have forced them to relocate to the north, and another group may have claimed the now-vacated Yolo Basin area as their own foraging grounds. If so, upon returning, they may have been treated as poachers or invaders by the new claimants. Alternatively, another ethnic group may have invaded the Yolo Basin as part of a territorial expansion, forcing evacuation by the three men. If so, a hostile borderland may have resulted in skirmishes between the new and former occupants. While raiding to expand territories is not commonly described in the ethnographic literature (Bettinger, n.d.), linguists believe Patwin-speaking peoples “intruded” into the region late in prehistory (Golla, 2011). Perhaps the three CA-YOL-117 men are a physical marker of the violent nature of such a linguistic intrusion.

It is also possible that the three males were traders. Patwin ethnography indicates that trading is one of four formally recognized categories of functional families (the others being ceremonial, shamanistic, and official; McKern, 1922). The traders could have been crossing the homeland of their youth, but were discovered and treated as poachers. Alternatively, they may have been killed as part of a trading deal gone bad.

Of course, there are many possible scenarios that could be hypothesized. In the future, ancient DNA analysis and/or serial sampling for isotopes across growth layers of teeth for the three males might provide additional detail to rule out some of the scenarios, or to suggest new ones. Additional excavations at the site could also provide more context for the occupational history and/or ethnic affiliation of the inhabitants. As well, more detailed mapping of biologically available strontium and oxygen isotope ratios across California will help provide better context to the growing number of bioarchaeological and forensic analyses incorporating isotopic data.

In any case, our analyses at CA-YOL-117, and other Central California sites, suggest that many individuals migrated in the course of their lives, between birth and adulthood, to and from regions with isotopically distinct local signatures. The reasons for such residence shifts are certainly varied, including marriage, village fissioning, and/or forcible removal, but provide important context to help archaeologists interpret the prehistoric record. Importantly, such data can help place individuals on various parts of the landscape at different points in their lives, and in the case study described here, can help archaeologists better understand the nature of ancient warfare and interpersonal conflict.

In the final analysis, we argue that isotopic analyses provide crucial data to help interpret patterns in ancient violence. Isotopic tracers of geography can help establish whether victims of violence were isotopic “locals” or “non-locals” and whether such violence was largely intra- or inter-group. Moreover, by sampling different tissues, we can trace those individuals across the landscape across different windows of time. In the case described above, analyses showed that an individual can be both an isotopic “local” and a “non-local” at different points in their lives. Such information helps contextualize excavation and osteological field and lab information, and provide a richer understanding of ancient human behaviors.

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