**Title**

Isotopic Reflections on the Sexual Division of Labor and Postmarital Residence in Precontact Central California: A Multi-Isotopic (δ13C, δ15N, δ34S, δ18O, and 87Sr/86Sr) Investigation at the Windmiller (CA-SAC-107) and Blossom (CA-SJO-68) Mounds

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# Isotopic Reflections on the Sexual Division of Labor and Postmarital Residence in Precontact Central California: A Multi-Isotopic ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$) Investigation at the Windmiller (CA-SAC-107) and Blossom (CA-SJO-68) Mounds

By

CANDICE ELAINE RALSTON
DISSERTATION

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# ABSTRACT

This study's research question and hypotheses are derived from early anthropological and social theories, which suggest that the sexual division of labor is correlated to postmarital residence patterns. Those studies hypothesized that matridominant subsistence favors matrilocality while patridominant subsistence favors patrilocality. Advancements in archaeometry, particularly isotope analysis of human skeletal tissues, permit archaeologists to generate nuanced data sets to investigate ancient diet and mobility patterns. Stable isotope analysis provides evidence of paleomigration and diet for individuals, can distinguish between site- and individual-level residential and dietary patterns, and permits comparison between male- and female-mobility and dietary patterns. The original objective of this dissertation research was to investigate the relationship between the sexual division of labor with postmarital residence for Early Period (*c.* 5000–2400 cal BP) populations from archaeological sites CA-SAC-107 and CA-SJO-68 in central California, using five different isotopic systems ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$). While new radiocarbon dates, reported here, reveal assays ranging from 4497 ± 27 to 3132 ± 24 RCYBP at CA-SJO-68, as expected, those from CA-SAC-107 range from 3427±26 to 135±20 RCYBP and thus necessitated re-evaluation of chronological patterns. Paleodietary reconstruction using $\delta^{13}C$ and $\delta^{15}N$ of human bone collagen and $\delta^{13}C$ of bone apatite largely support expectations from archaeofaunal, paleobotanical, and artifactual evidence from central California. Isotopic indicators of diet reveal that the CA-SAC-107 population foraged within a $C_3$-terrestrial food web with minimal sex differences in dietary behaviors. Confounding variables, including small sample sizes and the temporal bias of sampled elements, limited interpretation of sex-biased mobility and postmarital residence in the Early Period using $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ at CA-SAC-107. However, isotopic results relating to human geolocation at the site are generally consistent with marriage endogamy and increasing sedentism over time. Paleodietary reconstruction at CA-SJO-68 using $\delta^{13}C$ and $\delta^{15}N$ of human bone are consistent with high input of freshwater-riverine resources and demonstrate that males typically consumed higher-trophic-level resources than females. Results of paleomobility analysis and interpretation of postmarital residence using $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr at CA-SJO-68 are consistent with endogamous marriage practices and greater mobility for males, particularly during late adolescence.

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# CHAPTER I. INTRODUCTION

The objective of this dissertation research is to investigate the relationship between the sexual division of labor and postmarital residence patterns for Early Period (*c.* 5000–2400 BP) populations buried at the Windmiller (CA-SAC-107) and Blossom (CA-SJO-68) mounds in central California using five different isotope systems ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$). Where a couple chooses to live after marriage, known as postmarital residence, has broader sociocultural implications. Postmarital residence influences the sociality, obligations, and roles upheld by kin since it affects the number of individuals and their relational status within a household, and the regularity of interactions within a kinship system. Evaluating regional and diachronic postmarital residence patterns can therefore clarify how cultural systems are integrated and illuminate other aspects of human behavior and social organization.

This dissertation research is situated within broader anthropological and social theories, which propose that the sexual division of labor shapes societal rules about postmarital residence (Eggan 1950; Korotayev 2003a, 2003b; Lippert 1931; Linton 1936; Murdock 1949; Service 1962). Specifically, these theories posit that for societies in which male labor is highly valued, and male-associated subsistence practices contribute the most calories to the household (patridominant), living with or near the husband's family is favored (patrilocality). Alternatively, matrilocality (couple lives with or near the wife’s family) is favored when female labor is highly valued and contributes the most calories to the household (matridominant). Cross-cultural tests during the mid-20th century focused on Indigenous groups in North America (Driver 1956; Driver and Massey 1957) supported this hypothesis. However, other tests using worldwide samples did not substantiate the correlation between the sexual division of labor and postmarital residence (Divale 1974, 1975, 1984; Ember and Ember 1971; Hiatt 1970; Korotayev 2003a, 2003b; White 1967). These studies illustrate complex interactions among postmarital residence, the sexual division of labor, territoriality, and warfare.

For ethnographic California, females' subsistence labor is linked to plants foods while males are associated with hunting and fishing (Jackson 1991; Wallace 1978; Willoughby 1963). Female labor, particularly tied to the acorn economy, is significant; however, the predominant postmarital residence pattern reported is patrilocality or virilocality (Bettinger 2015; Jorgensen 1980). Alternative practices are allowed in about half of these groups, with matri-uxorilocality being the most common alternative (Jorgensen 1980: 174–190). However, it is likely that the earliest populations in California were readily accommodated by a highly mobile, bilateral band organization.

The complexities discussed above can be clarified by incorporating archaeological and archaeometric evidence to examine the degree to which ethnographic patterns apply to precontact California. Additionally, such evidence can be used to evaluate the evolution of covarying factors such as dietary behaviors, the sexual division of labor, mobility, and postmarital residence. For instance, paleobotanical and archaeofaunal evidence can be considered alongside stable isotope analysis of human bone, which provides a direct approximation of diet, to more accurately describe past dietary behaviors. Particularly, isotopic analysis is advantageous in that it permits individual-level assessments of diet and mobility. This allows for comparisons between female and male diets and mobility profiles that can be used to examine sex differences in food consumption patterns and hypothesized postmarital residence practices.

This dissertation uses the isotopic chemistry of human skeletal tissues to investigate the relationship between the sexual division of labor and postmarital residence for precontact populations in central California. Evidence comes from two burial populations from the Windmiller (CA-SAC-107) and Blossom (CA-SJO-68) Mounds, located in the southern Sacramento and northern San Joaquin Valleys of California and dating to the Early Period (c. 5000–2400 BP). The first objective was to reconstruct paleodiets of individuals within the populations from each site using stable carbon ($\delta^{13}C$) of bone collagen and bone bioapatite and stable nitrogen ($\delta^{15}N$) of bone collagen. If certain food resources are economically significant, they should comprise the bulk of a population's diet. Therefore, these economically important foods will drive the dietary isotopic signatures for those populations. Dietary isotope signatures consistent with foods traditionally acquired by females (e.g., low-trophic-level, terrestrial resources) or males (e.g., high-trophic-level, marine resources) provide insight into the relative value of female- and male-labor.

Sex-biased mobility is assessed using isotopic proxies of human geolocation. Sulfur ($\delta^{34}S$) of dentinal collagen and oxygen ($\delta^{18}O$) and strontium ($^{87}Sr/^{86}Sr$) of tooth enamel from first molars (or other early-forming teeth) and third molars were used to evaluate geographic residence during early childhood and late adolescence. The $\delta^{34}S$ of bone collagen, $\delta^{18}O$ of bone apatite, and $^{87}Sr/^{86}Sr$ of modern plant and shell samples are used to interpret the "local" isotopic signatures at CA-SAC-107 and CA-SJO-68. If individuals from the Windmiller and Blossom mounds married spouses from different villages or locations (exogamous marriage), and those couples later live together at those sites, there should be a significant difference between the isotopic mobility profiles of childhood/adolescence and adulthood. Additionally, if those populations practiced unilocal postmarital residence (e.g., matrilocality or patrilocality), there will be a significant difference between the isotopic mobility profiles of males versus females.

This dissertation is organized into seven chapters: this introduction, three topical chapters (chapters 2-4), methods (chapter 5), results (chapter 6), and a discussion with concluding remarks (chapter 7). Chapter 2 presents the archaeological background of the Early Period in central California, the original chronological period of focus of the present study. In so doing, the chapter describes the Windmiller culture, of which CA-SAC-107 is the type-site and presents archaeological evidence for different settlement-subsistence practices between foothill and valley sites during this period. Finally, the chapter describes archaeological sites, CA-SAC-107 and CA-SJO-68.

Chapter 3 provides an overview of theoretical perspectives, cross-cultural studies, and patterns in ethnographic California that inform this research. First, a literature review of seminal studies that investigate factors that influence postmarital residence is presented. Second, the chapter discusses postmarital residence patterns in ethnographic California and how this evidence and broader anthropological theory set expectations for the present study.

Chapter 4 presents the underlying principles of using isotopic analysis of human skeletal tissues to elucidate ancient diet and mobility. First, the fundamentals of stable isotopes are discussed. Next, there is a discussion of how $\delta^{13}C$ and $\delta^{15}N$ are used to reconstruct paleodiets. Following this, an overview of how $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ are used to ascertain ancient human geolocation and how the analysis of different skeletal tissues that form during different ages informs individual-level mobility. Also presented in that section is expected isotopic patterns by type of postmarital residence practice. Finally, the chapter discusses previously published archaeological studies that use isotopic evidence to understand paleodiets and mobility in California.

Chapter 5, the materials and methods, outlines the sample selection process of human skeletal remains and describes the demography of these collections from CA-SAC-107 and CA-SJO-68 curated at the Phoebe A. Hearst Museum of Anthropology (PAHMA). Next, procedures for pre-chemical processing of samples are discussed, followed by a description of isotopic methods, equipment, and facilities relevant to each type of isotopic analysis conducted. Finally, the chapter concludes by outlining the statistical tests used to evaluate the study's hypotheses.

Chapter 6 reports the results of radiocarbon dating and isotopic analysis of human skeletal tissues at CA-SAC-107 and CA-SJO-68. First, paleodietary reconstruction focused on bone $\delta^{13}C$ and $\delta^{15}N$, including general patterns and sex comparisons, is presented. Then, results of the paleomobility studies using $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ at each site are discussed, including comparisons of female and male mobility profiles, and, in the case of CA-SAC-107, diachronic assessment.

The dissertation concludes with a discussion in Chapter 7 of what is gleaned from radiocarbon dating and isotope analysis results concerning the association of sexual division of labor, mobility, and postmarital residence at the Windmiller and Blossom mounds. Additionally, results are compared to other isotopic studies that evaluate paleomobility and postmarital residence in central California (Burns et al. 2012; Harold et al. 2016; Jorgenson 2012; Ralston et al. 2020). Finally, the chapter concludes by advocating for multi-isotopic research programs that further explore regional and diachronic patterns of diet, population growth, skeletal trauma, and paleomobility to unpack the evolution of how these co-varying factors evolved in central California.

## CHAPTER II. ARCHAEOLOGICAL BACKGROUND OF THE EARLY PERIOD IN CENTRAL CALIFORNIA

As currently understood, the Early Period dates from about 5000 to 2500 cal BP (Groza et al. 2011; Table 2.1). While it was originally thought to be associated with the earliest inhabitants in central California (Heizer 1949; Lillard et al. 1939), we now know that many sites are much older, and people have been living in central California since at least 11,000 cal BP. Nevertheless, the nomenclature has stuck, and sites dating between 5000 and 2500 cal BP are still generally referred to as dating to the "Early" Period (Table 2.1; see Rosenthal et al. 2007). This chapter uses the temporal terms reported in Table 2.1 due to their common usage in California archaeology.

*Table 2.1: Chronological periods for Central California. All dates calibrated following Scheme D (Groza et al. 2011)*

| Period | cal BP | cal BC/AD |
|---|---|---|
| Late Period | 740–230 | AD 1210–1720 |
| Middle/Late Transition | 940–740 | AD 1010–1210 |
| Middle Period | 2160–940 | 210 BC–AD 1010 |
| Early/Middle Transition | 2450–2160 | 500–210 BC |
| Early Period | >3450–2450 | >1500–500 BC |

In central California, several distinct cultural complexes have been identified that roughly map onto different environmental niches within the Early Period. The sample population for this dissertation research comes from archaeological contexts in the Sacramento–San Joaquin Delta associated with the "Windmiller" pattern. Windmiller sites are commonly found on old levee ridges next to fresh-water marshes and riparian zones, and display a distinct burial arrangement of ventrally (face down) extended interments, head oriented towards the west, with a high frequency of grave goods (Heizer 1949; Lillard et al. 1939; Ragir 1972; Moratto 1984). Windmiller pattern sites and burials were documented before the advent of radiocarbon dating, and hence their absolute age was not known in the early 1900s. However, they were observed to occur stratigraphically below site components and burials with a different mortuary pattern, now generally referred to as the "Middle Period."

Other Early Period cultural patterns have been documented in central California. Thus, coeval sites, confirmed by radiocarbon dates, located elsewhere in the Sacramento Valley and into the foothills of the Coast Ranges differ in material culture and burial arrangements from Windmiller sites such as COL-81, COL-247, GLE-105, and GLE-217 (Meyer and Rosenthal 2008; White 2003). West of the Delta, sites that date to greater than 4000 years ago and contemporary with the Windmiller pattern exhibit distinct burial practices such as those identified in the Green Valley in Solano County (e.g., SOL-315), where interments are capped with milling tools and rock cairns. As well, archaeological sites located in the Los Vaqueros Reservoir area (CCO-696, -697), the Marsh Creek site (CCO-18/548), and into the Bay Area (e.g., ALA-307) that date to the same Early Period window show flexed-burial postures and are not associated with the same material-cultural characteristics associated with Windmiller burials (e.g., well-crafted charmstones) (Meyer and Rosenthal 2008). The Mesilla tradition, identified in the southern Cascades and northern Sierra Nevada, also dates to the Early Period, as does the Martis complex located more southernly in the Sierra Nevada.

This cultural diversity, manifest by divergent aspects of material culture including artifact types and differing mortuary practices, is apparent by at least the end of the middle Holocene (5000–4000 cal BP) and proliferates throughout the late Holocene (4000 cal BP to AD 1850). Previously these differences were argued to represent distinct, fairly isolated populations (Heizer 1949),). However, evidence for traded commodities, including obsidian from the eastern Sierra and north Coast Range quarries, and *Olivella* shell beads and ornaments that originate from the Pacific coast, demonstrates strong socio-economic links between Early Period groups in central California (Heizer 1974; Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007). Starting in the Early Period and continuing into the Middle Period, two settlement-subsistence strategies are evident in the Sacramento Valley, Coast Ranges, and the Sierra-Cascades that are linked to local ecological conditions: Valley and Foothill adaptations (Meyer and Rosenthal 2008; Rosenthal et al. 2007).

The summaries below focus on Early Period patterns within two general environmental types in central California: 1) the Foothillls and 2) the Central Valley/Delta. The archaeological sites that comprise the archaeometric analyses in the chapters that follow are at the boundary between these two environmental zones.

**Foothill Adaptation**

Differences in the environment and topography of the Sierra and North Coast Ranges compared to the Sacramento Valley and Delta environs influence the development of distinct residential-subsistence strategies; this difference is most apparent between paleobotanical remains and groundstone technology (Meyer and Rosenthal 2008; Rosenthal et al. 2007; Moratto 1984). The strong elevational gradient for foothill and upland sites produces greater spatial and temporal variability of various plant and animal resources. Exploitation of these seasonal and variably distributed resources can be accommodated by adopting a more mobile lifestyle, as well as use of more generalized and expediently made tools. These populations lived in low-density communities, relied on seasonal movements and adopted a  subsistence strategy consistent with Binford's (1980) forager model.

The material culture for upland sites or foothill-adapted peoples in the Coast Ranges and Sierra Nevada consists of cobble-based pounding, chopping, and milling mulling tools, and the almost exclusive use of handstones and millingslabs. Flaked-stone technology includes highly curated bifaces, heavily reworked dart points of various styles, and simple-flake tools crafted from local stone resources, in most cases. Compared to Valley populations, specialized tools are far less abundant and ornamental objects are widespread but rare (e.g., 'prestige goods' such as tabular-stone pendants, incised-slate ornaments, and perforated-stone plummets). Few shell beads or ornaments are recovered from these upland sites and exotic materials are lacking. Nonlocal materials reported from these sites are almost exclusively obsidian that originates from proximal quarries.

Large-mammal remains comprise approximately 70% of dietary bone from sites in the foothills and higher elevations of the Sierra Nevada (Meyer and Rosenthal 2008). The predominant artiodactyl represented is deer. Acorn, grey pine, and other nutshell remains are ubiquitous among foothill-adapted peoples during the Early Period, and show distinct proportional differences when compared to Valley sites. Acorn only accounts for about 20% of total nutshell recovered. Based on the abundance of charred shell remains, grey pine appears to be the more economically important plant resource of the two.

### Central Valley Adaptation

Populations that lived at Valley sites during the Early Period adopted a settlement-subsistence strategy conducive to exploitation of resources in the emerging patchwork of marshes, riparian zones, forests, and grasslands that developed during the middle Holocene as evidenced by the diverse technological and dietary assemblages recorded (Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007). No later than 4000 BP, more sedentary living emerged. For example, middens contain several hundred graves, storage pits, structural remnants, hearths, ash dumps, and other domestic features. In general, Valley populations in central California lived in fairly densely populated communities and relied on specialized tool kits. They likely employed a logistical-subsistence strategy of which they would predictably leave semi-permanent villages on forays to access economically important, seasonal resource patches (à la Binford's [1980] forager-collector model). Storage of surplus resources not only offset the effects of seasonal food precarity but permitted exchange of excess with neighboring communities for nonutilitarian goods.

Beginning around 6000 BP, mortar and pestle technology appeared in Valley sites in central California. The technology is especially associated with riparian, marsh, and estuarine environments (Meyer and Rosenthal 2008). In the valleys of the northern Diablo Range, mortar and pestle technology appears to have replaced handstones and milling slabs around 7000–6000 cal BP. At Blossom Mound (SJO-68), fragments of pestles and mortars have been recovered, which suggests that mortar and pestle technology developed south of the Delta as early as about 5000 cal BP (Ragir 1972). At COL-247, a pestle was recovered from a stratum that dates to between 4300 and 3500 cal BP (White 2003), and thus provides a minimum date for the introduction of mortar and pestle technology in the lower Sacramento Valley.

Pine, acorn, and manzanita dominate the paleobotanical remains recovered from the Los Vaqueros locale (e.g., CCO-696, -697; Meyer and Rosenthal 1997) and at CCO-18/548, the Marsh Creek site (Wiberg and Clark 2004). Throughout interior central California, including communities in both foothill and woodland environments, xerophytic nut and berry crops comprise significant parts of the subsistence economy (Meyer and Rosenthal 2008). There are differences in the proportion of plant remains represented in floral assemblages from upland compared to Valley sites. For example, starting in the Early Period and continuing into the Middle Period, acorn comprises about 60–80% of all recovered nutshell (compared to only 20% in foothill and upland environments) (Meyer and Rosenthal 2008:72–74; Rosenthal and Wohlgemuth 2006; Wohlgemuth 2004).

In the late middle Holocene (ca. 5000–4000 cal BP), increasing evidence for focused exploitation of emerging marshes, riparian zones, woodlands, and grasslands appears in central California. For instance, tule elk, pronghorn, deer, and smaller-bodied mammals such as rabbits and hares are reported in faunal assemblages (Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007). As well, sites include remains of waterfowl such as cranes, geese, swans, ducks and cormorants. Additionally, turtle, river otters, beaver, coyotes, and rodents are variously represented. There are noted differences in exploitation of artiodactyl species across central California. For example, sites located within the Delta have a greater proportion of elk remains (Meyer and Rosenthal 2008: 72–74). Elsewhere, the proportion of elk remains is low and deer are more prevalent. In the open plains of the San Joaquin Valley, archaeological sites show greater representation of pronghorn. Overall, evidence from Valley sites suggests that large-mammal bone accounts for no more than 45% of faunal assemblages, much lower than its representation at foothill and upland sites and demonstrates differences in the types of game exploited for valley-adapted versus foothill-adapted populations. Technology associated with hunting in Early Period valley sites includes flaked-stone projectile points, atlatl engaging spurs, and bone shaft wrenches.

Beginning in the middle Holocene (ca. 7000–5000 years ago), Valley sites in central California display a greater representation of fish remains and specialized fishing gear (Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007). Specialized fishing technology includes harpoons, hooks, net weights, and mesh gauges. There are demonstrated differences in the distribution of fish species exploited by valley-adapted peoples during the Early Period based on remains recovered from Valley sites (Broughton 1988; Meyer and Rosenthal 2008; Schulz 1981; White 2003). In proximity to the Sacramento River and Delta, assemblages are dominated by slow-water fish species, while sites on side streams throughout the Valley show greater representation of fast-water and anadromous fish species (e.g., salmon and sturgeon) (Meyer and Rosenthal 2008: 72-74).

Valley, Early Period sites demonstrate a diverse and specialized array of both utilitarian and nonutilitarian objects (Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007; Stevens et al. 2009). In addition to the aforementioned plant processing technologies, antler wedges thought to be associated with woodworking (although this is debated [Fitzgerald et al. n.d.]), bone awls, and chert drills are commonly found within sites. Of particular note is the prevalence of nonlocal materials in Valley, Early Period sites (Meyer and Rosenthal 2008; Moratto 1984; Stevens et al. 2009). One of the most prevalent nonlocal material is shell (Bennyhoff and Hughes 1987), which includes a variety of Pacific Coast shell beads and ornaments, especially from *Olivella* sp. and abalone (*Haliotis* sp.). As well, quartz crystals and objects made from alabaster, actinolite, and hematite that originate from the Sierra Nevada are recorded at Early Period, Valley sites (Meyer and Rosenthal 2008; Moratto 1984; Rosenthal et al. 2007).

Obsidian from quarries throughout northern and eastern California was also imported to Valley sites (Meyer and Rosenthal 2008; Rosenthal et al. 2007; Stevens et al. 2009). During the Early and into the Middle Period, three main quarries account for most of the obsidian in the Valley: Napa Valley, Borax Lake, and Bodie Hills (Bouey and Basgall 1984; Meyer and Rosenthal 2008; Stevens et al. 2009). At the quarries, rough-out bifaces and finished bifacial blades were produced and subsequentially distributed throughout central California (Meyer and Rosenthal 2008: 72). Differences in the distribution of obsidian sources throughout central California cannot be explained only by distance to a particular quarry but instead suggest distinct "cultural interaction spheres" (King and Hildebrandt 2006; Meyer and Rosenthal 2008: 76). Obsidian originating from Borax Lake near Clear Lake is prevalent at sites on the eastern edge of the North Coast ranges. By contrast, Napa Valley is more prevalent at sites located south of Cache Creek from the Coast Ranges on the west, extending into the Delta region and Sacramento Valley, and reaching the lower foothills of the Sierra. In the watershed of the middle and south forks of the American River and on the western slope of the Sierra, obsidian from Bodie Hills is dominant. North of there, obsidian from quarries in northeastern California are more prevalent.

Comparatively, Bodie Hills obsidian comprises only a small portion of natural glass reported for sites located in the Delta and lower Sacramento Valley, the focus of this dissertation. Meyer and Rosenthal (2008: 76) contends that "[t]hese patterns suggests that a social boundary probably existed in the lower foothills of the Sierra through much of the late Holocene." As well, they argue that a "poorly demarcated east and west boundary between the distribution of Napa and Borax Lake obsidian in the Sacramento Valley, may represent a more permeable division, or more likely, fluctuations over time in social boundaries" (Meyer and Rosenthal 2008: 76).

## Summary of Archaeological Sites

This dissertation focuses on archaeometric analysis of skeletal materials from two sites: the Windmiller (CA-SAC-107) and Blossom (CA-SJO-68) mounds (Figure 2.1). Both are seminal sites that figured prominently in defining the Windmiller cultural pattern (Heizer 1949), and in the development of the Delta sequence (Lillard and Purves 1936; Lillard et al. 1939) and the Central California Taxonomic System (CCTS) (Bennyhoff and Hughes 1987). Evidence from these sites have contributed to broader interpretations of cultural adaptations in central California that developed during the late Middle Holocene and into the early Late Holocene. Analyses of floral and faunal remains, flaked-stone and groundstone technology, and domestic features at these sites contributed especially to syntheses regarding subsistence and settlement patterns of valley-adapted groups.

While previous studies have documented the nature of Windmiller economies, what remains to be investigated is how different settlement-subsistence practices influenced the social organization of Windmiller people. As discussed above, the archaeology of central California suggests that distinct cultural patterns, adapted to particular environmental niches and contemporary with the Windmiller pattern, emerged during the late Middle and early Late Holocene. Evidence for trade suggest some degree of economic integration between these groups. As of yet, research is lacking on how facets of social organization within a specific community (such as marriage networks and postmarital residence practices) influence the degree of social-economic integration between different coeval cultural groups throughout central California.

This dissertation research aims to investigate the relationship between the subsistence economy and social organization for burial populations from SAC-107 and SJO-68, as well as the degree of social-integration between these two populations facilitated by postmarital residence practices. This synchronic and regionally specific approach will help clarify settlement-subsistence practices for Early Period populations in the Delta and should encourage future studies of other contemporary cultural patterns throughout central California. Such studies should further elucidate the role that subsistence practices play in shaping social organization, and how, in turn, the social organization of specific communities impacts the degree of social articulation between groups. A brief summary and discussion of the history of archaeological research for the two focus sites is provided below.

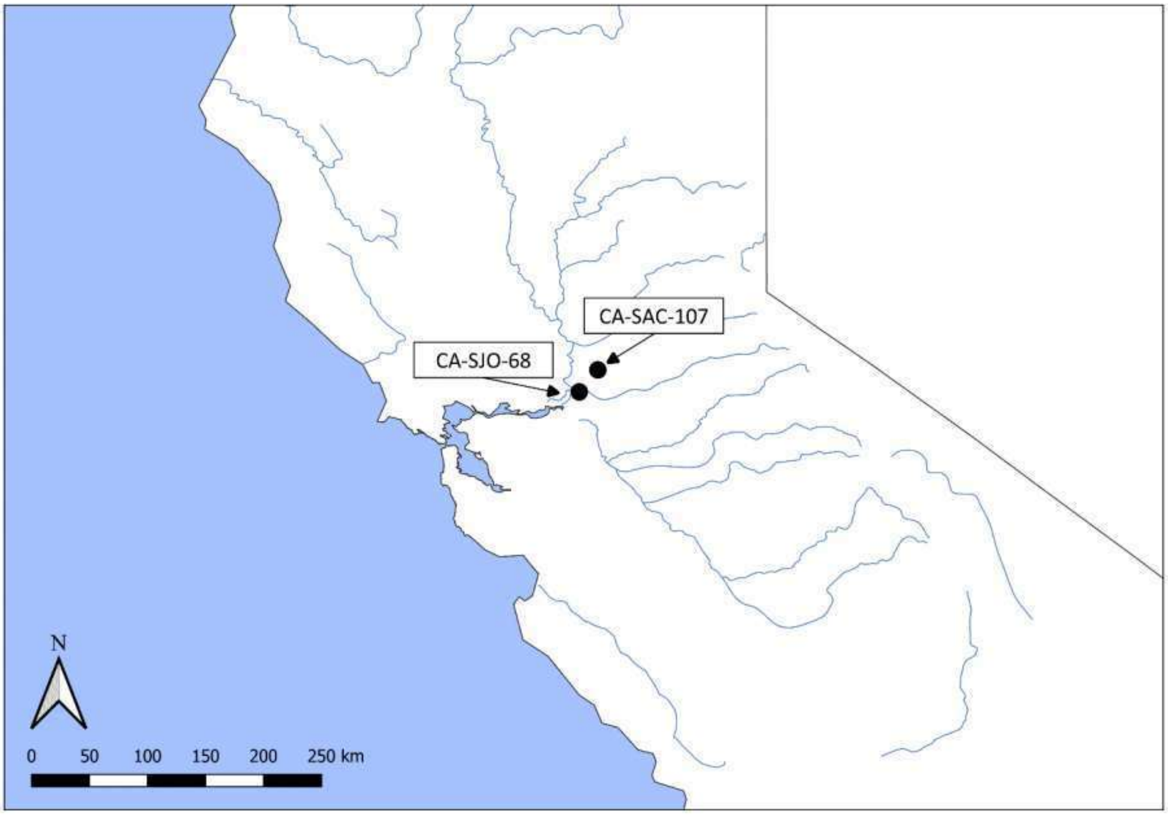

*Figure 2.1: Map of California showing the approximate locations of the Blossom (CA-SJO-68) and Windmiller (CA-SAC-107) mounds.*

### *CA-SAC-107 (Windmiller Mound)*

Jeremiah B. Lillard and William K. Purves of Sacramento Junior College (SJC) began excavations at SAC-107 in 1935 (Lillard et al. 1939; Lillard and Purves 1936). They conducted excavations intermittently until about 1937 when Lillard requested reinvestigations by the University of California (UC) (Heizer 1949, 1974; Lillard et al. 1939: 21). In recognition of the property owner of the site, H.H.

Windmiller, SAC-107 became known as the 'Windmiller Mound' and would later be accepted as the type site for the Windmiller cultural pattern (Kolpan 2009: 62; Lillard and Purves 1936). The Windmiller Mound was the third major site excavated in the Cosumnes River valley by SJC (Lillard et al. 1939: 21), although SJC would later excavate at dozens of other sites in the region. Data from these seminal excavations formed the basis of Lillard and Purves' basic chronological sequence in central California: the Early, Intermediate, and Recent Horizons (Lillard et al. 1939: 21; Lillard and Purves 1936).

Investigations conducted by the University of California, Berkeley focused on the identification of temporally diagnostic artifact types and horizontal stratigraphy. Based on these analyses, the UC team identified four chronological components at the Windmiller Mound: Early, Transitional, Late, and Post-contact. Archaeological collections (including artifacts and human remains) recovered by SJC were later transferred to the University of California, Berkeley under the care of Robert H. Heizer (Heizer 1974; Lillard et al. 1939).

The Windmiller Mound (CA-SAC-107) is located approximately 6.4 km east of Elk Grove in the Cosumnes River Valley (Figure 2.1; Lillard et al. 1939; Kolpan 2009:63). Initially, the Cosumnes River flowed east of the mound but has since meandered to its current location about 183 m west of the site (Lillard et al. 1939). The 1.6 to 2.4 km-wide Cosumnes River Basin is prone to flooding. Prior to European contact, Indigenous peoples established many of their communities on naturally raised landforms to avoid annual flooding (Lillard et al. 1939; Lillard and Purves 1936; Schenk and Dawson 1929). Like other sites in the area, CA-SAC-107 was situated on such a knoll.

When it was originally identified and recorded, the Windmiller Mound measured about 2.7 m from the alluvial floodplain; its surface area measured 82.3 by 86.9 m (Kolpan 2009: 63; Lillard et al. 1939). It is a stratified site divided into two strata: Levels I and II (Heizer 1949; Kolpan 2009: 63- Lillard et al. 1939). Level I is the lower stratum and the natural base of the mound. It contains the extended Windmiller burials used to define the Early Period. Bone from this level is often mineralized and occurs within a highly compact, red-sandy clay. Two radiocarbon dates on human remains recovered from between 1.0 and 1.5 m below the surface and within Level I range between about 2600 and 3200 BP (Table 2.2).

Lillard, Heizer, and Fenenga (1939) tabulate 59 Early Period burials. These interments were predominantly ventrally extended with arms positioned close to the body, or beneath it, and legs together (Lillard et al. 1939: 24–27). Two burials were dorsally extended and three are recorded as flexed. All burials from Level I, except for one flexed burial, are oriented with the head to the west.

Cultural constituents for Early Period burials include small, whole *Olivella* beads, rectangular *Olivella* beads, and *Haliotis* beads. Quartz crystals are common in Level I, including both complete crystals and those with flakes removed. As well, charmstones are frequent and are typically manufactured from amphibolite schist, which likely originates from the Sierra Nevada. Lillard, Heizer, and Fenenga (1939: 26) note that metates and manos are the typical grinding implement associated with the Early Period, but they also report a few mortars. Two fragmentary metates were recovered from the mound matrix and are not directly associated with burials, as are two unshaped manos with limited wear. In addition to the aforementioned material culture, other grave offerings include notched antler fish spear points, antler and bone strigils, red-painted obsidian bangles, ground slate "pencils", and baked-clay balls. Unmodified stream pebbles are occasionally associated with burials.

Superior to Level I is Level II, which consists of a loose midden. Soft black soil with ash, representative of habitation debris, is noted throughout this level along with features including house floors and ash pits. Middle and Late Period burials—or as previously identified: Transitional, Late, and Post-contact burials—are found in this stratum. Only 15 burials are described by Lillard, Heizer, and Fenenga (1939: 29) as belonging to the Transitional Period. The burial posture for these interments include tightly and loosely flexed individuals lain on either the back or side with variable orientation. As well, cremations are recorded for the Transitional Period (Heizer 1949; Lillard et al. 1939). These include secondary cremations that are interred in circular-dug pits. Cultural constituents that date to the Transitional Period include various *Olivella* shell beads, *Haliotis* ornaments, bird bone whistles, charmstones, and chisel-pointed pestles.

Lillard, Heizer, and Fenenga (1939: 30) report 94 burials and 10 cremations for the Late Period. Four mass burials are recorded with four, five, eight, and 10 individuals, respectively. The orientation of these burials is variable; however, the majority were oriented to the west. The material culture associated with Late Period burials includes clamshell disc beads, hourglass-shaped steatite beads, paired bone tubes with incised geometric designs, and *Haliotis* ornaments such as the 'banjo' type. Additionally, chisel-pointed pestles, carbonized net fragments, grooved-stone net sinkers, and circular, centrally perforated stone or baked-clay discoidals—possibly spindle whorls—were recovered. Several Late Period cremations were associated with tubular, biconically drilled steatite pipes. Bilaterally barbed fish spears also occurred within the mound matrix, but are not associated with burials. Of particular note are *Haliotis rufescens* shells that contain fetal and newborn infant remains.

*Table 2.2: Reported radiocarbon dates from CA-SAC-107, Windmiller Mound. PAHMA refers to the Phoebe A. Hearst Museum of Anthropology at the University of California, Berkeley. GX refers to Geochron Laboratories, and "I" refers to Teledyne Isotopes.*

| PAHMA No. | Original Burial No. | Lab No. | Age Range (BP) | Material | Reference |
|---|---|---|---|---|---|
| 12-5596 | 8 | GX-0659 | 2675 ± 125 | Bone | Breschini et al. 1996; Ragir 1972; Schulz 1981 |
| 12-5616 | 22 | I-02748 | 3075 ± 105 | Bone | Ragir 1972; Schulz 1981 |

### *CA-SJO-68 (Blossom Mound)*

The Blossom Mound (CA-SJO-68) is located about 2.4 km northwest of the town of Thornton, California (Figure 2.1; Ragir 1972: 22). This area is a marshy environment with tule and brushy vegetation (Ragir 1972: 27). In a modern context, the closest freshwater source is the Mokelumne River (located about 2.0 km south of the site). This area has been described as unfavorable for occupation in its current condition; however, evidence suggests that the precontact setting differs from that observed today (Ragir 1972: 27).

Beginning in the 1940s, the University of California Archaeological Survey (UCAS) conducted auger borings, which suggests that the base of the mound is currently below mean sea level (Ragir 1972). However, borings conducted about 10 meters northeast of the mound revealed river sands at approximately 1.2 and 2.3 meters below the current level of the Valley floor. As well, adobe clay was located south and west of the site. This evidence of alluvial filling suggests that the river, or one of its sloughs, formerly was located much closer to the northeastern edge of the site. As well, like other Early Period sites recorded throughout the Sacramento-San Joaquin Delta, CA-SJO-68 was originally located on a naturally elevated landform, which would have protected the mound from annual flooding.

E.J. Dawson conducted the first excavations at the Blossom Mound. This investigation occurred intermittently from May of 1923 to March of 1924, for a total of about 15.5 days (Ragir 1972: 32–34). At the time, Dawson recorded the dimensions of the site as 39.6 x 19.8 m measured on the long-axis running in a northeast-southwest direction (Ragir 1972: 27). Before Dawson's arrival, the owner of Blossom Mound had impacted the site and likely scraped about a third to half a meter from the crest of the mound (Ragir 1972: 27). At the time of Dawson's investigation, the height of the mound was recorded at about one meter above the valley's floor (Ragir 1972: 27).

Dawson conducted a systematic excavation on the Blossom Mound that focused on nine sections of the site and proceeded in one-foot (30.5 cm) levels (center, southeast, west, southwest, north, south, northeast, east, and northwest) (Ragir 1972: 32-34). He did not fully expose the north-central and northeastern part of the mound. Only burials identified by Dawson as significant were recorded with detailed provenience, including their depth below the surface. Otherwise, burials were assigned to "grave-lots," which most typically consisted of one burial and its associated grave goods. Dawson found that most of the interments were relatively undisturbed and lain in an extended posture with their heads oriented to the west. As well, he noted that the density of burials was relatively high. In the northeastern portion of the mound, Dawson reported disturbed burials, including those missing skeletal elements. Of particular note, was a cache of skulls buried in the northeastern tip of the mound; no intact burials were recovered surrounding it. These were later interpreted by Heizer (1949) as war trophies or sacrifices. In general, Dawson's excavations revealed that the majority of burials were grouped 12–24 inches (30.5–61 cm) below the surface. After 30 inches (76.2 cm) below the surface, noticeably fewer burials are reported with only three having been recovered 30–36 inches (76.2–91.4 cm) below the surface.

Heizer returned to the Blossom Mound in the 1940s. By then, the site had been impacted further and now measured just 28.3 by 20.7 meters with a rise of about 24 inches (61 cm) above the valley floor (Heizer 1947; Ragir 1972: 27). Ragir (1972) published two profiles of SJO-68, including an east-west and a north-south section that ran through the middle of the mound. Meighan (1987) argues that the base stratum of the mound, which represents the original, natural clay knoll, likely stood about 1.5 meters above the surrounding plain. Ragir's (1972) north-south profile shows an occupation layer that is about 3 feet (91.4 cm) thick and covers the entire extent of the natural mound. Meighan (1987) believes that the north-south profile is an overgeneralization and that the east-west one is the more reliable of the two for understanding the stratigraphy of the site.

Results of archaeological excavations conducted between the 1920s and 1960s demonstrate that the Blossom Mound consists of about 1.7 to 1.9 meters of calcareous accumulation of midden (Ragir 1972: 29-30). As well, those who excavated at the site note that there was a layer, approximately 15 cm thick, of alluvial material on top of the mound but this stratum is excluded in many of the published profiles of the site, although it is mentioned briefly in some of the text descriptions by Heizer and Ragir (Heizer 1949; Meighan 1987; Ragir 1972). Burials were identified at depths of about 15.2 to 167.6 cm (1.676 m) from the surface. Evidence recovered from SJO-68 suggests that the eastern edge of the site was more intensively occupied before contact, as would be expected given that this portion of the mound is located closer to the freshwater source. Based on a synthesis of data gathered from the Blossom mound and the east-west profile, Ragir (1972) identified four strata.

Stratum I is the top-most layer of the mound, approximately 12.7 to 15.2 cm thick and consists of loose topsoil. Immediately inferior to Stratum I is a hardpan layer identified as Stratum II. This second stratum is thickest in the center of the mound as well as in the eastern portion of the site and thins out towards the western extent. Stratum II consists of three discontinuous layers: upper hardpan, soft-dark soil, and second hardpan. The upper hardpan is found consistently throughout the site and is about 15.2 to 20.3 cm thick on the western-third of the mound and up to 38.1 cm thick elsewhere. The softer, dark soil component of Stratum II is 30.5 to 45.7 cm below the surface and approximately 15 thick in the western-third of the mound and 30.4 cm thick elsewhere. This second hardpan is only found on the western half of the mound and at the northern and southern edges. In the western-third portion of the site, the second hardpan is about 15.2 and 45.7 cm thick elsewhere. Ragir (1972) suggests that this second hardpan likely marks the base of the pit of Dawson's excavation, which is 76.2–91.4 cm below the surface at the center of the mound.

Cook and Heizer (1951) argued that this carbonate layer is the result of the fixation of calcium from burnt wood, plant, shell, and animal residues and therefore is the direct result of human occupation of the site. Meighan (1987: 30) was not satisfied with this explanation and stated that the midden components of the site must be "demonstrated rather than assumed." In particular, Meighan (1987) contends that this type of calcium carbonate hardpan observed at SJO-68 is unique to Early Period sites in the Delta. Therefore, if this hardpan stratum is the result of human occupation it should be observed at other, older sites located throughout California; however, sites older than 5000 years in southern California do show this.

Stratum III consists of a brown midden and is about 76.2–91.4 cm thick. Like the other strata noted at this site, it thins from east to west. In the western third of the mound, it is about 86.4 cm thick and 0.9–1.2 meters thick elsewhere. This stratum contains considerable amounts of ash and baked-clay debris. Approximately 2.2 m below the surface is the natural mound base, identified as Stratum IV, which is characterized by sterile, red-yellow clay.

Two hundred and thirty burials were recovered from the Blossom Mound, of which 154 were exhumed during excavations conducted by the UCAS. Of these, 84 are reported in Heizer's 1949 monograph. Radiocarbon dates from human bone and charcoal recovered from the site reveals assays ranging from 2900 to 4600 BP (Table 2.3).

*Table 2.3: Reported radiocarbon dates from CA-SJO-68, Blossom Mound. PAHMA refers to the Phoebe A. Hearst Museum of Anthropology at the University of California, Berkeley. "C" refers to Chicago, "I" refers to Teledyne Isotopes, and "M" refers to University of Michigan.*

| PAHMA No. | Original Burial No. | Lab No. | Age Range (BP) | Material | Reference |
|---|---|---|---|---|---|
| 12-7570 | 22 | I-03038 | 2980 ± 110 | Human bone collagen | Breschini et al. 1996; Ragir 1972 |
| 12-7571 | 23 | I-02749B | 3775 ± 160 | Human bone collagen | Breschini et al. 1996; Ragir 1972 |
| 12-7572 | 24 | I-02749A | 3585 ± 110 | Human bone | Breschini et al. 1996; Ragir 1972 |
|  | Cremation 1 | M-0646 | 3080 ± 300 | Human bone, calcined | Breschini et al. 1996; Cook and Heizer 1959: 189; Heizer 1958 |
|  | Cremation 3 | M-0647 | 4350 ± 250 | Human bone, burned | Breschini et al. 1996; Heizer 1958 |
|  | NA | M-0645 | 4100 ± 250 | Charcoal | Breschini et al. 1996; Heizer 1958 |
|  | NA | C-0440/ 0522 | 4052 ± 160 | Charcoal | Breschini et al. 1996; Heizer 1958 |

The density of graves at this site is relatively high. As Meighan (1987) notes, in many cases, these interments were only separated by a few inches either horizontally or vertically. Excavators at the Blossom Mound report that these burials were minimally disturbed and found relatively intact. However, Meighan (1987) suggests that there were likely more disturbances than those recorded because of the nature of excavation, which was focused on grave plots and only dealt with complete burials while likely ignoring any isolated bones in the matrix or other evidence of disturbed graves.

Meighan (1987) offers several possible explanations for the lack of burial disturbance at the site. First, it is possible that graves were created at the same time or within a narrow time frame. He contends that this may be possible in some instances; however, the separation of burials by vertical elevation suggests that they likely do not represent common graves or being buried closely in time. Second, individuals may have engaged in the careful burying of the dead at SJO-68. In other words, people would adjust their digging strategy to avoid disturbance, such as opting to dig a more shallow grave, if they encountered previously interred remains. Another possible explanation is that grave markers were used to identify the location of older burials and therefore made it easier to avoid those graves. Finally, it is possible that an accrual of new materials placed on top of the mound, which effectively increased its depth, provided sufficient new soil in which to inter new graves. Of the 230 burials mentioned above, 136 were found in the top 35 inches (88.9 cm) of the mound, and provenience was carefully recorded for 80% of the burials. Meighan (1987) argues that the natural accumulation of new soils at the site would not have been fast enough to accommodate new burials without probable disturbance of burials located below. Therefore, if the accrual of new soils adequately accommodated later burials, it is likely the result of artificial deposition of soils on top of the mound, much like that observed in the Eastern United States.

Heizer (1949) believed that SJO-68 was predominantly a cemetery and that most of the artifactual remains recovered from the site are mortuary offerings. Additionally, Heizer reports there are no large ash pits or hearths, and only a relatively small amount of shell and animal bone. In Heizer's 1949 monograph, there is no mention of domestic artifacts such as metates, manos, and pestles; only two mortar fragments are reported. Heizer initially argued that the lack of groundstone technology associated with the processing of plant remains suggests that seeds, acorns, and other plant foods were not a significant part of the diet. Despite the paucity of animal remains recovered from the site, Heizer thought that those buried at SJO-68 relied mainly on hunted game and fish. Although a minimal amount of fish remains were recovered from the site, fishing implements such as fish hooks and spears were recovered from burials and not from residential debris. In Heizer's 1974 retrospective piece, he did change his mind on the relative importance of plant foods. He stated that despite the lack of technology associated with plant processing at the site, inhabitants of SJO-68 likely were exploiting plant foods in much the same way as other cultures throughout central California.

Ragir (1972) analyzed collections from SJO-68 and published tabulations of artifacts, which suggests there was more evidence for domestic artifacts than previously reported. For instance, she notes 13 fragments of mortars and metates and 17 groundstone artifacts identified as manos or pestles. Meighan (1987) argues that these numbers are sufficient to suggest the presence of midden material at the site; however, he cautions that this number is less than would be expected based on the number of burials and the amount of cubic yards excavated from the site. In addition to groundstone technology, there are eight small, baked-clay objects and 13 bone implements including eight bird- and mammal-bone awls, three antler fish spears, one needle, and one bone fishhook. The only commonly recovered domestic items are flaked-stone points and knives; however, they are predominantly associated with burials.

Before the 1947 excavation at SJO-68, flaked-stone debitage was largely ignored and not collected. Ragir (1972) tabulates flaked-stone "waste" and includes non-burial-associated flakes, pebbles, scrapers, and choppers that total 116 objects. This number is higher than reported in Heizer's 1949 monograph. Meighan (1987) notes that this flaked-stone debris is suggestive of a midden component at the site; however, in low quantities—less than one item per cubic yard of excavation. As Meighan (1987: 33) notes, "most midden sites in California yield far greater amounts of [lithic] waste than this usually more than a factor of hundreds or thousands."

Like flaked stone, faunal remains were more carefully excavated and tabulated in the 1947 excavation totaling 165 fragments of mammal bone, including deer, elk, antelope, and rabbit. This evidence suggests that many of the mammals and birds common to the area are represented at the site. Meighan (1987) notes that a contributing factor to the low recovery of faunal remains is the excavation technique employed. Specifically, the calcareous, hardpan layer had to be removed in chunks with a pickaxe. There was no attempt to break down these chunks because it was thought impossible to reduce them to a fine enough matrix conducive for screening. Therefore, it is possible that a lot of material was not adequately screened and midden constituents systematically missed. As well, these early excavations were primarily interested in recovery and interpretation of human burial features and not midden components.

**Summary and Discussion**

Changing frequencies of artifacts associated with gendered subsistence practices (e.g., projectile points vs milling equipment) have been used as proxies for reconstructing sexual division of labor. For instance, the ubiquitous increase of mortar and pestle technology from about 2800 to 1200 BP is considered evidence of a shift toward intensified use of acorns and, therefore, reflects a greater emphasis on female labor in California (Hildebrandt and McGuire 2003; Jones 1996; McGuire and Hildebrandt 1994). Mortars and pestles are especially common in marshland and riparian regions of the northern San Joaquin and southern Sacramento Valleys, where CA-SAC-107 and CA-SJO-68 are located, as early as 6000 years ago (Moratto 1984; Rosenthal et al. 2007). At sites with and without this technology, pine nuts and acorn are dominant in paleobotanical assemblages (Rosenthal et al. 2007; Wohlgemuth 1996). This may indicate that there were inter-site differences among Early Period groups in the intensity with which these resources were exploited (i.e., manufacturing mortars and pestles requires significant time and energy, therefore presence of these technologies should indicate greater importance on extracting and processing nut crops). Other sites that date to this period include evidence for new technologies such as baked clay, simple pottery, fine twisted cordage, twined basketry, and basketry awls (Moratto 1984; Rosenthal et al. 2007). Evidence for cooking baskets and baked-clay balls, as an alternative for "cooking stones," are interpreted as indirect indicators of plant processing and female labor.

While paleobotanical evidence and frequency of mortar fragments at some sites suggest that grinding of acorns and/or other seeds were relatively important (Moratto 1984: 201; Wohlgemuth 1996), high frequencies of large projectile points as well as remains of deer, elk, pronghorn, rabbits and hares, and waterfowl had been interpreted as evidence for the importance of hunting. However, in the case of large game, hunting often requires pursuit across large swaths of land and is better accommodated by higher mobility. Jorgensen (1980: 153) notes that even when large herds of game are present, that pursuit of this resource is rarely preferred over more sedentary, and more predictable, extractive subsistence strategies. Given evidence for greater sedentism in Early Period Delta populations, it is important to consider that even if hunted game composed a portion of the diet, this does not necessarily suggest that it was economically dominant. Another male-associated subsistence practice, fishing, may have had greater economic importance for Early Period populations since this resource could provide more predictable returns, be collected in greater numbers, and is more amenable to storage (Jorgensen 1980: 153). Gorge hooks, composite bone hooks, and spears along with a robust representation of fish remains, including sturgeon, salmon, and smaller fish, indicate that fishing had become an important component of the subsistence-economy (Moratto 1984; Rosenthal et al. 2007). The ethnographic record in California suggests that fishing stations were often owned by families and were managed/exploited by tasks-groups of men related patrilineally (Jorgensen 1980:153). If this pattern also held true for Early Period populations, it would have significant implications for residence practices.

Overall, technological, botanical, and faunal assemblages reveal that the patchwork of marshes, riparian forests, and grasslands that developed during the Middle Holocene in Central California were heavily exploited. Early Period sites in the Central Valley are associated with an elaborate material culture and diverse technological and dietary assemblages. Finely made and specialized tool assemblages and features, variability of utilitarian objects, and floral and faunal remains suggest a residentially stable settlement pattern for Valley populations. Together, assemblages indicate that logistically organized subsistence practices developed during this time along river corridors.

objective with this dissertation research is to investigate the relationship between the relative importance of male versus female contributions to subsistence and diet, and postmarital residence for Early Period populations in Central California. This study's research question and hypotheses are derived from previous analyses of Indigenous, ethnographic groups of North America which suggest that the sexual division of labor is strongly correlated with postmarital residence. By employing a multi-isotopic approach to understand sex-biased mobility patterns and paleodiets, this project tests how sexual division of labor co-varies with postmarital residence for two burial populations from archaeological sites CA-SAC-107 and CA-SJO-68 using five isotopic discriminants (carbon, nitrogen, oxygen, strontium, and sulfur). The following chapter, Chapter III, provides an overview of the anthropological theory and ethnographic analyses that inform this dissertation research.

# CHAPTER III. POSTMARITAL RESIDENCE: OVERVIEW OF THEORETICAL PERSPECTIVES, CROSS-CULTURAL STUDIES, AND PATTERNS IN ETHNOGRAPHIC CALIFORNIA

Place of residence after marriage, or postmarital residence, impacts the structure of societies and their kinship networks. Since cultural systems are integrated, understanding changes in postmarital residence practices can help inform on other facets of human behavior and social organization. For example, societal rules for postmarital residence determine the frequency with which members of a kinship system interact, shape the nature of social arrangements, and impact the size and configuration of household units. The degree of conformity to these rules depends on how married couples balance individual needs and desires with prescribed societal norms. Therefore, postmarital residence is often structurally flexible and best understood vis-à-vis ideal versus actual practices. The dynamic complexion of postmarital residence rules results in variable arrangements that can be difficult to define; however, general patterns are described in cross-cultural studies (Table 3.1).

Postmarital residence and other cultural variables reported for societies in key cross-cultural samples (e.g., the *Ethnographic Atlas* and the *Standard Cross-Cultural Sample*) were collected mainly by ethnographers in the 19th and early 20th centuries (Kirby et al. 2016; Murdock and White 1969; Murdock et al. 1999; Walker 2015). These researchers conducted surveys that asked members of a population whether couples would typically live with or near one set of relatives or another after marriage. Typically, what was recorded by the ethnographer was the preferred or ideal arrangement and, occasionally, the most commonly reported residence patterns. Variation was typically ignored. Prevailing patterns for marital residence with kin are reported in Table 3.2 and its distribution is illustrated in Figure 3.1.

*Table 3. 1. Types of Postmarital Residence.*

| | |
|---|---|
| **Patrilocal/ Virilocal**[1] | Married couple establish residence near or in husband's family's household |
| **Matrilocal/ Uxorilocal**[2] | Married couple establish residence near or in the wife's family's household |
| **Avunculocal** | Married couple establish residence near or in the husband's maternal uncle's household |
| **Neolocal** | Married couple establish residence in a new location independent from kin |
| **Natolocal** | Individuals remain in community of birth |
| **Ambilocal** | Married couple chooses whether to reside near or in either the husband's or wife's family's household |
| **Multilocal** | Married couple does not follow specific residence rules and moves to new locations through time in response to social, economic, or subsistence pursuits |

[1] Virilocality in the *Ethnographic Atlas* (Murdock et al. 1999) specifically refers to instances where the husband's patrikin are not aggregated in patrilocal and patrilineal kin groups.

[2] Uxorilocality in the *Ethnographic Atlas* (Murdock et al. 1999) specifically refers to instances where the wife's matrikin are not aggregated in matrilocal and matrilineal kin groups.

*Table 3. 2 Prevailing Global Patterns for Marital Residence with Kin*

| **Postmarital Residence** | **# Societies** | **%** |
|---|---|---|
| Patrilocal | 638 | 50.36 |
| Virilocal | 159 | 12.55 |
| Matrilocal | 58 | 4.58 |
| Uxorilocal | 45 | 3.55 |
| Avunculocal | 54 | 4.26 |
| Neolocal | 62 | 4.89 |
| Duolocal/Natolocal | 8 | 0.63 |
| Ambilocal | 83 | 6.55 |
| Optionally Patrilocal/Virilocal or Avunculocal | 11 | 0.87 |
| Optionally Uxorilocal or Avunculocal | 5 | 0.39 |
| Ambilocal with Preponderance of Uxorilocal Practice | 37 | 2.92 |
| Ambilocal with Preponderance of Virilocal Practice | 107 | 8.45 |
| ***Total*** | **1267** | **100.00** |

Note:
Data retrieved from D-PLACE (Kirby et al. 2016) using variable #12 in the *Ethnographic Atlas* [EA012] (Murdock et al. 1999)

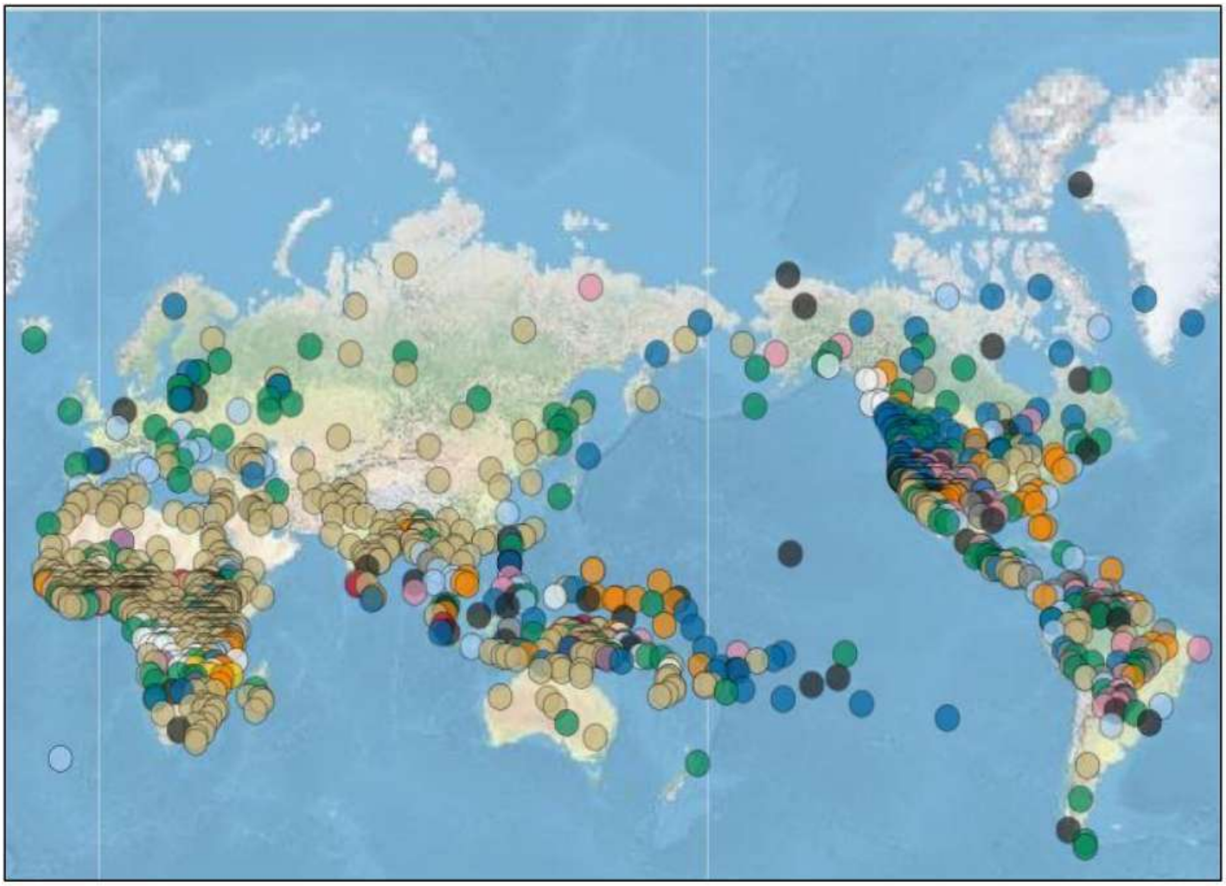

*Figure 3. 1 . Global distribution of marital residence with kin based on data from variable #12 in the Ethnographic Atlas (Murdock et al. 1999). Patterns include avunculocality (white), ambilocality (black), avuncu-uxorilocality (yellow), avuncu-virilocality (purple), matrilocality (orange), neolocality (light blue), separate (red), patrilocality (light green), uxorilocality (grey), virilocality (green), ambi-uxo (pink), and ambi-viri (blue). Map generated using D-PLACE (Kirby et al. 2016).*

## An Evolutionary Perspective on Postmarital Residence

Anthropologists belonging to the "evolutionist" paradigm in the 19th century were the first to attempt to understand the evolution of social organization, including what would later be termed postmarital residence (Fox 1967: 16–20; Johnson and Earle 2000; Murdock 1949: 184). Their proposed evolutionary sequence suggested the earliest form of human social organization was the matrilineal sib, which then developed into patrilineal-patriarchal systems followed by the emergence of the nuclear family with bilateral descent.

Perhaps the most notable scholar of social organization and kinship at that time was Lewis Henry Morgan, whose first-hand studies of the Iroquois and secondary analysis of Aztec, Roman, and Greek societies seemingly supported this hypothesized evolutionary sequence (Fox 1967: 20). This idea was further cemented in anthropological parlance by Bachofen, who proposed that the close biological association between mother and child coupled with low paternity certainty resulted in the earliest matrilineal-matrilocal structure (Engels 2007/1884: 106). Their inference, however, seemingly logical, incorrectly assumes that this information demonstrates a universal, unilinear succession for the development of human social organization.

More recent research looking to understand the evolutionary history of human postmarital residence practices and sex-biased dispersal patterns refers to comparative primate studies (Fox 1967: 31–33; Walker 2015). These studies demonstrate that male philopatry is common among apes and has led some to conclude that patrilocality represents a "core human tendency" with deep evolutionary roots (Walker 2015). Stable isotopic studies of australopithecines (Copeland et al. 2011) and mitochondrial DNA (mtDNA) studies of Neanderthals (LaLueza-Fox et al. 2011) suggest that both populations were likely engaged in either *Pan*-like philopatry or residence practices akin to patrilocality. This seemingly lends support to the deep evolutionary history of patrilocality, although these results are still preliminary given that, in some cases, genetic results are inconclusive and the debate over appropriate models for human societies persist (Koenig and Borries 2012; Vigilant and Langergraber 2011; Walker 2015).

Increasingly, there are studies that rely on large genetic databases and allow for more nuanced analyses, which permit interpretations of human social structures and demographic histories of human populations (Walker 2015). Inheritance of X-linked, Y-linked, and mtDNA differ between the sexes and therefore, captures population-level mobility of females versus males. When taken together, these kinds of studies demonstrate some sex-biased migration patterns. Global human genetic studies primarily suggest that there is more "movement" associated with mtDNA than Y-chromosomes, which is consistent with patrilocality (Seielstad et al. 1998, Walker 2015). Finer-grained genetic studies reveal variation among sex-biased mobility profiles within a population and largely conform to patterns observed in the ethnographic record (Walker 2015; Webster and Wilson Sayres 2016).

## Investigating the Factors that Influence Postmarital Residence: A Review of Seminal Studies

Early anthropological theories about the conditions and circumstances that shape human social organization identified the sexual division of labor as a determinant for postmarital residence patterns (Eggan 1950; Korotayev 2003a, 2003b; Lippert 1931; Linton 1936; Murdock 1949; Service 1962). Among the first, and likely the most influential, of this research is Murdock's (1949) monograph that evaluates the relationship between a society's economy, particularly the sexual division of labor, and its social organization. As well, Murdock (1949) investigated the link between postmarital residence and descent rules and proposed an evolutionary sequence (Figure 3.2). The following sections briefly outline Murdock’s (1949) hypotheses about how subsistence-economies and the sexual division of labor impacts postmarital residence.

### *Matrilocality/Uxorilocality*

Murdock's (1949: 213) global sample of 224 traditional societies show that more than 75% define women's labor as those associated with cooking, grain grinding, the gathering of plant resources and fuel, the preservation of meat and fish, water carrying, the production and repair of clothing, weaving, and the manufacture of pottery, baskets, and mats. The kinds of skills and knowledge generally linked with female labor are locally restricted but transferable. In other words, women's work is typically confined to the immediate vicinity of, or surrounding, the community. As well, her skill set is suitable for and can easily be transported into a new community.

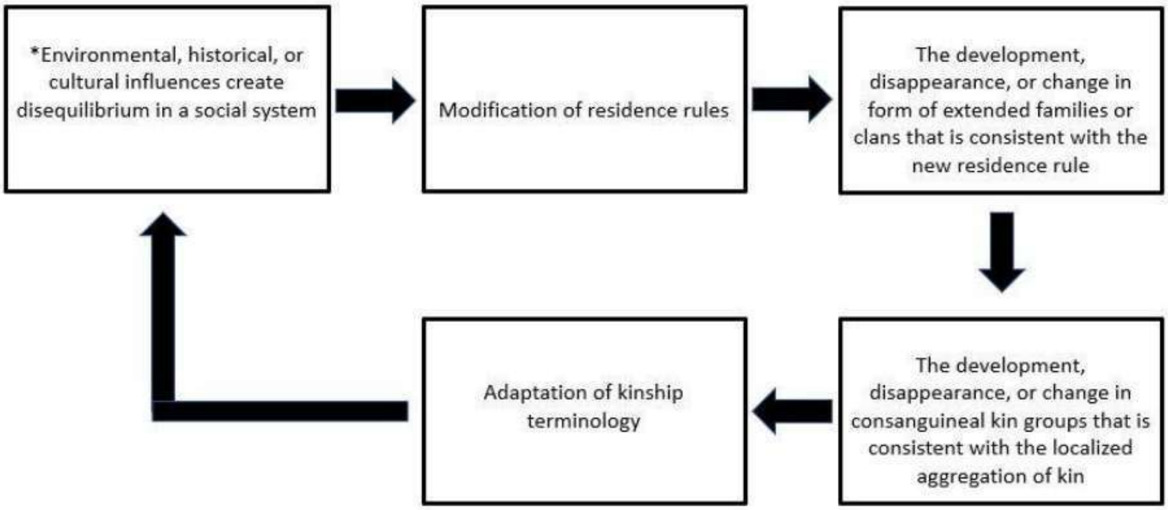

*Figure 3. 2. Murdock's (1949: 220-221) theory for the evolution of social organization. * At any time during or after this sequence, new environmental, historical and cultural pressures can influence the development of a new rule of residence and may overlap the previous sequence.*

A predictor for matrilocality is when female labor is highly valued in a society and she is the predominant contributor to subsistence (matridominant) (Lippert 1931: 237; Murdock 1949: 204–205). Murdock's (1949) sample demonstrates that for simple agricultural groups (for which women's work is essential) that there is a higher prevalence of matrilocal residence (Figure 3.1; Figure 3.3). Agriculture permits the production of abundant and stable food resources. Therefore, women are responsible for more profuse and consistent foodstuffs compared to males whose subsistence activities are generally more precarious (e.g., hunting). As well, females tend to inherit land in such agricultural systems. Taken together, this may enhance the status of women in these societies. Bilocal residence may also be favored in cases where females have comparatively high status; however, the inheritance of land and significant gear through women is a predictor for matrilocality.

Matrilocality is inhibited when moveable property (e.g., herds of animals) are in the hands of men, even in cases where land ownership is tied to women. As well, higher levels of political integration beyond the local community impedes matrilocality. Murdock (1949: 205–206) states that "[w]ider political authority brings to the holders, who are almost invariably men, increased power, property, and prestige which often spell doom to the matrilocal principle."

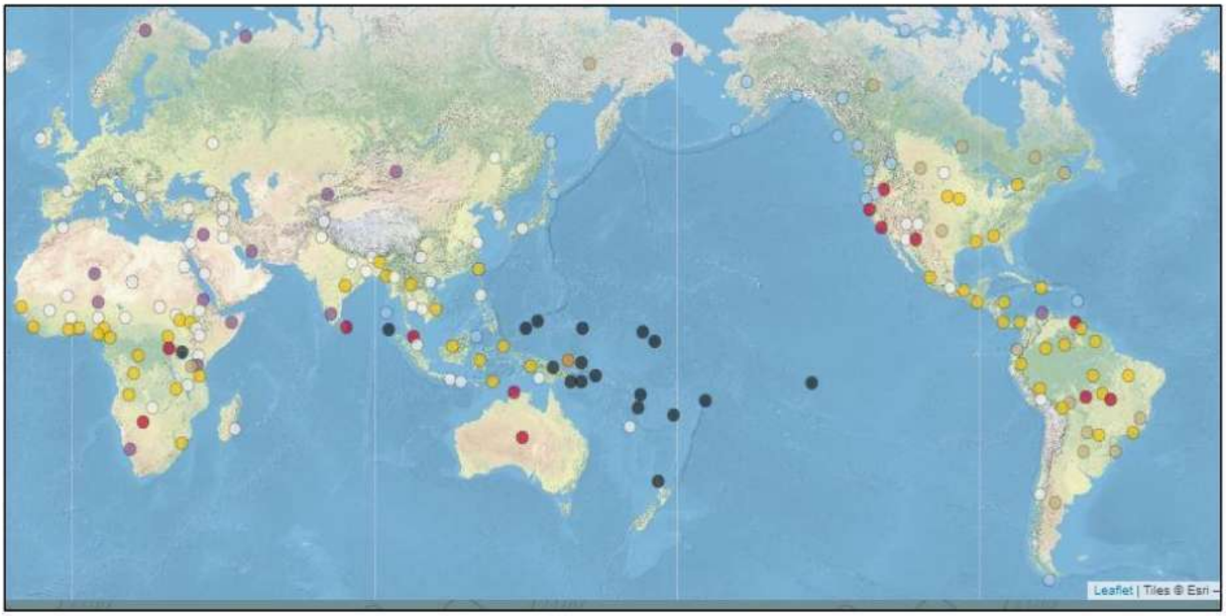

*Figure 3. 3. Global distribution of types of subsistence-economies based on data from variable #833 in the Standard Cross Cultural Sample (Murdock and White 1969). Types of subsistence-economies include advanced agriculture (white), horticulture (black), simple or shifting cultivation (yellow), domestic animals (purple), exchange (orange), fishing (blue), gathering (red), and hunting (green). Map generated using D-PLACE (Kirby et al. 2016).*

### *Avunculocality*

Murdock (1949: 207) contends that avunculocality represents an adjustment of previously matrilocal systems; it cannot develop from other postmarital residence practices. The same conditions or circumstances that precipitate a shift from matrilocality to patrilocality may also produce an avunculocal residence pattern. The key difference between the two (matrilocal to patrilocal, and matrilocal to avunculocal) is the pattern of descent observed. In the avunculocal case, residence practices are adapted to changing conditions within a society while maintaining matrilineal descent systems.

### *Patrilocality/Virilocality*

Approximately 75% of Murdock's (1949: 213) sample characterizes men's work as lumbering (92%), mining and quarrying (95%), herding (84%), trapping (95%), hunting (98%), fishing (86%), and acquiring sea mammals (99%). Relative to female's work, male labor and subsistence or economic activities are more territorially specific, require greater travel distance, and call for more extensive knowledge of terrain surrounding their communities (i.e., knowing the locations of key fishing spots or the paths of migratory game). Consequentially, men's knowledge and skills are not readily transferable to new locales.

A determinant of patrilocality is any condition that increases the status of men in a society, including shifts in the subsistence-economy in which male enterprises take on greater value or contribute more to the community (patridominant) (Lippert 1931; Murdock 1949: 206–207). For example, patrilocality is predominant in pastoral and plow-agricultural economic systems where men have a more significant role in the management of land and livestock (Figure 3.1, 3.3). A predictor for patrilocality in hunter-gatherer societies is if hunted game is sufficiently abundant and predictable to supersede the importance of plant foods procured by women (Murdock 1949: 206–207). The development of moveable property or wealth are both associated with polygyny and patrilocality. In cases where men are responsible for this valuable property, a shift in descent practices (i.e., patrilineality) is also expected (Murdock 1949: 208).

Variation on the patrilocal rule is matri-patrilocality (Murdock 1949: 207) where a newly married couple initially live with or near the wife's family before permanently residing patrilocally (e.g., after the birth of their first child). Matri-patrilocality is common for societies that use bride service as an extension of or replacement for bride price (Murdock 1949: 207). As well, the husband is expected to stay with his wife’s family in societies that permit the payment of bride price over time, as opposed to one lump sum, until it is paid in full.

### *Unilocal Residence: Concluding Remarks*

As discussed above, data from world-wide samples generally indicate that female labor and skills are more easily transferrable to new communities than those for men. Thus, it is more cumbersome for males to leave their natal regions than women (Murdock 1949). Since male knowledge is typically specialized in a particular locale, for instance, knowing where trails, mineral deposits, or fishing spots are located, moving to a new area would require significant adjustments. Together, this would serve as a discouragement for men to relocate to new villages and creates a constraint for the development of matrilocal residence.

In most cases where matrilocality is reported, marriage arrangements are endogamous (Table 3.3; Murdock 1949: 214). In other words, couples are not relocating to new villages but, rather, are moving in or near the wife's family's household within the same community. Matrilocality with marriage endogamy alleviates the constraint of men's locally specialized knowledge. Murdock (1949: 214) notes that only three out of the 25 matrilocal and matrilineal societies in his sample show evidence for exogamy. In those cases, men either equally split their time between their natal home and their wife's village or were part of highly mobile, migratory bands.

### *Nonunilocal Residence: Multilocality, Bilocality, and Neolocality*

Cross-cultural tests conducted by Marlowe (2004) reveal no correlation between male contribution to the diet and postmarital residence for hunting-gathering populations. Interestingly, the data instead suggest that when male contribution is less, patrilocality is more common in foraging societies. Marlowe thought that this result may be the consequence of polygyny in patrilineal, patrilocal groups in which females tend to contribute more to household units. Marlowe's data suggest that emphasis on hunting correlates with bilateral descent and multilocality. This is most likely because many game resources are highly mobile and move over large ranges, which in turn, tends to restrict group size. The smaller populations typical of foragers (due to land and biomass constraints), therefore often require that people find marriageable partners outside their camp. Multilocality is advantageous in this scenario, because the ability to choose where to live and change residence as needed maximizes the potential pool of mates, although seasonal aggregations can also accomplish this. Additionally, cognatic descent and ambilocality/multilocality allow individuals to access a large kinship system. This is advantageous in cases of cooperative childcare and other situations in which a couple may need assistance.

*Table 3. 3. Community Marriage Organization.[1]*

| **Type of Marriage Organization** | **# Societies** | **%** |
|---|---|---|
| Demes[2] | 83 | 7.53 |
| Segmented[3] | 261 | 23.68 |
| Agamous[4] | 396 | 35.93 |
| Exogamous[5] | 117 | 10.62 |
| Segmented with Local Exogamy | 8 | 0.73 |
| Clan | 237 | 21.51 |
| *Total* | 1102 | 100.00 |

[1] Data retrieved from D-PLACE (Kirby et al. 2016) using variable #15 in the *Ethnographic Atlas* [EA015] (Murdock et al. 1999)
[2] Communities with a tendency towards local endogamy but not segmented into clan-barrios
[3] Those divided into barrios, wards or hamlets, each of which is essentially a localized kin group, a clan or ramage, in the absence of local exogamy. Large extended families are treated as clan-barrios if they are integrated by a rule of ambilineal, matrilineal, or patrilineal descent
[4] Without localized clans or any marked tendency toward either local exogamy or local endogamy
[5] Without having the specific structure of clans

In general, bilocality is common for highly mobile groups that live in unstable bands (Murdock 1949: 204). For relatively sedentary societies, status equity between the sexes (e.g., equal access to ownership and inheritance of property and privileges) is a predictor for bilocality. In both cases (mobile and sedentary groups), bilocality permits flexibility in residence choice. It allows a couple to select a location that affords them the greatest opportunities, whether that be food resources, material wealth, or status. In general, bilocality is favorable for societies that require strong kinship bonds (e.g., an emphasis on collective rather than individual endeavors), but where unilineal connections are weakened (Murdock 1949: 204).

Neolocal residence is reported for societies with equitable contributions of males and females to the subsistence-economy and is favored when any conditions or circumstances lead to an emphasis on the nuclear family (Murdock 1949: 203). Neolocality is especially expected when factors disintegrate or weaken lineal ties within a population and inhibit large aggregations of kin (i.e., political evolution from gentile to territorial forms of state that lead to the dissolution of clans and incapacitate linear systems). The formation of independent households by a couple is facilitated by increased individualism, including relaxation of marriage rules in which individuals are free to choose their preferred spouse, individually driven economic pursuits, and control over private property (Murdock 1949). Processes such as overpopulation driving persons to move to a new territory, broadening of economic pursuits (e.g., trade), and the emergence of urbanization can drive increased individualism in a society (Murdock 1949: 203-204). As well, neolocality is favored when there is a modification of inheritance rules, such as the replacement of primogeniture with a system that permits multiple heirs.

### *Reinvestigating Determinants for Postmarital Residence: Post-1950 Cross-Cultural Tests*

Cross-cultural tests conducted by Driver (1956) and Driver and Massey (1957) on Indigenous groups of North America substantiate many of Murdock's hypotheses. On the other hand, many cross-cultural tests that use worldwide samples failed to support the correlation between the sexual division of labor and postmarital residence (Divale 1974, 1975, 1984; Ember and Ember 1971; Hiatt 1970; Korotayev 2003a, 2003b; White 1967). For example, Ember and Ember (1971) systematically evaluated the different conditions that would favor patrilocality versus matrilocality, including the sexual division of labor, the relative status of the sexes, and the presence of warfare, using a subset of Murdock's data (Baker and Jacobsen 2007; Korotayev 2003a, 2003b). Their analysis did not reveal a significant correlation between the sexual division of labor and postmarital residence. Instead, Ember and Ember (1971) observed that a high incidence of internal warfare is a significant predictor for patrilocality. In their estimation, patrilocality fosters cooperation among related males, and is advantageous in situations where group cohesion is necessary, such as internal warfare.

Internal warfare refers to conflicts among communities within the same cultural group, while external warfare takes place among different cultural groups. Based on Ember's and Ember's (1971, 1983) results, there is an interesting interaction between the sexual division of labor and external warfare (Korotayev 2003a, 2003b). In societies where males contribute more to labor and subsistence (patridominant) and engage in external warfare, there is a significant association with patrilocality. By contrast, matridominant (i.e., females predominantly contribute to labor and subsistence) groups that engage in significant amounts of external warfare are typically matrilocal (Figure 3.4; Korotayev 2003a: Figure 1).

Korotayev (2003a) argues that external warfare is not the only condition that interacts with the sexual division of labor in predicting postmarital residence pattern. Instead, any condition or circumstance that requires men to participate in long-distance forays for extended periods, referred to as the "male absence factor," will shape postmarital residence rules (Korotayev 2003a). Korotayev (2003a) demonstrates that the "male absence factor" is a significant predictor for matrilocality, even in patridominant societies. Whether males are largely absent due to external warfare or economic activities, such as trade, peace in their home villages is vital (i.e., mechanisms that lessen internal warfare are necessary). One method that inhibits internal warfare is connecting unrelated men from across various households or neighboring villages to form the basis of these enterprises; matrilocality would facilitate this (Harris 1997; Korotayev 2003a). It is important to note, however, that there is not a significant correlation between "the male absence factor" and patridominant societies (Korotayev 2003a). In other words, most societies for which male labor contributes the most economically do not engage in activities that require their extended absence. Therefore, the "male absence factor" will not significantly impact the association between patridominant societies and patrilocality.

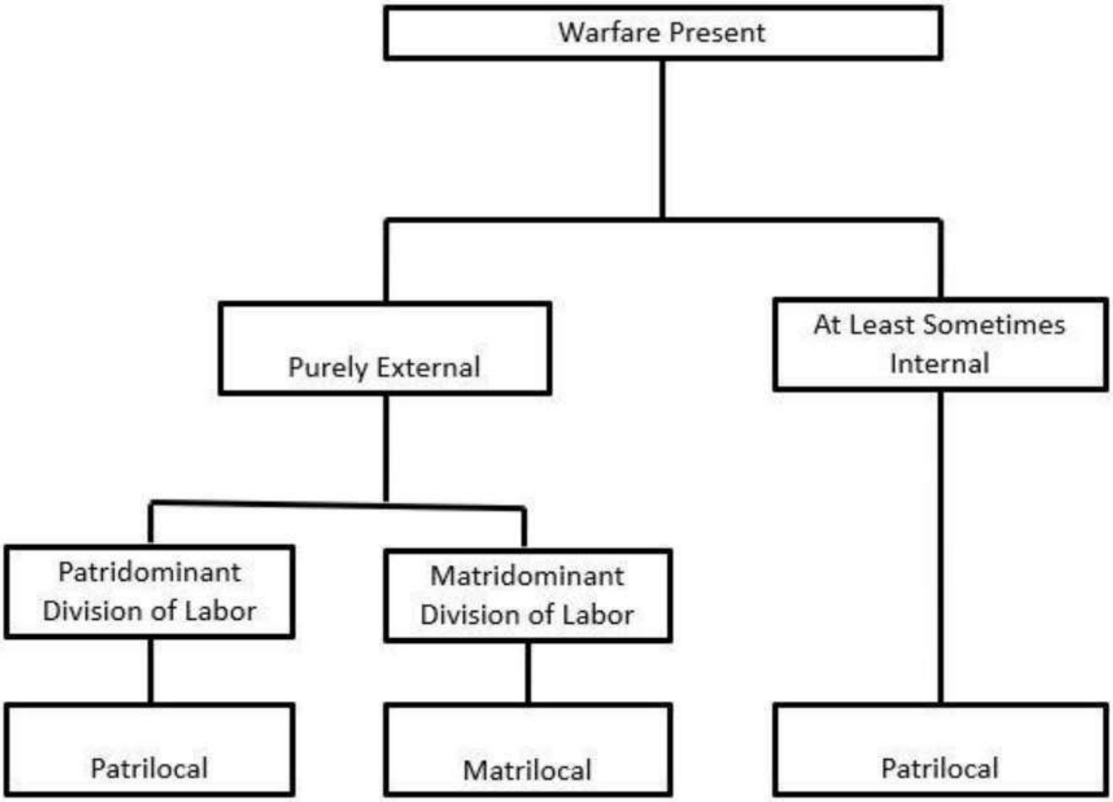

*Figure 3. 4. Model of the evolution of postmarital residence with the variables, the sexual division of labor and warfare, under consideration. Redrawn after Korotayev 2003a: Figure 1.*

In some cross-cultural tests, matrilocality appears to be associated with high rates of migration into a region (Korotayev 2003a). Divale (1974) hypothesized that this correlation is the result of changing strategies in response to increasing conflict between different cultural groups. Divale (1974) envisioned that once a group moves into a new locale, that conflict would inevitably arise between resident populations and immigrants (Korotayev 2003a). As a consequence, immigrant populations would have to adapt by engaging in external warfare. A possible impediment to waging successful between-group campaigns is the presence of internal warfare. In this instance, matrilocal residence is advantageous because it inhibits the development or continuance of fraternal interest groups (that facilitate internal warfare). In other words, if a society is experiencing internal warfare, and that group moves into a new area where they would have to adjust to external warfare, then matrilocality would ease internal tensions by, (1) dissolving fraternal interest groups, and (2) distributing agnatically related males into several different communities that fosters a cooperative network across several villages.

C.R. Ember (1974) confirms the association between migration and matrilocal residence, but she challenges Divale's interpretation (Korotayev 2003a). While it may be true that matrilocality counteracts internal warfare and promotes intra-village cooperation (and both are advantageous in cases of external warfare), this does not explain why a society would choose to adopt this residence rule. In other words, community members would not be consciously aware of the potential within-group peace-keeping qualities of matrilocality (Korotayev 2003a). C.R. Ember (1974) argues that a predictor for matrilocal residence in cases where migration has taken place is a combination of, (1) an initial absence of internal warfare, and (2) a matridominant subsistence economy (Korotayev 2003a). Instead, the lack of an association between internal warfare and migration is a function of population size since highly mobile societies tend to have small local group sizes (Ember 1974; Korotayev 2003a).

Korotayev (2003a) generally supports Ember's interpretation; however, he argues that it does not explain known ethnographic examples with shifts from patrilocality to matrilocality (e.g., the Munduruku). In Korotayev's (2003a) view, this could represent an extension of social mechanisms already present in the society, including, for example, patrilocal groups that allow for a matrilocal alternative—such as initially observing matrilocality followed by a shift to permanent patrilocality.

According to the Standard Cross-Cultural Sample (Murdock and White 1969), about 52% of patrilocal societies allow for these alternative arrangements.

Korotayev (2003b) re-visited these earlier findings and conducted new cross-cultural tests which initially revealed no correlation between postmarital residence practices and the sexual division of labor. However, a review of data scatterplots reveals that "the absence of a correlation hides a complex nonunilinear relationship between the variables under consideration" (Korotayev 2003b: 71). His results suggest an initial strong correlation of matrilocality with high female subsistence contributions. However, after a "certain threshold level," the correlation dissipates and reverses revealing a significant curvilinear relationship. In other words, both low (e.g., less than 20%) and high (e.g., greater than 70%) female input to subsistence is predictive of patrilocality. Korotayev (2003b) believes that this result is most likely due to general non-sororal polygyny. He argues that while an increase in female contribution to subsistence typically will lead to matrilocal residence, that the importance of this contribution can also make polygyny a viable economic solution for males. Essentially, a family unit can maximize economic output by having more females work in the household. Cross-cultural tests conducted by Burton and Reitz (1981), White and Burton (1988), and White, Burton, and Dow (1981) reveal a significant positive correlation between the economic importance of female subsistence and polygyny.

Murdock (1949) recognized the negative association between nonsororal polygyny and matrilocality and the positive association between general polygyny and patrilocality. He argued that in patrilocal societies, women are isolated from their relatives and occupy lower status compared to men; both are factors that favor polygyny (Korotayev 2003a; Murdock 1949). Korotayev's (2003a) tests show a weak correlation between general polygyny and patrilocality, while nonsororal polygyny, specifically, proves to be a strong predictor for non-matrilocality. He argues that there is a bidirectional, causal link between these factors. In other words, matrilocality inhibits the development of nonsororal polygyny, and, conversely, the development of nonsororal polygyny will lead to the dissolution of matrilocality

(Korotayev 2003a). Numerous cross-cultural tests show that there is a significant positive correlation between female contribution to subsistence and polygyny (e.g., Burton and Reitz 1981; White and Burton 1988; White, Burton, and Dow 1981). Figure 3.5 illustrates the positive and negative associations between the beforementioned variables and matrilocality and patrilocality based on Korotayev's (2003a, 2003b) models.

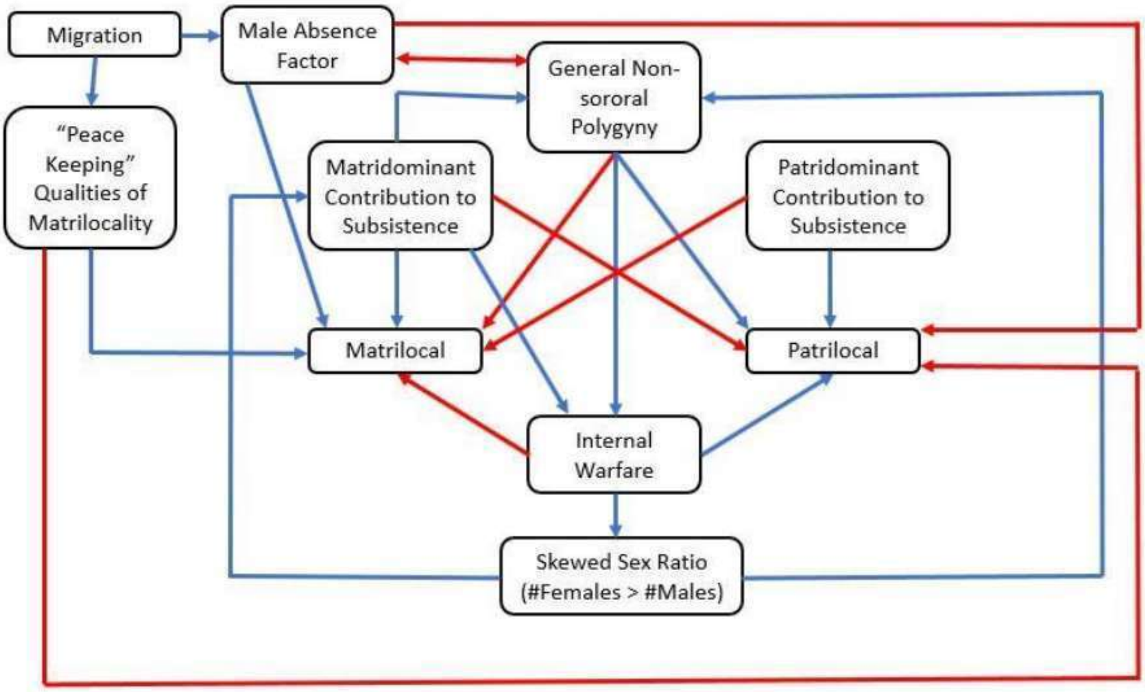

*Figure 3. 5. Positive (blue) and negative (red) predictors for unilocal residence (matrilocality versus patrilocality). Depopulation, resource fluctuations, small group size, and commercialization show a negative association with unilocality. Source: Korotayev 2003a: Figures 3 and 4, 2003b: Figure 11.*

### Postmarital Residence in Ethnographic California

The high environmental productivity in California set the stage for plant intensification and subsequent population growth (Figure 3.6; Basgall 1987; Bettinger 2015: 95-118; Jorgensen 1980: 29-33; Rosenthal et al. 2007 159-162). The earliest populations in California were likely accommodated by highly mobile, bilateral band organization. As population density increases, the ratio of available resources in an environment per person decreases, resulting in greater resource competition.

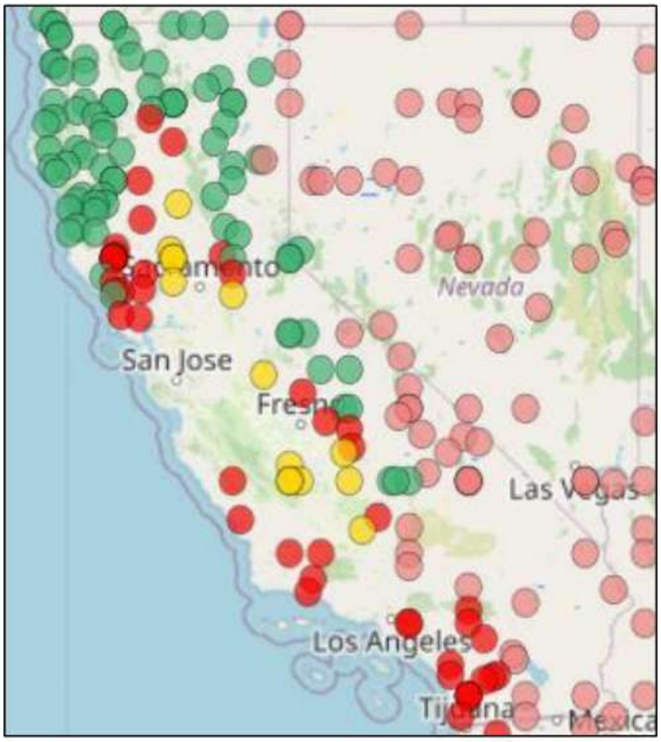

*Figure 3. 6. Terrestrial biomes for California and Nevada showing temperate conifer forests (green), mediterranean forests, woodland & scrub (red), temperate grasslands, savannahs & shrubland (yellow), and desert & xeric shrubland (pink). Map generated with D-PLACE (Kirby et al. 2016) using data from Olson et al. 2001.*

Bettinger (2015) makes a case for the broad distribution of patrilocality in California (Figure 3.7; Table 3.4) as a consequence of emerging patrilineal tribelets and sibs in response to increasing population-densities, resource competition, and the need for territorial defense. Comparing groups living east vs. west of the Sierra Nevada mountains is illustrative. They differ in their subsistence-economies regarding the types of plants targeted and are marked by differences in plant-resource-predictability, which has a significant effect on the group social organization. East of the Sierra Nevada, plant exploitation focuses on pinyon, which is relatively unpredictable compared to the plant staple of acorn west of the Sierra Nevada (Bettinger 2015: 64–81, 110–116, 119–120; Rosenthal et al. 2007: 159-161). In the case of acorns, a population could rely on several different groves, each with different species, and in so doing, decrease the likelihood of resource shortfall. Therefore, a population could establish a defensible home territory focused on acorn groves, along with other nearby vital resources (Bettinger 2015: 119–148). In comparison, the payoffs for defending home territories organized around pinyon groves are not as high. The precarity of pinyon crops makes it difficult for individuals to hold patches as a territory.

Contention over, for instance, important acorn, mesquite, and screwbean groves necessitate safeguarding, an activity typically carried out by males (Bettinger 2015: 119–140). Therefore, it is advantageous to foster cooperation among men within a group, particularly between related males. A system for keeping related males together, patrilocality, promotes this cohesion. Over time, greater sedentism coupled with patrilocality creates an arrangement of settlements that are connected and coordinated by patrilineally related families. Thus, the development of patrilineal bands or patrilineages.

Patrilineal bands consist of small residential kin groups that are patrilocal and connected through patrilineal descent (Bettinger 2015: 120). Typically, they comprise about three to four families per band that hold and defend a home territory. The socio-political organization that dominates California is the patrilineal tribelet in the north and the patrilineal sib in the south (Table 3.5; Bettinger 2015: 119–140; Jorgensen 1980: 174–190). Tribelets are relatively small, only consisting of about 100 to 500 persons that hold a common territory. There is a central or principal village within the tribelet accompanied by 3 or 4 smaller outlying communities. These villages operate independently and are mostly autonomous, both economically and politically.

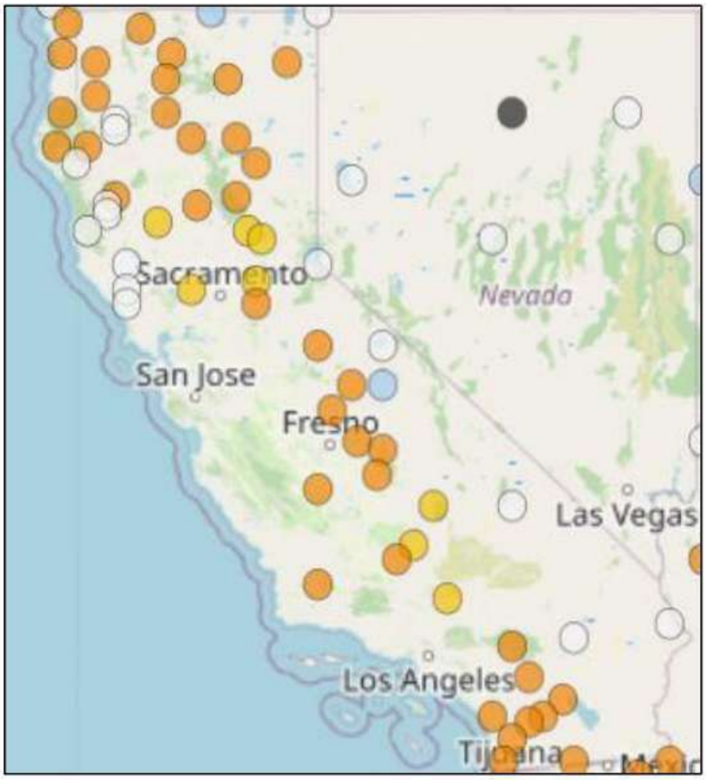

*Figure 3. 7. Distribution of the predominant postmarital residence practices for California and Nevada. Showing patrilocality (orange), ambilocality (white), virilocality (yellow), matrilocality (blue), and neolocality (black). Map generated with D-PLACE (Kirby et al. 2016) using data from Jorgenson 1980.*

*Table 3. 4. Predominant Postmarital Residence Practices for Ethnographic Groups with Territories in California*

| **Region** | **Patrilocality/Virilocality** | | **Matrilocality** | | **Ambilocality** | | |
|---|---|---|---|---|---|---|---|
| | **# Societies** | **%** | **# Societies** | **%** | **# Societies** | **%** | **Total** |
| Northwest | 9 | 82 | | | 2 | 18 | 11 |
| Northeast | 4 | 80 | 1 | 20 | | | 5 |
| North Coast Ranges | 1 | 17 | | | 5 | 83 | 6 |
| Sacramento Valley | 11 | 85 | | | 2 | 15 | 13 |
| San Joaquin Valley | 10 | 77 | 1 | 8 | 2 | 15 | 13 |
| Southern Coast | 3 | 100 | | | | | 3 |
| Southern Interior | 8 | 89 | | | 1 | 11 | 9 |
| ***Total*** | **46** | **77** | **2** | **3** | **12** | **20** | **60** |

Note: Data retrieved from D-PLACE (Kirby et al. 2016) using variable #308 in *Western North American Indians* [WNAI308] (Jorgensen 1980).

*Table 3. 5. Distribution of Variants of Social Organization for Ethnographic Groups with Territory in California.*

| **Region** | **Bilateral Tribelet (%)** | **Patrilineal Kin Group (%)** | **Bilateral Kin Group (%)** | **Patrilineal Tribelet (%)** | **Patrilineal District** | **Bilateral District** | **Matrilineal District** | **Total** |
|---|---|---|---|---|---|---|---|---|
| Northwest | 45 | 9 | 36 | 9 | | | | 11 |
| Northeast | 67 | | 33 | | | | | 6 |
| North Coast Ranges | 86 | | 14 | | | | | 7 |
| Sacramento Valley | 54 | | 8 | 15 | | 23 | | 13 |
| San Joaquin Valley | 20 | 20 | 20 | 40 | | | | 15 |
| Southern Coast | | 50 | | 50 | | | | 4 |
| Southern Interior | | 80 | | | 10 | | 10 | 10 |
| *Total* | 38 | 21 | 17 | 17 | 2 | 5 | 2 | 66 |

Note: Recreated from Bettinger 2015: Table 6.4.

Tribelets maintain ties to neighboring tribelets through shared recognition of moieties that facilitates the exchange of marriage partners and coalescence to perform ritual activities (Bettinger 2015: 136; Jorgensen 1980: 190–192). Tribelets differ from sibs in that the latter is a residential kin group in which belonging to the appropriate patrilineage affords the right to live in a particular community. Comparatively, tribelets do not possess the same standard of cohesion found among sibs; however, it adequately brings together a large number of people to achieve a common goal: protection of the territory.

For tribelets in California, female labor and contributions to the diet are central for the subsistence-economy (Figure 8; Bettinger 2015: 135; Jorgensen 1980: 127–128; Rosenthal et al. 2007). As discussed previously, conventional social theory predicts a preference for matrilocality or, perhaps, bilocality; however, nearly 75% of California tribelets show a predilection for patrilocality or virilocality (Bettinger 2015: 135). Bettinger (2015) contends that this pattern supports the hypothesis that territorial defense was important, superseding any potential influence from the sexual division of labor, and shapes postmarital residence practices in California.

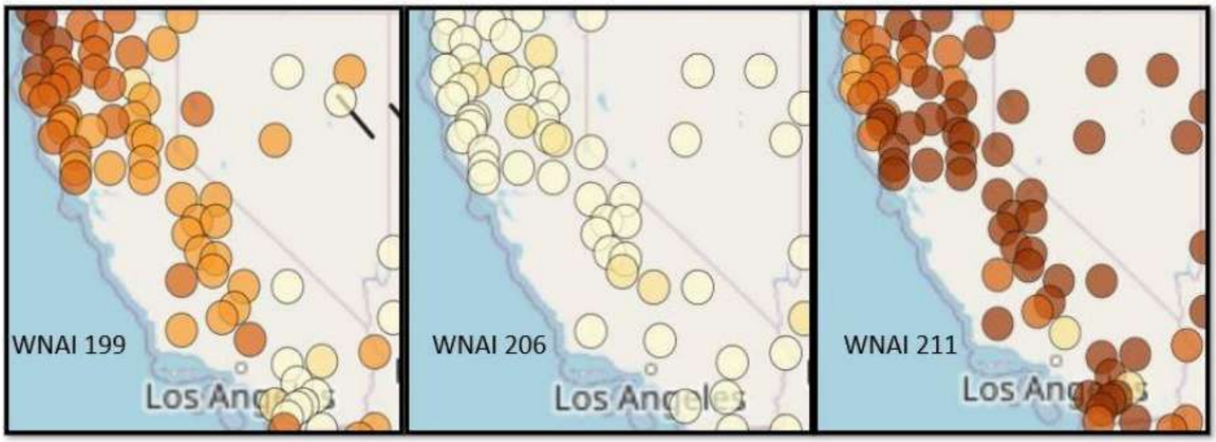

*Figure 3. 8. Probable percentage of the diet for ethnographic groups in California for variables #199 (aquatic animals), #206 (large game, small Animals, and fowl procured locally), and #211 (roots, seeds, berries, nuts, leaves, tubers, etc., procured locally). Range of percentages include 0% (light yellow), 1-10% (yellow), 11-25% (orange), 26-50% (brown), and 51-100% (dark brown). Maps generated with D-PLACE (Kirby et al. 2016) using data from Jorgensen 1980.*

While plant-resource-patches (e.g., acorn groves) are considered the property of the patrilineage, the plant resources themselves (e.g., stored acorns) belong to the village (Bettinger 2015: 125–140; Jorgensen 1980: 124–128). Freeloading is a potential problem that arises when there are food supplies (public resources) that are made available to all community members (Bettinger 2015: 125–140). Bettinger (2015) argues that this freeloading problem may have encouraged the splintering of patrilineal sibs as families began to work in their self-interests. The Cahuilla, for example, developed privately held lands by households and families, and converted food storage to mitigate obligate sharing. While these are some patterns observed among the patrilineal sibs (e.g., the Cahuilla), tribelets adopted the privatization of food to ameliorate the freeloading problem.

Approximately 38% of ethnographically recorded groups in California are organized into bilateral tribelets (Table 3.5; Bettinger 2015: 149; Jorgensen 1980: 174–190). Jorgensen (1980) proposes that over time patrilineal tribelets began to expand certain roles or obligations to include maternal lineages and thus evolved into bilateral tribelets. Bettinger (2015) argues that this took place as a result of the lessening need for territorial protection and, therefore, relaxing rules for patrilineality and patrilocality.

This allows for families, households, and individuals the ability to reassert themselves and to work in their self-interest.

In Northwest California, the Yurok, Karuk, and Hupa evolved into bilateral tribelets that eventually dissolved into household groups (Bettinger 2015: 149–167). These household groups are small (averaging about 7.5 people) and kin focused. As population densities increased in California, resource availability became precarious encouraging nuclear-family-centered groups to work in their self-interest. As diet-breadth expanded to include backloaded resources such as nuts and seeds, food resource availability was no longer a problem since these foodstuffs were relatively abundant and easy to gather. Instead, the new challenge was ensuring sufficient human labor to process them, especially women's labor.

A similar problem appears for eastern Californian groups that rely on pinyon, where we see the privatization of pinyon groves (Bettinger 2015: 149–167). Here, the emergence of sororal polygyny helps to mitigate female labor shortages by introducing more women per household. The incorporation of sororal polygyny may have also been a solution for other Californian groups. The problem with polygyny, and sororal polygyny, in particular, is that while this can help solve the labor problem, it is self-limiting in terms of cost-saving because household productivity will drop with each wife added following the Chayanovian principle (Sahlins 1972). In other words, a family unit's goal is not necessarily to maximize surplus from their labor, but simply to meet that household's needs. Therefore, once a consumption-resource balance is achieved, any additional labor by an added wife is functionally unnecessary.

Bettinger (2015) argues that over time the priority for Californian groups shifted from territorial defense to solving the female-labor shortage problem. In other words, the focus transfers to rationalizing female-labor and making sure it is where it needs to be. With this shift, a potential bride's family will have a greater stake in marriage arrangements since they are losing female-labor from their household. Thus, societies evolved higher bride prices and services to accordingly compensate the bride's family (Figure 3.9; Jorgensen 1980: 168–169). Together (sororal polygyny, bride price, and bride service), these adjustments shape postmarital residence practices in California.

Unilineal landholding groups and unilocal practices significantly impede the flexibility of a village or family to adjust to fluctuations in land or resource availability, or stochastic shifts in the ratio of male and female offspring (Bettinger 2015; Jorgensen 1980; Murdock 1949). In particular, it will make it challenging to achieve a regional ideal-free-distribution, in which the number of individuals within an area is proportional to resource availability (Bettinger 2015: 152). Relaxation of the unilocal residence rule permits a newly married couple to choose to live with, or near, the husband's or wife's family, dependent on which set of kin has sufficient resources. Such a pattern effectively results in ambilocality or bilocality.

For practically all of California, the preferred form of postmarital residence was patrilocality or virilocality (Table 3.4; Figure 3.7; Bettinger 2015; Jorgensen 1980). Yet, approximately half of these groups also permitted alternative forms, most commonly matri-uxorilocality (Jorgensen 1980: 174–190). Even for groups that did not permit these alternatives, many practiced matri-patrilocality in which a couple lives with or near the wife's family immediately after marriage—typically until the birth of their first child—followed by a permanent shift to patrilocality. Additional flexibility can also be achieved by shifting the timing of when a couple moves from the wife’s to the husband’s village (e.g., only one year versus five years) to adjust to changing local conditions. As well, this would allow for the performance of bride service by males.

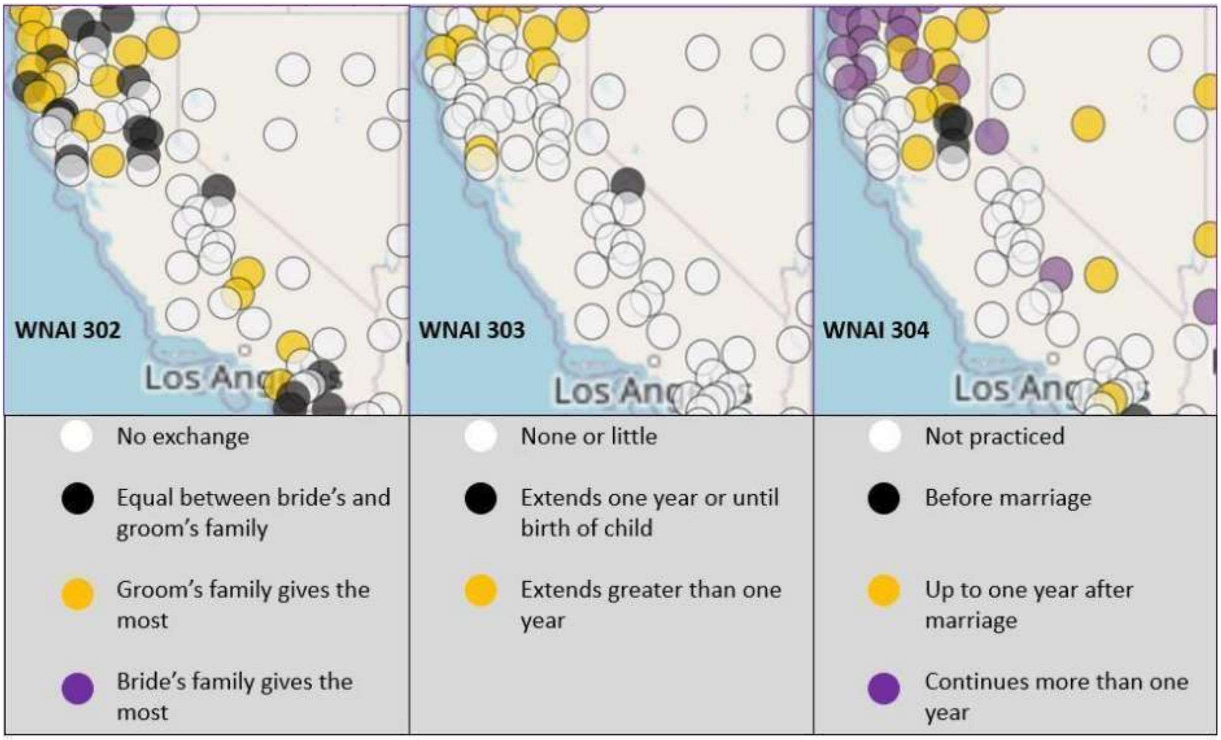

*Figure 3. 9. Incidence of bride price and bride service in ethnographic California for variables # 302 [exchange of gifts (goods or services) between relatives of the bride and groom before or during nuptial rite], # 303 [exchange of gifts (goods or services) between relatives of the bride and groom after nuptial rite], and # 304 [bride service (in which a man performs services for his bride's, or prospective bride's, family)]. Maps generated with D-PLACE (Kirby et al. 2016) using data from Jorgensen 1980.*

For example, in Yurok society, a couple's marriage is considered complete once the bride price is paid in full (Bettinger 2015: 153). This arrangement grants the husband rights to his daughter's bride price as well as any expected compensation due him for injuries suffered by his children or wife. However, on occasion, when a bride price is not fully paid, the Yurok husband is considered only 'half-married' and is not entitled to these privileges. Additionally, the couple remains with the wife's family. Bride price becomes increasingly difficult to afford in situations where female labor is of great value. Thus, 'half-marriages' would become progressively more common, and couples would be effectively practicing matrilocality. Waterman and Kroeber (1934) theorize that 'half-marriages' could serve as a mechanism for the transition from patrilineal to matrilineal descent as well as from patrilocality to matrilocality.

Bettinger (2015: 168) agrees with the Waterman and Kroeber assertion but emphasizes shifts from unilineal to bilateral descent systems because of the increase in value of female-labor and bride price. Unilineal descent is optimal for sorting individuals into nonoverlapping social groups, ensures within-group cooperation, and impedes individual self-interest and actions. In contrast, bilateral descent allows for overlapping kin-networks that expand the number of individuals that a person can rely on as well as permits greater flexibility in determining what relationships to prioritize.

> "... [R]ising bride-price made marriage more competitive and for that reason more amendable to compromise and alternative social arrangements that hinge less on cultural conventions than on individual resourcefulness and entrepreneurship; individuals became increasingly differentiated from one another, individual characteristics becoming more important than group membership (Bettinger 2015: 169)."

## Concluding Remarks

Older anthropological studies proposed a relationship between the relative importance of male versus female contributions to subsistence and postmarital residence practices. In particular, they hypothesized that matridominant and patridominant subsistence favors matrilocality and patrilocality, respectively. However, a cursory examination of geographic point-data (Jorgensen 1980; Kirby et al. 2016; Murdock et al. 1999; Murdock and White 1969; Olson et al. 2001) concerning ethnographic groups of California, illustrate that environment (Figure 3.6), diet (Figure 3.8), and cultural practices such as postmarital residence (Figure 3.7), and bride price/service (Figure 9) seemingly does not support this association. For instance, large swaths of California rely on plant foods, yet patrilocality is broadly reported for ethnographic groups.

Subsequent studies conducted by Korotayev (2003a, 2003b) illustrate how the sexual division of labor and postmarital residence practices does not follow a simple linear relationship. Instead, as increasing female-subsistence contributions exceed a certain threshold (e.g., greater than 70%), additional factors are introduced that can be more advantageously accommodated by patrilocality. As

Bettinger (2015) implies, considering broad food categories alone (e.g., plants versus hunted foods) masks the intersection of gendered labor associated with procurement, maintenance, and protection of resource patches. In particular, plant-resource-predictability influences the value of resource defense, a predominantly male-associated endeavor.

Archaeological data can help clarify the aforementioned complexities by introducing evidence to evaluate to what degree ethnographic patterns apply to the past and capture the evolution of covarying facets of human behavior and cultural systems. For example, past dietary behaviors can be more accurately described when paleobotanical and archaeofaunal evidence are paired with stable isotope analysis of human bone, which gives direct approximations of ancient diets. Furthermore, individual-level variation in diets can be captured using isotopic data. Likewise, isotopic tracers of geography can be used to investigate individual-level data to reconstruct paleomobility. In particular, it permits comparison between male and female mobility profiles to evaluate hypothesized postmarital residence practices. The following chapter introduces the five isotopic systems (carbon, nitrogen, sulfur, oxygen, and strontium) employed in this study, the underlying principles of stable isotope analysis, and its utility for understanding ancient human diets and mobility.

# CHAPTER IV. ISOTOPIC ANALYSIS OF HUMAN SKELETAL TISSUES TO ELUCIDATE ANCIENT DIET AND MOBILITY

Physicists and chemists first identified stable isotopes in 1913, most of which were discovered by the mid-1930s (Katzenberg 2008). During that time, the field successively improved in its instrumentation and methodology, enabling the first commercial spectrometers to be used to analyze petroleum by 1942. Greater interest and advancements in understanding the distribution of stable isotope abundances in natural substrates during the 1950s and 1960s advanced analyses of past climates and variation in the biosphere and geosphere. Botanists and geochemists investigated the distribution and discrimination of stable carbon isotopes in plants (Craig 1954; Katzenberg 2008; Smith and Epstein 1971) while greater interest grew in using stable carbon isotopes studies to refine radiocarbon dating methods (Bender 1968; Hall 1967; Lowdon 1969).

Application of stable isotopic analyses in archaeology began in the 1970s (DeNiro and Epstein 1978, 1981; van der Merwe and Vogel 1978; Vogel and van der Merwe 1977) including Vogel and van der Merwe (1977) who used stable carbon isotope analysis to understand maize consumption patterns among North American prehistoric groups (Katzenberg 2008). At the time, the instrumentation needed to conduct stable isotope analysis was expensive, and methodology was laborious, severely limiting the number of samples that could be run. Throughout the 20th century, there were progressive improvements in instrumentation and analytical methods associated with stable isotope analyses (Katzenberg 2008). By the late 1980s, these advancements led to the simplification of sample preparation, the introduction of automated samples into the systems, a reduction in necessary sample size, quicker delivery of results, and decreased cost. As a result, ecologists, geologists, and archaeologists could test more samples and investigate new avenues for stable isotope research. In the case of archaeology, these advancements permitted evaluation of isotopic variation within and between subsets of a population, including age and sex categories, as well as produce more meaningful diachronic assessments. This allows for a more nuanced interpretation and understanding of demographic patterns and past human behavior.

## Fundamentals of Stable Isotopes

Isotopes are atoms of the same element with the same number of protons but a different number of neutrons in the nucleus (Katzenberg 2008; Reitsema 2015). The differing number of neutrons affects the atomic mass of isotopes, which influences the strength of chemical bonds and how atoms behave in chemical reactions. Unlike radioactive isotopes with unstable atomic nuclei that lose energy by radiation and either gain or lose a neutron in the process, stable isotopes do not decay over time (Ben-David and Flaherty 2012; Katzenberg 2008; Reitsema 2015). Light isotopes of an element are typically more common in natural abundance, especially for elements lower in the periodic table (Table 4.1).

*Table 4. 1 Natural Abundances of Isotopes Used in this Study*

| Element | Isotope | Abundance (%) |
|---|---|---|
| Carbon | $^{12}C$ | 98.89 |
| | $^{13}C$ | 1.11 |
| Nitrogen | $^{14}N$ | 99.63 |
| | $^{15}N$ | 0.37 |
| Oxygen | $^{16}O$ | 99.759 |
| | $^{17}O$ | 0.037 |
| | $^{18}O$ | 0.204 |
| Sulfur | $^{32}S$ | 95.00 |
| | $^{33}S$ | 0.76 |
| | $^{34}S$ | 4.22 |
| | $^{36}S$ | 0.014 |
| Strontium | $^{84}Sr$ | 0.56 |
| | $^{86}Sr$ | 9.86 |
| | $^{87}Sr$ | 7.02 |
| | $^{88}Sr$ | 82.56 |
| Note: Recreated from Katzenberg 2008: Table 13.1 | | |

The natural abundance of stable isotopes are shaped by how different isotopes of an element behave in chemical reactions, known as isotope effects (Ben-David and Flaherty 2012; Katzenberg 2008). The mass of an atom influences the strength of chemical bonds; the greater the mass, the more energy is required to break bonds. Therefore, heavier isotopes react more slowly, and lighter isotopes are preferentially used in chemical reactions. Isotopes transfer between substrates through chemical reactions such as evaporation or metabolism of dietary protein (Reitsema 2015). Fractionation refers to changes that occur in a single reaction, while discrimination refers to the difference between the origin compounds and the product (Ben-David and Flaherty 2012; Katzenberg 2008; Reitsema 2015). Since lighter isotopes are preferentially used during chemical reactions, the original substrate will be enriched in the heavier isotope compared to its by-product. Observed isotopic patterns or the distribution of isotopic ratios across natural substrates result from fractionation (Reitsema 2015).

Conventionally, isotopic values in stable isotope research report the ratio of heavier to lighter isotopes in substrates and tissues under study (Ben-David and Flaherty 2012; Katzenberg 2008; Reitsema 2015). These isotopic abundances are standardized using the delta notation (Equation 4.1) and reported in parts per thousand or per mil (‰). Standards (Table 4.2) are made available through the National Bureau of Standards as well as the International Atomic Energy Agency in Vienna, the circulation of which allows comparison of results among different researchers and laboratories (Ben-David and Flaherty 2012; Katzenberg 2008; Reitsema 2015). Since it can be costly to distribute these international standards, laboratories typically have internal standards that are well characterized relative to the international ones.

$$\delta = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 1000$$

*Equation 4. 1 Delta Notation for Reporting Stable Isotope Values Relative to International Standards. R represents the ratio of heavy to light isotopes (e.g.,* $^{13}C$*:*$^{12}C$*)*

*Table 4. 2 International Standards for Stable Isotopes used in this Study*

| **Element** | **International Standard** |
|---|---|
| $\delta^{18}O$ | Standard Mean Ocean Water (VSMOW) |
| $\delta^{13}C$ | PeeDee Belemnite (VPDB) |
| $\delta^{15}N$ | Atmospheric Nitrogen (AIR) |
| $\delta^{34}S$ | Canyon Diablo Meteorite Troilite (VCDT) |
| $^{87}Sr/^{86}Sr$ | *United States Geological Survey Tridacna |
| Note: Adapted from Katzenberg 2008: Table 13.2; *Ben-David and Flaherty 2012 | |

**Paleodietary Analysis using Stable Carbon and Nitrogen Isotopes**

The relative abundance of carbon-13 ($^{13}C$) to carbon-12 ($^{12}C$) and nitrogen-15 ($^{15}N$) to nitrogen-14 ($^{14}N$) are conventionally used in stable isotope studies to reconstruct paleodiets (DeNiro and Epstein 1976, 1978, 1981; van der Merwe and Vogel 1978; Vogel and van der Merwe 1977). Studies reveal patterned differences in the relative abundance of $^{13}C/^{12}C$ in the tissues of plants that vary according to their photosynthetic pathway (Farquhar 1989). Research focused on stable nitrogen isotopes report variation corresponding to trophic levels and environment (Schoeninger and DeNiro 1984) and are useful for understanding meat versus plant consumption patterns. As well, studies of stable carbon and nitrogen isotopes are used to differentiate between marine- and terrestrial-resource-based diets in humans (Chisholm et al. 1982; Schoeninger et al. 1983; Tauber 1981). Stable isotope ratios recorded in consumer's tissues provide information about general types (e.g., animal-derived protein, $C_3$ versus $C_4$ based plant foods) of foods eaten and time-averaged dietary patterns (Katzenberg 2008; Reitsema 2015). Additionally, stable carbon and nitrogen isotopes are increasingly used to detect and assess the impact of metabolic disorders or deviations from physiological homeostasis, including diabetes, osteoporosis, and protein stress (Reitsema 2015).

This study focuses on paleodietary analysis using stable carbon and nitrogen isotopes in human skeletal tissues. Approximately 30% of dry mammalian bone by weight is organic, of which 85 to 90% consists of collagen (Katzenberg 2008; White et al. 2012: 35-36). Collagen, the structural protein component of bone, is derived from a mixture of both essential and nonessential amino acids (Katzenberg 2008). Differential metabolic routing of macronutrients in bone tissues results in stable carbon and nitrogen isotopes in bone collagen as predominantly obtained from dietary protein. Bone collagen consists of about 35% carbon and between 11 and 16% nitrogen by weight (Ambrose and Norr 1993; Katzenberg 2008; Tieszen and Fagre 1993). The remainder of the organic portion of bone includes noncollagenous proteins, proteoglycans, and lipids.

The inorganic or mineral component comprises the majority (70%) of dry bone by weight and consists predominantly of hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) (Katzenberg 2008; White et al. 2012: 35-36). Carbonate in bone is acquired from bicarbonate in the blood, which is biologically routed from dietary carbohydrates, lipids, and proteins. Figure 4.1 shows an isotopic biplot of nitrogen and carbon values for economically important food resources in Central California based on research reported in Bartelink (2006: 138-155). The following provides a brief overview of carbon in bone collagen and apatite, and nitrogen in bone collagen.

### *Stable Carbon Isotopes*

Plants fix carbon from the atmosphere through photosynthesis, which is transferred to other organisms through the food chain. Fractionation processes produce variation in the relative abundance of $^{13}C$ to $^{12}C$ (Bender 1968; Farquhar et al. 1989; O'Leary 1981, 1988; Smith and Epstein 1971; van der Merwe 1982). The proportional abundance of $^{13}C$ to $^{12}C$ is reported relative to a standard in per mil (‰) using the delta notation symbol ($\delta^{13}C$) (Fry 2006). Plants in temperate regions (e.g., trees, shrubs, legumes, and most tubers) characteristically use the $C_3$, or Calvin-Benson, photosynthetic pathway (Farquhar et al. 1989; O'Leary 1981, 1988) and yield average $\delta^{13}C$ values of about -27.1‰. Plants that grow in hot, arid environments like tropical grasses (e.g., maize, millet, sorghum, and sugarcane) commonly use the $C_4$, or Hatch-Slack, photosynthetic pathway (Farquhar et al. 1989; Katzenberg 2008).

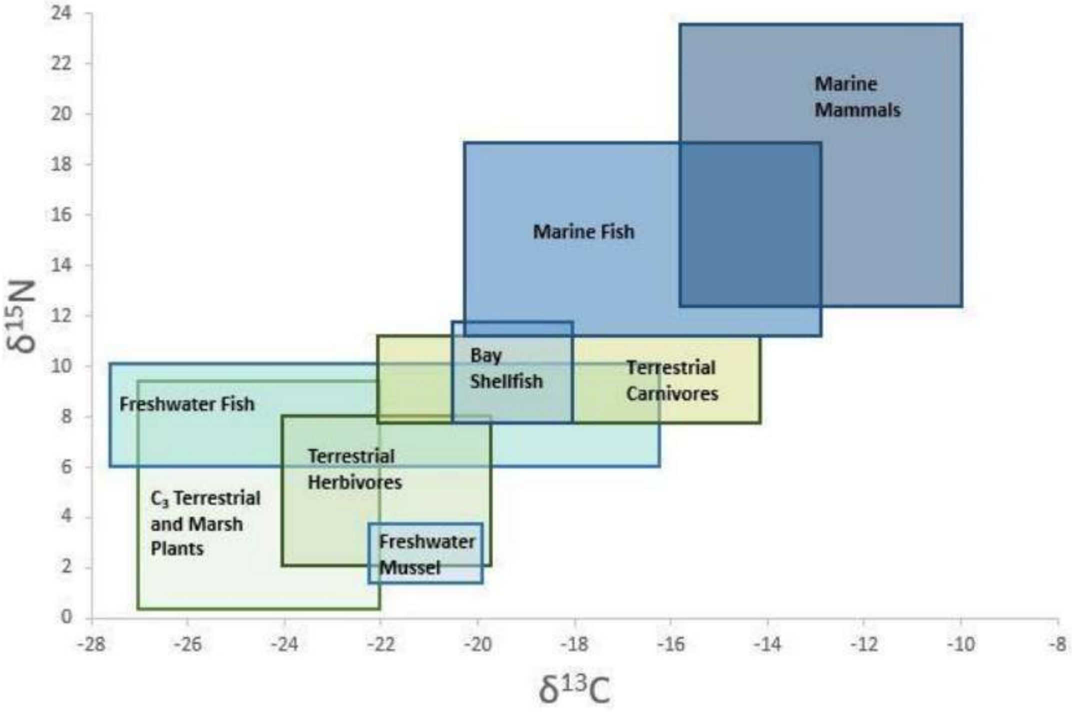

*Figure 4. 1 Economically important food resources in Central California (adapted from Bartelink 2006:156)*

As an adaptation to the aridity and temperature of the environments in which they grow, $C_4$ plants show a reduction in the time that leaf pores (stomata) remain open during photosynthesis, minimizing water loss (Katzenberg 2008; Farquhar et al. 1989). Plants that use the $C_4$ photosynthetic pathway integrate more $^{13}C$ (Farquhar et al. 1989) and show comparatively high $\delta^{13}C$ values relative to those that use the $C_3$ photosynthetic pathway (Reitsema 2015). On average, $C_4$ plants show $\delta^{13}C$ values of -13.1‰ (O'Leary 1988). Some plants that grow in water-limited environments (e.g., pineapple and cactus) use the Crassulacean Acid Metabolism (CAM) cycle resulting in $\delta^{13}C$ values that are intermediate and at times overlapping with those observed from $C_3$ and $C_4$ plants (Reitsema 2015).

Given that $C_3$ and $C_4$ plants produce non-overlapping $\delta^{13}C$ values, studying stable carbon isotope abundances in skeletal tissues can reveal significant information about ancient diets (Katzenberg 2008;

Reitsema 2015). For example, various studies that focus on prehistoric populations in eastern North America (Katzenberg 1995; Schurr and Redmond 1991; Larsen 1997) demonstrate the effectiveness of tracking shifts in dietary behaviors from one focused on consuming exclusively $C_3$ diets to one that incorporates maize (a $C_4$ plant) using stable carbon isotopes. However, the application of stable carbon isotope analysis to understand the adoption of maize agriculture is more complicated in arid regions, such as the Southwest (Katzenberg 2008), where consumption of other $C_4$ or CAM plants, and terrestrial animals that consume a variety of $C_4$ or CAM plants, can complicate interpretations of isotopic results. However, researchers have tackled this challenging region (Benson et al. 2006; Coltrain et al. 2006; Decker and Tieszen 1989; Katzenberg and Kelley 1991; Matson and Chisholm 1991; Spielmann et al. 1990). In general, stable carbon isotope analysis is less informative when working in regions that lack a diversity of plant-food resources that rely on isotopically distinct photosynthetic pathways.

In addition to tracking $C_3$ vs. $C_4$ plant consumption patterns, stable carbon isotope analysis is also useful for differentiating among marine- versus terrestrial-based diets (Katzenberg 2008). Marine organisms' primary source of carbon is dissolved carbonate in the water ($\delta^{13}C$ = ~0 ‰), while terrestrial animals' predominant source is atmospheric carbon dioxide, which before the impact of fossil fuels, was about -7 ‰. Due to the integration of carbon from dissolved bicarbonate in water, as well as the effect of photosynthesizing phytoplankton, plants in aquatic, coastal, and estuarine environments have $\delta^{13}C$ values that can resemble those of $C_4$ plants with average $\delta^{13}C$ values of about -19.0‰ (Ambrose et al. 1997; Schoeninger and DeNiro 1984). Compared to terrestrial animals that subsist on $C_3$ resources, those that live in coastal and estuarine environments show $\delta^{13}C$ values enriched by 6 to 7‰ (Ambrose et al. 1997; Schoeninger and DeNiro 1984).

There are numerous sources of carbon for freshwater ecosystems, including atmospheric carbon dioxide, carbon dioxide in water, bicarbonate and carbonate from rocks and soil, and organic carbon in the form of waste products from decomposing plants and animals (France 1995; Hecky and Hesslein

1995; Katzenberg 1989, 2008; Kiyashko et al. 1991; Zohary et al. 1994). Within freshwater ecosystems, $\delta^{13}C$ values vary according to particular niches, each with a unique combination of carbon sources (Katzenberg 2008). For instance, freshwater fish $\delta^{13}C$ values vary with their position in the food chain (e.g., primary consumers versus secondary consumers) and microhabitats delineated by water depth.

Diet-tissue spacing refers to the difference between the isotopic ratios in the substrate (i.e., food in the case of mammals) to those observed in consumers' tissues (Ambrose and Norr 1993; Katzenberg 2008; Reitsema 2015). Various physiologic conditions and processes influence fractionation and result in different offsets dependent on the type of tissue under study. The diet-tissue spacing reported for $\delta^{13}C$ values in bone collagen for animals raised on diets (protein, carbohydrates, and fats) derived exclusively from $C_3$ or $C_4$ resources is about 5 ‰ (Ambrose and Norr 1993; Katzenberg 2008; Lyon and Baxter 1978; Tieszen and Fagre 1993; van der Merwe and Vogel 1978). In cases of mixed diets, where the primary source for protein differs from those for carbohydrates and fats (e.g., protein derived from terrestrial mammals that consume $C_3$ plants while carbohydrates are derived from $C_4$ plants such as maize), results in greater variation in the offset between the diet and animal tissues (Ambrose et al. 1997; Katzenberg 2008).

Carbon in apatite is synthesized from bicarbonate in the blood, while carbon in bone collagen is primarily (approximately 74%) acquired from dietary protein (Fernandes et al. 2012). As such, the carbon in bone apatite is a better proxy for the "whole diet" including proteins, carbohydrates, and lipids (Ambrose and Norr 1993; Howland et al. 2003; Warinner and Tuross 2009; Tieszen and Fagre 1993). Studies show that the spacing between an animal's whole diet and apatite is 9–10 ‰ (Fernandes et al. 2012; Froehle et al. 2010; Warinner and Tuross 2009). Apatite-collagen spacing, therefore, is a function of the enrichment of $^{13}C$ from dietary protein ($\delta^{13}C_{col}$) when compared to $\delta^{13}C$ from the whole diet ($\delta^{13}C_{ap}$). If the protein component of the diet ($\delta^{13}C_{col}$) is equal to the whole diet ($\delta^{13}C_{ap}$), then the dietary spacing is about 4.4‰ (9.4‰ – 5.0‰ = 4.4‰). $\delta^{13}C_{col}$ derived from marine protein will be more enriched in $^{13}C$, and therefore, the offset will be less than 4.4‰. In comparison, terrestrial $C_3$ diets will show lower $\delta^{13}C$ values, and therefore, the spacing will be greater than 4.4‰.

### *Stable Nitrogen Isotopes*

The ratio of $^{15}N$ to $^{14}N$ is reported in ‰ relative to an international standard (atmospheric $N_2$ or AIR set at 0‰) and is reported using the delta notation ($\delta^{15}N$) (Katzenberg 2008; Reitsema 2015). $\delta^{15}N$ values strongly correlate to ingested protein resources since nitrogen in bone collagen is assimilated entirely from dietary protein (DeNiro and Epstein 1981). Plant resources are about 10 to 25% protein, while meat is approximately 85 to 90% protein (Ambrose et al. 2003; DeNiro and Epstein 1981). Therefore, researchers typically use $\delta^{15}N$ values in bone collagen to understand the contribution of animal proteins or their products to the diet (Reitsema 2015). $\delta^{15}N$ values within an environment vary according to trophic effects (Katzenberg 2008; Reitsema 2015).

Nitrogen is incorporated into plant tissues from the atmosphere and ocean water (Heaton 1987). Some plants (e.g., legumes) uptake nitrogen from a bacteria belonging to the genus *Rhizobium*, with which they have a symbiotic relationship, and show $\delta^{15}N$ values close to 0‰ (Katzenberg 2008). Other plants fix nitrogen from the soils in which they grow, which contains compounds such as ammonia ($NH_3$) and nitrite ($NO_3$) resulting from decomposed organic materials. These plants are more enriched in $^{15}N$ and show higher $\delta^{15}N$ values than those with a symbiosis with *Rhizobium*, typically between 1 and 3‰ (Katzenberg 2008).

Other organisms fix nitrogen from the diet (Katzenberg 2008; Reitsema 2015). Fractionation of nitrogen during metabolism results in differential excretion of lighter $^{14}N$ in urea, leaving more of the heavier $^{15}N$ for tissue synthesis. This is referred to as a trophic effect. Studies show that trophic effects vary by taxa and biological tissues (DeNiro and Epstein 1981; Katzenberg 2008; Schoeninger and DeNiro 1984; Vanderklift and Ponsard 2003), but increase $\delta^{15}N$ on average by about 2–4‰ with each trophic level (DeNiro and Epstein 1981; Katzenberg 2008; Minagawa and Wada 1984; Reitsema 2015). The longer the food chain in a food web, the more considerable the increase in $\delta^{15}N$. As a result of longer food chains in marine environments, top predators in marine environments are more enriched in $^{15}N$ compared to top predators in terrestrial ecosystems (Katzenberg 2008; Reitsema 2015). $\delta^{15}N$ values also vary by climate and are impacted by physiologic effects such as nutrition and water stress (Ambrose 1991; Heaton et al. 1986; Katzenberg 2008; Reitsema 2015; Sealy et al. 1987). Arid regions show an enrichment in $^{15}N$. Animals of the same species that live in different environments (e.g., arid versus wetter ecosystems) show patterned differences in $\delta^{15}N$ values.

Studies demonstrate that individuals experiencing nutritional or protein stress also show an enrichment of $^{15}N$ in recently forming tissues (Katzenberg 2008; Reitsema 2015). A lack of dietary protein results in the body catabolizing proteins from endogenous tissues, such as muscle, and mimics the trophic-effect. Research focused on persons suffering from anorexia and bulimia show elevated $\delta^{15}N$ values in portions of hair samples representing the time when they were first admitted into treatment facilities compared to later periods during recovery from their eating disorders (Hatch et al. 2006; Mekota et al. 2006; Reitsema 2015). Other studies show elevated $\delta^{15}N$ values in the diseased portion of bones (e.g., osteomyelitis and osteoporosis) compared to those that lack pathologies (Katzenberg 2008; Katzenberg and Lovell 1999; White and Armelagos 1997).

Studies also demonstrate a $\delta^{15}N$ trophic effect for breastfeeding infants; this principle is increasingly used to understand weaning practices for prehistoric populations (Eerkens et al. 2011; Fogel et al. 1989, 1997; Katzenberg 2008; Reitsema 2015). Since the protein in breastmilk is derived from the mother's endogenous protein, breastfeeding infants show enrichment of $^{15}N$ in their tissues, roughly 2-4 ‰ higher $\delta^{15}N$ than the mother (Fogel et al. 1989; Koch 1997). $\delta^{15}N$ values decrease as infants undergo weaning and transition onto solid foods (Katzenberg 2008; Reitsema 2015).

**Reconstructing Human Mobility using Isotopic Evidence**

Increasingly, isotope research is applied in bioarchaeological studies to distinguish between locals and nonlocals in burial populations, and incorporated into models developed to assess colonization, culture change, migration, trade, and exchange (Price et al. 2008; Slovak and Paytan 2011). The reconstruction of human mobility using stable isotopes is dependent on the premise that the isotopic signatures of human bone and teeth reflect isotopic values of regional substrates in the environment.

The extracellular matrix of human bone is composed of a fibrous protein, collagen, and tissue mineral, hydroxyapatite. As a result of their chemical similarity, the calcium in hydroxyapatite can sometimes be replaced by other ions such as strontium (Sr), barium (Ba), lead (Pb), and radium (Ra) (Hilson 1996). Since calcium is preferentially used by the body, this substitution of similar elements typically occurs when dietary resources contain insufficient calcium. Bone undergoes a process known as remodeling. The continuous resorption and reconstruction of skeletal tissues results in approximately an 18% annual turnover of adult human bone (Steele and Bramblett 1988). Complete remodeling varies by skeletal element and generally occurs between five and 25 years (Hedges et al. 2007).

Dental tissue, unlike bone, does not remodel. Teeth are composed of three dental tissues, which include enamel, dentin, and cementum (Hillson 1996; Nelson and Ash 2009). Calcium phosphates are the primary component of enamel (between 95–98%), which constitutes hydroxyapatite (Jacobson 2002). The development of deciduous teeth begins at about 14 to 16 weeks after fertilization, while permanent teeth begin forming approximately 28 to 32 weeks after fertilization (Hillson 1996). Tooth formation begins with the crown and ends at the apex of the root (Nelson and Ash 2009; Table 4.3). For the permanent first molar, enamel begins growing at about the time of birth, while the crown is completed between 2.5 and 3 years of age (Table 4.3). Dentin continues accumulating through the apical root tip through age 9–10 years (Table 4.3). By contrast, enamel of the permanent third molar begins forming between 7 and 10 years and is completed between 12 and 16 years (Table 4.3). Dentin in the root continues growing until 18–25 years when the apical root tip closes (Table 4.3).

*Table 4. 3 Timeline of the Development of Human Permanent Teeth (Nelson and Ash 2009)*

| **Permanent Teeth** | **Initial Calcification** | **Crown Completed** | **Root Completed** |
|---|---|---|---|
| *Maxillary* | | | |
| Central Incisor ($I^1$) | 3–4 mo. | 4–5 yr. | 10 yr. |
| Lateral Incisor ($I^2$) | 10–12 mo. | 4–5 yr. | 11 yr. |
| Canine | 4–5 mo. | 6–7 yr. | 13-–15 yr. |
| First Premolar ($P^3$) | 1.5–1.75 yr. | 5–6 yr. | 12–13 yr. |
| Second Premolar ($P^4$) | 2–2.25 yr. | 6–7 yr. | 12–14 yr. |
| First Molar ($M^1$) | At birth | 2.5–3 yr. | 9–10 yr. |
| Second Molar ($M^2$) | 2.5–3 yr. | 7–8 yr. | 14–16 yr. |
| Third Molar ($M^3$) | 7–9 yr. | 12–16 yr. | 18–25 yr. |
| *Mandibular* | | | |
| Central Incisor ($I_1$) | 3–4 mo. | 4–5 yr. | 9 yr. |
| Lateral Incisor ($I_2$) | 3–4 mo. | 4–5 yr. | 10 yr. |
| Canine | 4–5 mo. | 6–7 yr. | 12–14 yr. |
| First Premolar ($P_3$) | 1.5–2 yr. | 5–6 yr. | 12–13 yr. |
| Second Premolar ($P_4$) | 2.25–2.5 yr. | 6–7 yr. | 13–14 yr. |
| First Molar ($M_1$) | At birth | 2.5–3 yr. | 9–10 yr. |
| Second Molar ($M_2$) | 2.5–3 yr. | 7–8 yr. | 14–15 yr. |
| Third Molar ($M_3$) | 8–10 yr. | 12–16 yr. | 18–25 yr. |

The strontium, oxygen, and sulfur of bone, first molars, and third molars evaluated in this study should reflect isotopic values of the environments in which individuals resided during the time those skeletal tissues were forming. A shift in residence can be determined if the stable isotopic values reported for teeth and bone are divergent for an individual, and when dietary shifts are unlikely to explain this difference (Table 4.4). In this respect, understanding local food-webs and predictions about the spatial distribution of isotopic values across an area, based on modern sampling, are important for interpreting mobility profiles. Further, comparing female versus male mobility profiles may reveal sex-biased dispersal patterns and be used to deduce postmarital residence practices. The following section provides an overview of the radiogenic and stable isotopes of strontium, oxygen, and sulfur. These isotopic systems will be used in this study to reconstruct mobility profiles for individuals from archaeological sites CA-SAC-107 and CA-SJO-68.

*Table 4. 4 Definitions of and Expected Isotopic Patterns for Types of Postmarital Residence*

| **Postmarital Residence Pattern** | **Residential Group** | **Expected Stable Isotopic Patterns by Sex** | | | | | | **Comments** |
|---|---|---|---|---|---|---|---|---|
| | | *Males* | | | *Females* | | | |
| | | *1st Molar* | *3rd Molar* | *Bone* | *1st Molar* | *3rd Molar* | *Bone* | |
| *Patrilocal* | Husband's Family | L | L | L | NL | NL | L | 3rd Molar for some females may be local, depending on their age when moving to husband's village<br>3rd Molar for males may be non-local if practicing bride service |
| *Matrilocal* | Wife's Family | NL | NL | L | L | L | L | |
| *Avunculocal* | Husband's Maternal Uncle | NL | L | L | NL | NL | L | 3rd Molar for males may be non-local, depending on their age when moving to uncle's village<br>Females may show non-local bone values if returned for burial with matrilineal kin |
| *Neolocal* | Couple Creates New Residential Group | NL | NL | L | NL | NL | L | Typical for groups that are residentially mobile |
| *Natolocal* | Couple Remains in Natal Residential Group | L | L | L | L | L | L | Typical for groups with large enough villages for marriageable partners<br>Possibly represents groups for which couple do not live together (impregnation only) |
| *Ambilocal* | Couple Chooses Either Husband's or Wife's Family | — | — | — | — | — | — | Flexible residence rules<br>Variable results for tooth and bone values |

NL = non-local L = local — = variable

*Radiogenic Strontium*

There are four isotopes of strontium ($^{84}$Sr, $^{86}$Sr, $^{87}$Sr, and $^{88}$Sr) in geological (e.g., igneous, metamorphic, and sedimentary rock) and hydraulic (e.g., river water, groundwater, and seawater) systems (Slovak and Paytan 2011). The ratios of strontium isotopes in nature are a product of the unique geochemistry of geological formations (Faure 1986). Three isotopes are of importance here, strontium-86 ($^{86}$Sr), which is stable, strontium-87 ($^{87}$Sr) which is stable, and rubidium-87 ($^{87}$Rb) which is unstable and decays over geological time into $^{87}$Sr, with a half-life of approximately 49 billion years (Faure 1986; Slovak and Paytan 2011). As a result, $^{87}$Sr is radiogenic, and increases in abundance relative to $^{86}$Sr in geological formations or soils over time (i.e., $^{87}$Sr/$^{86}$Sr increases slowly with geological time). The absolute value of $^{87}$Sr/$^{86}$Sr is dependent on the initial concentrations of Sr and Rb, as well as the geological age of the formation. A mixture of inputs from the geological and hydrological cycles produce distinct strontium signatures for a local environment (Figure 4.2).

In living organisms, strontium can substitute for calcium in biomolecules (e.g., hydroxyapatite) due to similar chemical properties (Price et al. 2008; Slovak and Paytan 2011). Plants acquire strontium from the soil and pass it up through the food chain. Since there is little difference in mass between the two isotopes, fractionation of strontium within living organisms is negligible. Therefore, $^{87}$Sr/$^{86}$Sr values in biological tissues represent the geochemical origin of the bedrock from which the soils were formed.

The $^{87}$Sr/$^{86}$Sr value of modern seawater is shaped by the precipitation of strontium into sediments and then dissolution into waters which flow to the oceans and is set globally at 0.7092 (Faure 1977; Slovak and Paytan 2011; Veizer 1989). Therefore, the use of strontium isotopes to evaluate human mobility in populations relying primarily on marine resources is generally unproductive since those individuals' $^{87}$Sr/$^{86}$Sr values manifest the marine signature and not the local bedrock $^{87}$Sr/$^{86}$Sr composition (Slovak and Paytan 2011; Veizer 1989). Ericson (1985) was the first to illustrate how radiogenic isotope analysis of human bone and teeth could be used to assess prehistoric human mobility, and it has become increasingly applied in bioarchaeological studies (Beehr 2011; Eerkens et al. 2014; Haak et al. 2008; Harold et al. 2016; Jorgenson 2012; Laffoon 2012; Laffoon and de Vos 2011; Price et al. 2004; Richards et al. 2007; Slovak and Paytan 2011; Tung and Knudson 2011; Welton 2011).

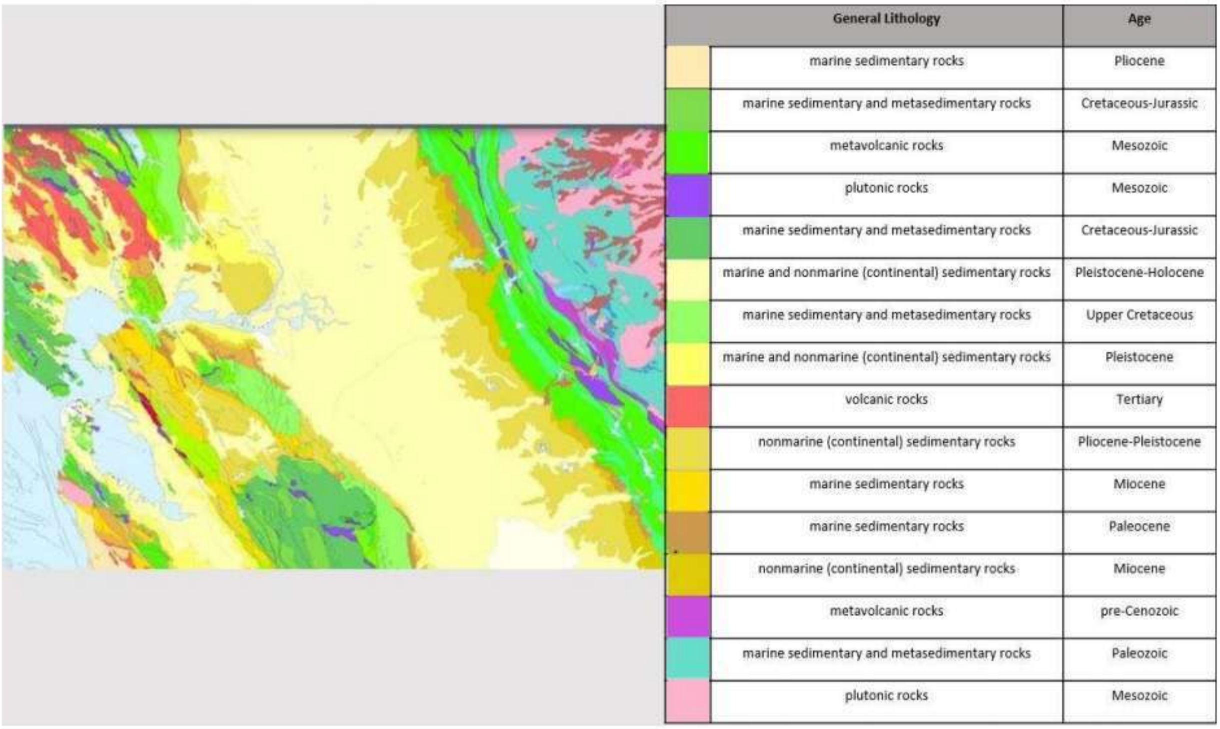

*Figure 4. 2 Geologic map of central California showing general lithology and age of formations (modified from Jennings et al. 2015, California Geological Survey).*

### *Stable Oxygen Isotopes*

The relative abundance of oxygen-18 ($^{18}$O) to oxygen-16 ($^{16}$O) is expressed using the delta notation (i.e., $\delta^{18}$O), relative to an international standard, and reported in per mil (‰). Oxygen is incorporated into the tissues of most organisms predominately through drinking water, but also from atmospheric oxygen and water from food (Bryant et al. 1996; Longinelli 1984; Kohn 1996; Sponheimer and Lee-Thorp 1999). $\delta^{18}$O discrimination in different dietary resources are particularly influential on the stable oxygen isotopic values for mammals that acquire all of their water from food (Sponheimer and Lee-Thorp 1999). For instance, oxygen isotope values of leaves show greater enrichment of $^{18}O$ than those in the roots and stem; higher $\delta^{18}O$ values are also reported for plant leaves compared to animal-derived foods. Some studies suggest that herbivores with different consumption patterns (e.g., grazers versus browsers) differ in their $\delta^{18}O$ values by as much as 8–9 ‰ (Sponheimer and Lee-Thorp 1999). Other studies imply that oxygen transport through the body is impacted by physiologic conditions (e.g., anemia and consequences of smoking) and influences $\delta^{18}O$ in human tissues (Reitsema 2015). For example, the diffusion of oxygen across calloused pulmonary membranes in smokers is slower than for individuals with healthy tissues; this increases the time during which fractionation takes place and results in greater diet-tissue offsets in $\delta^{18}O$ (Reitsema 2015). More research is needed to better understand the influence of diet and physiology on stable oxygen composition of animal tissues (Sponheimer and Lee-Thorp 1999).

Fractionation during evaporation, condensation, and precipitation in the hydrological cycle produces regional patterns of $\delta^{18}O$ (Katzenberg 2008; Longinelli 1984; Reitsema 2015; Sponheimer and Lee-Thorp 1999). The mean annual $\delta^{18}O$ in precipitation is affected by latitude and altitude because the fractionation factor for oxygen demonstrates an inverse dependence on temperature. During evaporation, $^{16}O$ is preferentially used so that water vapor is depleted in $^{18}O$ compared to ocean water (Katzenberg 2008; Longinelli 1984; Reitsema 2015; Sponheimer and Lee-Thorp 1999). Conversely, $^{18}O$ condenses first so that precipitation is enriched in $^{18}O$ compared to the water vapor that remains in clouds. As a result, environments where evaporation rates are high (e.g., lochs and lakes) show higher $\delta^{18}O$ values than those where evaporation is low (e.g., aquifers) (Reistema 2015). The same process causes heavier $^{18}O$ to precipitate first as rainclouds pass over a landscape. As a result, there is a gradual decrease in $\delta^{18}O$ the further away from the coast that precipitation falls. This pattern is reflected in California along an east-west gradient (Figure 4.3; Kendall and Coplen 2001; Unikrishna et al. 2002).

Humans that obtain their drinking water further to the east in California will generally have lower $\delta^{18}O$ values.

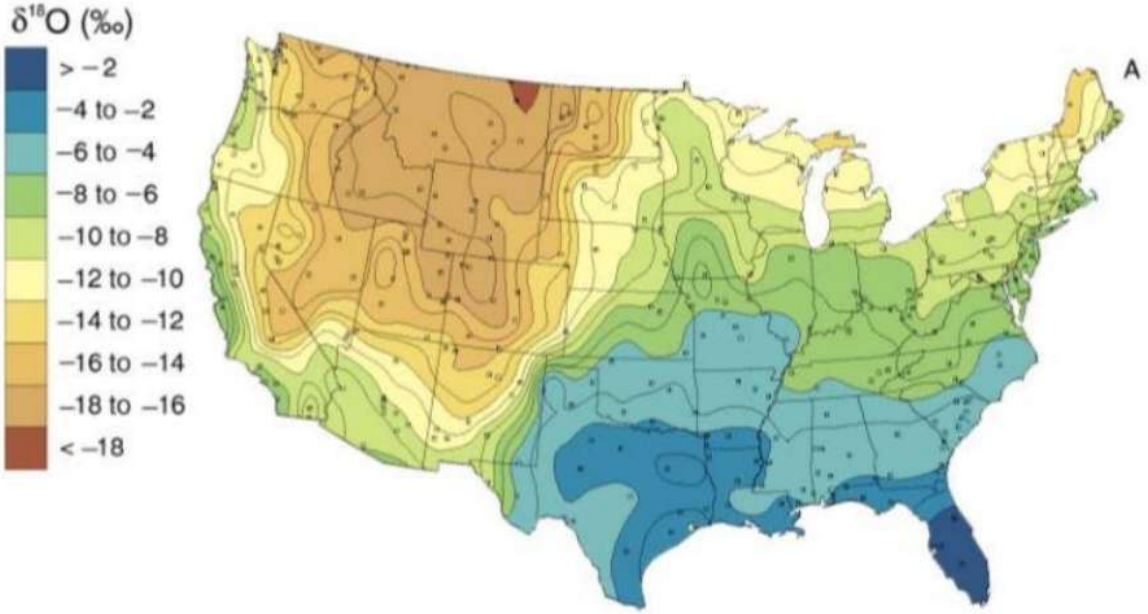

*Figure 4. 3 Distribution of $\delta^{18}O$ values in river water in the continental United States (From Kendall and Coplen 2001: Figure 6)*

*Stable Sulfur Isotopes*

There are three major reservoirs of sulfur in nature (Newton and Bottrell 2007) which include oceanic dissolved sulfates ($SO_4$) in the hydrosphere, evaporitic $SO_4$, and pyrite ($FeS_2$) in the geosphere (Nehlich 2014). Additionally, there are minor reservoirs which include the atmosphere, biomass (such as fossil fuels) and soils. "Inorganic environmental sulfur cycles through weathering, evaporation, rainfall, and tectonic movements" (Nehlich 2014: 1), and is modified by microorganisms and bacteria through the oxidation/reduction of sulfur atoms (Bottrell and Newton 2006). In nature, there are four stable isotopes of the element sulfur, sulfur-32 ($^{32}S$), sulfur-34 ($^{34}S$), sulfur-33 ($^{33}S$), and sulfur-36 ($^{36}S$) (Nier 1938; Faure 1986). Conventionally, the relative abundance of the heavier $^{34}S$ compared to the lighter $^{32}S$

is examined and expressed as $\delta^{34}S$. Sulfur in collagen is contained in the amino acid methionine, which plays an important role in protein structure in the tissues of organisms (Ingenbleek 2006). A study conducted by Nehlich and Richards (2009) demonstrated that the amount of sulfur in mammalian bone collagen is 0.28 ± 0.07 percent by weight. Since methionine cannot be synthesized by animals, it must be acquired through food (only plants synthesize methionine), making it an essential amino acid for humans.

Local environmental conditions shape $\delta^{34}S$ values in plant tissues including the underlying geology, soil salinity, and climate (Nehlich et al. 2014; Oelze et al. 2012; Reitsema 2015). Animals acquire sulfur from dietary protein (both plant and other animal resources). There is little to no fractionation of sulfur between the diet and the consumer. Therefore, sulfur isotope values of bone collagen reflect the average bioavailable sulfur isotope composition of the environment in which the base of the food chain, plants, are grown. $\delta^{34}S$ values are highly variable for bedrock ranging from about -40 to 40‰ (Nehlich et al. 2014; Thode 1991). Freshwater and terrestrial resources reflect this variability (typically ranging between -20 and 20‰), while marine resources show high $\delta^{34}S$ values (e.g., ~20‰) (Bartelink and Chesson 2019; Nehlich and Richards 2009; Nehlich et al. 2014). As well, coastal resources show elevated $\delta^{34}S$ values due to the "sea spray" effect or the influence of oceanic sulphates (Nehlich et al. 2014; Reitsema 2015). In recent years, sulfur has been increasingly used for the reconstruction of mobility patterns of past populations (Bentley 2006; Nehlich 2014; Oelze et al. 2012; Vika 2009).

## Discussion

Stable carbon and nitrogen isotopic studies evaluating paleodiets of Early Period populations have been conducted in central California (Bartelink 2006, 2009; Bartelink et al. 2020; Barton et al. 2020; Eerkens et al. 2020; Ralston et al. 2016). Bartelink et al. (2020) report regional dietary variation in central California by examining $\delta^{15}N$ and $\delta^{13}C$ of bone collagen, and $\delta^{13}C$ of bone apatite from 238 burials from CA-CCO-548 (Marsh Creek), which dates to between 5420 and 2975 cal BP, and comparing results to previously published paleodietary isotopic studies. This study found that dietary isotopes at the Marsh Creek site suggest a reliance on terrestrial $C_3$ resources and freshwater fish. In particular, mean $\delta^{13}C$ (−19.8 ± 0.6‰) and mean $\delta^{15}N$ (9.5 ± 1.0‰) from the Marsh Creek population are most consistent with freshwater fish-flesh mean values once diet-to-tissue offset and trophic effects are taken into account (-18.9‰ and 10.7‰ for $\delta^{13}C$ and $\delta^{15}N$, respectively). A linear mixing model predicts that approximately 86% of gross dietary protein is derived from freshwater and $C_3$ ecosystems, while only about 14% comes from marine sources (Bartelink et al. 2020). Therefore, marine contributions to the diet of the Marsh Creek population are minimal and are most likely obtained from brackish environs close to the mouth of the San Francisco Bay estuary or, perhaps, acquired through trade (Bartelink et al. 2020).

While $\delta^{13}C$ and $\delta^{15}N$ of bone collagen at Marsh Creek suggest that the source of dietary protein is consistent between 5420 and 2975 cal BP, $\delta^{13}C$ of bone apatite reveals a dietary shift over time. Specifically, bioapatite $\delta^{13}C$ suggests that by 3000 cal BP, the Marsh Creek population incorporated more $^{13}C$-depleted $C_3$ plants (e.g., acorns) in their diet (Bartelink et al. 2020). This finding is consistent with resource intensification models (Basgall 1987; Beaton 1991; Broughton 1994a, 1994b) and paleobotanical remains at the site, which show an increase in acorns relative to small seeds (Wohlgemuth 2010).

Bartelink et al. (2020) compared dietary $\delta^{13}C$ and $\delta^{15}N$ evidence from CA-CCO-548 to nine other Early Period populations (CA-CCO-637, CA-CCO-696, CA-SCL-928, CA-SJO-68, CA-SJO-112, CA-SJO-142, CA-SOL-69, CA-SOL-315, and CA-ALA-307); these comparisons yielded regional dietary patterns for central California. Data generated from Marsh Creek is most compatible with sites located in Contra Costa and Solano counties (Bartelink et al. 2020; Eerkens et al. 2020; Ralston et al. 2016). They show lower $\delta^{13}C$ but higher $\delta^{15}N$, which is consonant with dietary protein from brackish water ecosystems

(Bartelink et al. 2020; Eerkens et al. 2013). Dietary isotope evidence from Early Period populations in Contra Costa and Solano counties are markedly different than that observed for the San Francisco Bay Area (CA-ALA-307) and in the Delta (CA-SJO-68 and CA-SJO-142) (Bartelink 2006; Bartelink et al. 2020). Data from the CA-ALA-307 population indicates greater consumption of marine resources. Sites in the Delta, including previously reported data (Bartelink 2006) from one site evaluated in this dissertation research (CA-SJO-68), show isotope values consistent with terrestrial $C_3$ diets. Additionally, they show greater enrichment in $^{15}N$ than other sites in the Central Valley, which implies greater consumption of higher trophic-level resources, likely freshwater fish (Bartelink et al. 2020).

Using isotopic evidence to compare male and female mobility profiles is a valuable method to evaluate the extent to which observed ethnographic patterns apply to the past and have been increasingly employed in California (Burns et al. 2012; Eerkens and Bartelink 2020; Eerkens et al. 2014a, 2014b, 2015, 2016; Harold et al. 2016; Jorgenson 2012). Burns et al. (2012) evaluated diachronic and regional postmarital residence patterns in central California utilizing an ANOVA analysis of $\delta^{18}O$ of bone apatite from four Early Period (CA-SJO-142, CA-SJO-68, CA-SJO-56, and CA-ALA-307), six Middle Period (CA-SAC-43, CA-SAC-60, CASJO-154, CA-ALA-309, CA-ALA-329, and CA-ALA-328), and five Late Period (CA-SAC-43, CA-SAC-60, CA-SAC-06, CA-ALA-309, and CA-ALA-329) components. While Early Period populations from the San Francisco Bay region show a preference for matrilocality, those from the Central Valley are characterized by endogamy (Burns et al. 2012). During the Middle Period, populations in the Central Valley show a strong preference for patrilocality. In contrast, Middle Period populations living near the San Francisco Bay demonstrate a shift from matrilocality to patrilocality with evidence for increasing endogamy into the Late Period (Burns et al. 2012).

Two studies (Harold et al. 2016; Jorgenson 2012) examined postmarital residence patterns of Early Period populations in central California using $^{87}Sr/^{86}Sr$ to generate individual-level mobility profiles. Based on $^{87}Sr/^{86}Sr$ of early-forming teeth (e.g., first molars, incisors, and canines), third molars, and bone from eight females and ten males, Harold et al. (2016) demonstrated that the population from archaeological site CA-SJO-112 likely practiced patrilocality. Sixty percent of males show "local" $^{87}Sr/^{86}Sr$ values of enamel from early-forming teeth but "nonlocal" values of third molars, while two males (20%) show "local" $^{87}Sr/^{86}Sr$ values for all sampled tooth enamel. Therefore, about 80% of males from CA-SJO-112 lived locally during their early childhood and adult years. Comparably, most females (75%) show "nonlocal" values of tooth enamel, a pattern consistent with women dispersing from their natal villages to later live as adults at CA-SJO-112. Additionally, the data suggest that females likely emigrated from similar areas before moving to the site, as evidenced by the range of $^{87}Sr/^{86}Sr$ values, indicating they previously lived in environments with similarly available strontium sources.

The $^{87}Sr/^{86}Sr$ values of third molar enamel from males (60%) showing a local ⇢ nonlocal ⇢ local mobility profile correspond with the "natal region" signature for females. This implies that during late childhood or early adolescence, the males from CA-SJO-112 left their local area to reside in the "natal region" of immigrant females before returning to their home village as adults. Harold et al. (2016) suggest that this pattern represents mobility associated with the performance of bride service in which males, at puberty and until approximately 16 years of age, migrate to villages where their future wives live to carry out these duties.

Using $^{87}Sr/^{86}Sr$ of tooth enamel and bone apatite, Jorgenson (2012) evaluated postmarital residence of a burial population from the Marsh Creek site (CA-CCO-548). Data from this study demonstrated that 40% of males (n = 35) and 22% of females (n = 23) show "nonlocal" values during the Marsh Creek 3 phase (3340–3900 cal BP) (Jorgenson 2012:149-150). Approximately 74% of immigrants (n = 19) are male (n = 14) at Marsh Creek during that time. During the Marsh Creek 4 phase (2900–3300 cal BP), the proportion of immigrants is coequal between the identified sexes, with about 54% of males (n = 13) and 41% of females (n = 17) showing "nonlocal" $^{87}Sr/^{86}Sr$ values (Jorgenson 2012:149–150). In other words, there is a shift from a slight preference for matrilocality towards ambilocality overtime at the Marsh Creek site (Jorgenson 2012). There is a lower percentage of "nonlocals," but greater variation in $^{87}Sr/^{86}Sr$ values reported for the Marsh Creek 3 phase. This suggests that while there is a lower incidence of immigration at that time, those migrants came from a broader range of areas than during the Marsh Creek 4 phase.

The different postmarital residence patterns reported for contemporaneous archaeological sites, CA-SJO-112 and CA-CCO-548, are unexpected. Given that both sites are located in proximity to each other and date to the Early Period, it was expected that the two villages were intermarrying and, therefore, should have been practicing comparable postmarital residence rules. However, the results suggest different postmarital residence practices, and hence, that SJO-112 and CCO-548 belonged to different marriage exchange networks. More data are needed from other archaeological sites to clarify Early Period interaction spheres. This dissertation research is a step towards acquiring necessary information for understanding synchronic patterns of postmarital residence, by examining two additional Early Period sites in the region. Additionally, a multi-isotope approach improves the ability to assess the origins of individuals in a population—as well as lessens ambiguity in determining non-locals—than studies that rely on fewer or a single isotopic system(s).

# CHAPTER V. MATERIALS AND METHODS

This study focuses on reconstructing sex-biased mobility profiles and diet using stable isotope analysis of skeletal samples from CA-SAC-107 and CA-SJO-68. Results are used to evaluate hypothesized postmarital residence patterns and investigate their relationship to diet and subsistence. This chapter outlines the sample selection process of human skeletal remains curated at the Phoebe A. Hearst Museum of Anthropology (PAHMA). Next, procedures for pre-chemical processing of samples are discussed, followed by a description of chemical methods, equipment, and facilities contingent on the type of isotopic analysis conducted. Finally, the chapter concludes by outlining the statistical tests used to evaluate the study's hypotheses.

## PAHMA CA-SAC-107 and CA-SJO-68 Skeletal Collections

The Phoebe A. Hearst Museum of Anthropology (PAHMA) at the University of California, Berkeley campus, curates human remains and artifacts from archaeological sites CA-SAC-107 and CA-SJO-68. The PAHMA director, Dr. Benjamin Porter (2015–2019), and museum staff granted permission to conduct isotopic analyses on human skeletal remains in full compliance with the Native American Graves Protection and Repatriation Act (NAGPRA).

Records made available through the Hearst Museum Portal (https://portal.hearstmuseum.berkeley.edu/) show that there are a minimum of 267 individuals represented in the collections from archaeological site CA-SJO-68, and a minimum of 170 individuals from CA-SAC-107. Representation of skeletal remains ranges from a single element to nearly complete skeletons. Age and sex estimates of individuals were previously assessed by other researchers, PAHMA staff, and UC Berkeley students. As part of projects associated with preparing NAGPRA inventories, students, staff, and consultants updated these evaluations in the mid-1990s.

Sexually diagnostic characteristics of the cranium and pelvis were used to estimate sex. Features of the pelvis, including subpubic concavity, sciatic notch, ventral arc, ischiopubic ramus ridge, and preauricular sulcus, are demonstrated to have an accuracy of about 95 percent when used to estimate sex (Phenice 1969; Walker 2005; White et al. 2012: 415-418). Sexually diagnostic characteristics of the cranium, including mastoid process, glabella, supra-orbital ridge, nuchal crest, and mental eminence, were scored using a five-point ordinal scale, which represents a range from the most gracile to the most robust (Buikstra and Ubelaker 1994). Overall, blind studies on individuals with known sex show that the use of non-metric criteria of the skull is correct between 80 to 90 percent of the time (Spradley and Jantz 2011; White et al. 2012: 408).

There are 123 individuals from SJO-68 curated at the PAHMA with sexually diagnostic skeletal features available to estimate sex; approximately 46% of these individuals are female (n = 57), and 54% are male (n = 66) (Figure 5.1). Fifty-seven individuals with sex estimations from the SAC-107 burial population reveal 32 females (56%) and 25 males (44%) (Figure 5.1).

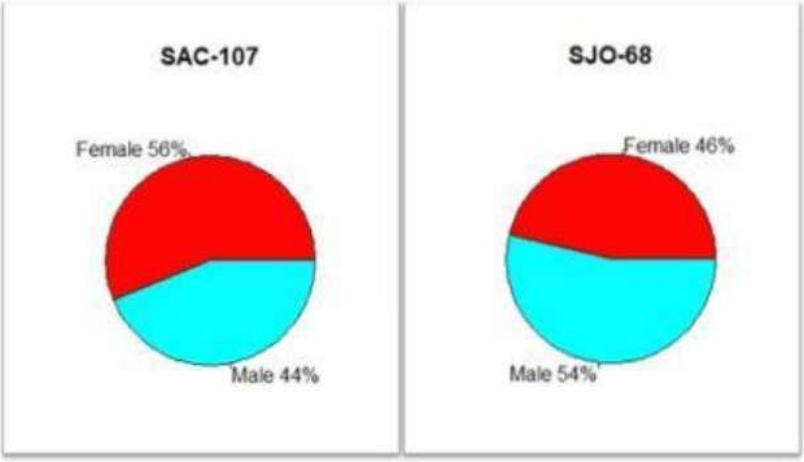

*Figure 5. 1 Pie charts showing proportion of females and males for the PAHMA CA-SAC-107 and CA-SJO-68 skeletal collections*

Age assessments of 147 individuals from SAC-107 demonstrate that approximately 75% are adults (110) and 25% are subadults (n = 37) (Figure 5.2). Within the subadult category, one infant (less than one year of age) is recorded, 12 are between one to five years of age, five between ages 6 and 10, ten between ages 11 and 15, and nine between ages 16 and 20. Forty-four individuals from CA-SAC-107 are recorded as 'adult' (without a specific numerical age provided), 25 fall within 20 and 35 years of age, and 41 individuals are aged 36 to 50 years.

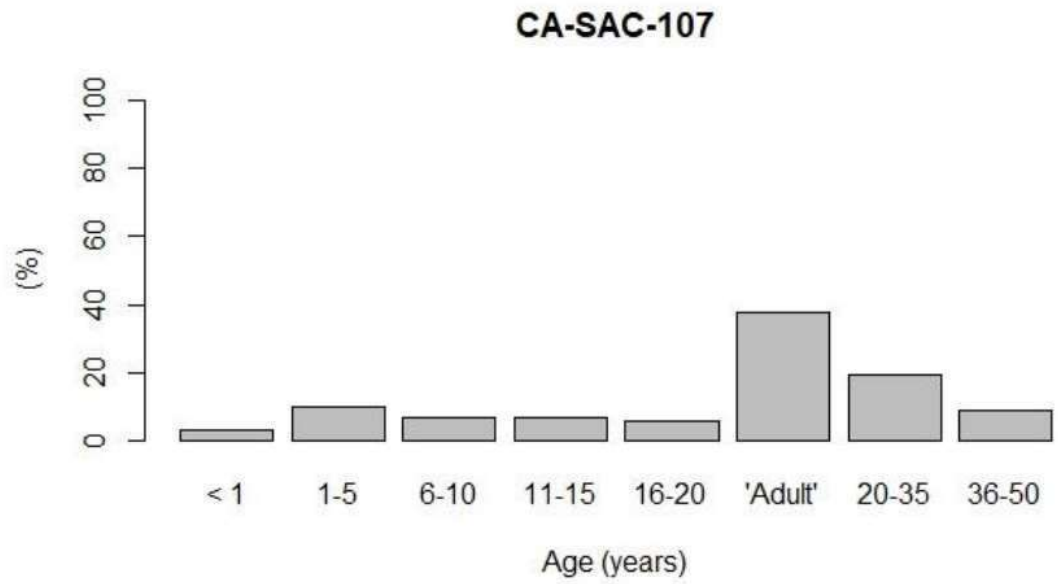

*Figure 5. 2 Distribution of PAHMA CA-SAC-107 human remains collection by age category*

Two hundred and sixty-five individuals from SJO-68 with age assessments show 66% adults (n = 175) and 34% subadults (n = 90) (Figure 5.3). Within the subadult category, one individual is recorded as 'immature,' nine are infants (less than one year of age), 26 fall within ages one through five years, 19 between ages 6 and 10, 19 between ages 11 and 15, and 16 between ages 16 and 20. One hundred individuals from SJO-68 are recorded as 'adult' (without a specific numerical age provided), 52 fall within 20 and 35 years of age, and 23 individuals are aged 36 to 50.

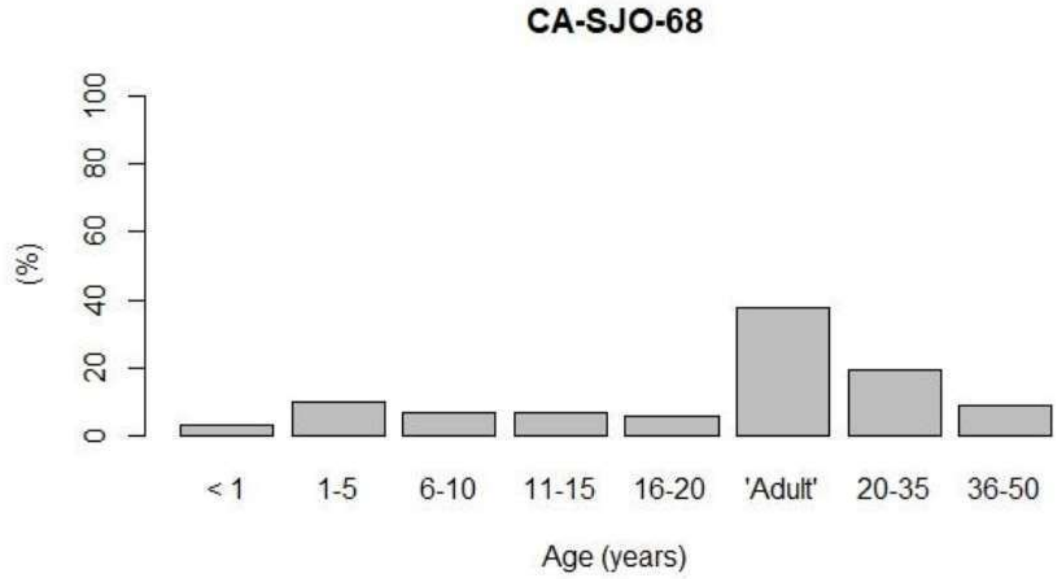

*Figure 5. 3 Distribution of PAHMA CA-SJO-68 human remains collection by age category*

In consultation with museum staff, adult individuals with confident sex assessments were selected to study diet and potential sex-biased mobility using isotopic analysis. As part of the selection process, previous osteological assessments were reevaluated. In addition to selecting individuals with sufficiently complete skeletal remains to dependably assess sex, individuals with a first and third molar and bone fragment (2–3 grams) available for study were preferentially selected. Samples also had to meet the selection criteria established by the PAHMA (e.g., teeth must be loose and lack pathology, preferential selection of rib fragments). After skeletal remains were evaluated according to selection criteria established by both the PAHMA and the study's research design, ten females and six males from SAC-107 (Table 5.1), and 12 females and 15 males from SJO-68 (Table 5.2) were sampled.

*Table 5. 1 Burials Sampled from Archaeological Site CA-SAC-107*

| PAHMA # | Original Burial # | Age | Sex | Burial Depth (cm) | Burial Mode | Burial Orientation | Bone Sampled* | Tooth Sampled |
|---|---|---|---|---|---|---|---|---|
| 12-5589.1 | 2 | 41 | Female | 73.7 | Ventral extension | West | $Y^{\ddagger}$ | $C_1$ |
| 12-5598(0) | 9 | 35 | Male | 119.4 | Ventral extension | Southwest | $Y^{\ddagger}$ | N |
| 12-5600(0) | — | 45 | Male | — | — | — | $Y^{\ddagger}$ | $I_2$, $M_3$ |
| 12-5610.1 | 18 | 40 | Female | 106.7 | Ventral extension | West | $Y^{\ddagger}$ | N |
| 12-5615(0) | — | 17 | Female | — | — | — | N | $M^{1\ddagger}$ |
| 12-5616.3 | 22 | 45 | Female | — | Ventral extension | West | $Y^{\dagger}$ | N |
| 12-7787(0) | S-49 | 45 | Male | 61.0–91.4 | — | — | N | $M_3^{\ddagger}$ |
| 12-7789(0) | S-53 | 21 | Female | 91.4–121.9 | Possible extension | Southwest | N | $M^{1\ddagger}$ |
| 12-7791(0) | S-46 | 45 | Female | 61.0–91.4 | — | Southwest | N | $P_3^{\ddagger}$ |
| 12-7830(0) | S-50 | 40 | Male | 61.0–91.4 | Possible extension | West | N | $P^{3\ddagger}$ |
| 12-7835(0) | S-55 | 45 | Female | 61.0–91.4 | — | — | N | $P^{4\ddagger}$ |
| 12-7867(0) | S-54 | 30 | Female | 91.4–121.9 | Semi-flexed on right side | Northwest | N | $P^{3\ddagger}$, $M^3$ |
| 12-7874(0) | S-51 | 40 | Male | 61.0–91.4 | Possible ventral extension | Southwest | N | $M^{1\ddagger}$ |
| 12-7878(0) | S-30 | 40 | Female | 91.4–121.9 | Possible extension | West | N | $M^{1\ddagger}$ |
| 12-7885(0) | S-29 | 40 | Female | 91.4–121.9 | Ventral, semi-extension | Southwest | N | $M^{1\ddagger}$ |
| 12-7893(0) | S-56 | 35 | Male | 61.0–91.4 | Ventral, flexed | Northeast | N | $M^1$ |

Note: — indicates missing record

[*] rib fragments selected for sampling unless otherwise indicated

[†] previously powdered bone sample

[‡] radiocarbon dated

*Table 5. 2 Burials Sampled from Archaeological Site CA-SJO-68*

| PAHMA # | Original Burial # | Age | Sex | Burial Depth (cm) | Burial Mode | Burial Orientation | Bone Sampled$^{*}$ | Tooth Sampled |
|---|---|---|---|---|---|---|---|---|
| 12-5824(0) | 1 | 42 | Male | 47.0 | Ventral extension | West | $Y^{\ddagger}$ | N |
| 12-5833(0) | 13 | 45 | Male | 114.3 | Dorsal extension | West | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-6472(0) | 16 (41-3) | 25 | Female | 73.7 | Dorsal extension | West | $Y^{\ddagger}$ | $M_1$ |
| 12-7568(0) | 21 | Adult | Male | 68.6 | Right side | Possibly North | N | $M^{1\ddagger}$ |
| 12-7569(0) | 21b | 17 | Female | 68.6 | Dorsal | Possibly North | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7575(0) | 27 | 30 | Female | 121.9 | Ventral extension | West | $Y^{\ddagger}$ | $M_1$, $M_3$ |
| 12-7577 | 29 | Adult | Female | 134.6 | Ventral extension | West | Y | $M^{1\ddagger}$ |
| 12-7581.1 | 33 | 25 | Female | 91.4 | Dorsal extension | West | $Y^{\ddagger}$ | $M^1$ |
| 12-7582(0) | 33a | 29 | Male | 91.4 | — | — | $Y^{\ddagger}$ | $I_2$ |
| 12-7588(0) | 36 | 30 | Female | 45.7 | Ventral extension | West | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7591(0) | 39 | 17 | Male | 38.1 | Dorsal extension | West | Y | $P_3$, $M_3^{\ddagger}$ |
| 12-7598(0) | 46 | 28 | Female | 63.5 | Ventral extension | Southwest | $Y^{\ddagger}$ | $M^1$ |
| 12-7603(0) | 51 | 30 | Male | 116.8 | Ventral extension | Southwest | Y | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7608(0) | 56 | 18 | Female | 114.3 | Dorsal extension | West | $Y^{\ddagger}$ | $M_1$, $M_3$ |
| 12-7613(0) | 61 | 35 | Male | 25.4 | Ventral extension | West | $Y^{\ddagger}$ | $M_1$, $M_3$ |
| 12-7614.1 | 62 | 29 | Male | 86.4 | Ventral extension | West | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7621(0) | 67 | 26 | Male | 91.4 | Dorsal extension | West | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M^{3\ddagger}$ |
| 12-7622.1 | 68 | 24 | Female | 106.7 | Right side, loosely flexed | Northeast | $Y^{\ddagger}$ | $M^1$ |
| 12-7624(0).1 | 70 | 25 | Male | 111.8 | Dorsal extension | West | N | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7634(0) | 79 | 23 | Male | 78.7 | Ventral extension | West | $Y^{\ddagger}$ | $M^{1\ddagger}$, $M_3^{\ddagger}$ |
| 12-7638.1 | 83 | 35 | Female | — | Right side, tightly flexed | Northeast | $Y^{\dagger}$ | $I_1$, $M_3^{\ddagger}$ |
| 12-7640.1 | 85 | 24 | Male | 121.9 | Ventral extension | Northwest | $Y^{\dagger}$ | $M_1^{\ddagger}$, $M^{3\ddagger}$ |
| 12-7646(0) | 91 | 35 | Male | 116.8 | Ventral extension | Northwest | Y | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-7652.1 | 97 | 24 | Male | 33.0 | Dorsal extension | Southwest | $Y^{\ddagger}$ | $M_1^{\ddagger}$, $M_3^{\ddagger}$ |
| 12-8022(0) | 105 | 18 | Male | 83.8 | Dorsal extension | West | $Y^{\ddagger}$ | $M_1$, $M_3$ |
| 12-8024(0) | 108 | 35 | Female | 50.8 | Ventral extension | West | $Y^{\ddagger}$ | $M_1$ |
| 12-8025(0) | 109 | 18 | Female | 132.0 | Dorsal extension | West | Y | $M_1$ |

Note: — indicates missing record

* rib fragments selected for sampling unless otherwise indicated

† previously powdered bone sample

‡ radiocarbon dated

## Laboratory Methods

Biogenic isotope values in bone and dentinal collagen and bone and tooth bioapatite can be diagenetically altered. The chemical element (e.g., oxygen, strontium) and the type of tissue (e.g., bone bioapatite, tooth bioapatite, bone collagen, dentinal collagen) influence the potential for diagenetic contamination over time. The mechanisms that produce these alterations are well-known for bone collagen and bone and tooth enamel bioapatite (Collins et al. 2002; Lee-Thorp and van der Merwe 1987; Schoeninger et al. 2003). Methods are available to monitor the effects and degree of diagenesis for these tissues (Ambrose 1990; Beasley et al. 2014; Roberts et al. 2018). Standard diagenetic checks for bone and dentinal collagen include %C, %N, C:N atomic ratio, and % collagen yield, while those for bone and tooth enamel bioapatite consider %$CO_3$ and FTIR spectral measurements (carbonate to phosphate ratio and infrared splitting factor) to check for calcite and changes in crystallinity parameters (Roberts et al. 2018).

While studies demonstrate approximate *in vivo* isotope values for carbon in bone apatite when appropriate pretreatment protocols are administered, oxygen is more susceptible to diagenetic alteration, and strontium, in particular, is often considered suspect (Bentley 2006; Hedges 2002; Lee-Thorp and Sponheimer 2003; Nelson et al. 1986). Tooth enamel is less affected by diagenesis due to its highly crystalline, nonporous structure, and low organic content (Bentley 2006; Budd et al. 2000; Lee-Thorp and Sponheimer 2003). Numerous strontium isotope studies of tooth enamel demonstrate that ancient samples' biogenic strontium can be recovered with minimal pretreatment (Budd et al. 2000; Hoppe et al. 2003; Horn et al. 1994; Koch et al. 1997; Lee-Thorp and Sponheimer 2003). Bone has a poor crystalline structure, is highly porous, and has a high organic content; therefore, bone apatite is not as resistant to diagenetic changes. Contaminants in the burial matrix (e.g., clay, calcite, and quartz) can leach into pore spaces of bone tissue (Bentley 2006; Roberts et al. 2018). Exogenous strontium can be incorporated during the dissolution and recrystallization of bone mineral. This affects the strontium levels and the ratio of strontium to other elements (e.g., calcium and phosphorus). Therefore, modern plant and shell samples were collected to determine environmental strontium values in place of measurement of strontium in human bone as a geolocational proxy (further details on strontium methods are described later in this chapter).

Before mechanical and chemical processing of samples, each skeletal element was photographed from multiple angles, and dental plaster casts were made of tooth crowns. When feasible, teeth were cut in half using a saw, and one-half of the tooth preserved. The outermost layer of bone was removed using a diamond-grit drill bit. Both bone and tooth samples were cleaned in a deionized $H_2O$ ultrasonic bath for, at a minimum, three five-minute bath rotations. The deionized $H_2O$ was decanted and replaced after each rotation. Once dry, skeletal materials were processed for apatite and collagen extraction. Chemical processing contingent on the type of isotopic analysis to be conducted is described below.

### *Preparation of Bone Apatite and Tooth Enamel for $\delta^{13}C$ and $\delta^{18}O$ Analysis*

For bone, a fragment was ground to a powder using an agate mortar and pestle. For enamel, powder was removed using a diamond-grit drill bit. Approximately 10 mg of sample powder is needed to conduct dual $\delta^{13}C$ and $\delta^{18}O$ analyses. Samples are soaked in 1.5 sodium hypochlorite solution for 48 hours to remove organics (Koch et al. 1997; Sponheimer and Lee-Thorp 1999). This solution is decanted and replaced after 24 hours. Samples are then decanted and rinsed with deionized $H_2O$ prior to adding 0.1 M acetic acid to remove secondary carbonates. Samples soak in this solution for 24 hours, which is replaced once after 12 hours. After chemical cleaning is complete, samples are rinsed thrice with deionized $H_2O$ and dried down.

*Table 5. 3 Stable Isotope Facility (SIF) Laboratory References for $\delta^{13}$C and $\delta^{18}$O of Bone Apatite and Enamel*

| SIF Laboratory Reference | N | $\delta^{13}$C (‰)* | $\delta^{13}$C (‰) Mean† | $\delta^{13}$C (‰) Standard Deviation† | $\delta^{18}$O (‰)* | $\delta^{18}$O (‰) Mean† | $\delta^{18}$O (‰) Standard Deviation† | Comments |
|---|---|---|---|---|---|---|---|---|
| NBS-18 | 36 | -5.01 | -5.02 | 0.13 | -23.01 | -23.01 | 0.11 | Scale correction |
| NBS-19 | 6 | 1.95 | 1.96 | 0.06 | -2.20 | -2.20 | 0.09 | Scale correction |
| LSVEC | 6 | -46.60 | -46.60 | 0.09 | -26.50 | -26.46 | 0.14 | Scale correction |
| G-86 | 6 | -34.95 | -34.99 | 0.13 | -21.42 | -21.39 | 0.13 | Drift and linearity correction |
| IAEA-603 | 6 | 2.46 | 2.41 | 0.12 | -2.37 | -2.39 | 0.09 | Quality control |
| K142-HU (apatite)‡ | 6 | -12.64 | -12.79 | 0.06 | -6.33 | -6.36 | 0.20 | Quality control |
| K156-HU (apatite)‡ | 6 | -10.66 | -10.76 | 0.13 | -5.55 | -5.44 | 0.25 | Quality control |
| NIST 120c (phosphate rock) ‡ | 6 | -6.48 | -6.57 | 0.09 | -2.45 | -2.19 | 0.12 | Quality control |
| Talcott (apatite) ‡ | 6 | -13.70 | -13.63 | 0.04 | -3.10 | -3.43 | 0.29 | Quality control |

Note: *SIF laboratory references are used to calibrate data on the VPDB scale.
†Mean and standard deviation exclude references below limit of quantification (LOQ)
‡Working values of $^{13}$C and $^{18}$O in carbonate (as $CO_2$). Limit of quantitation is approximately 150 nanomoles.

Samples were submitted to the Stable Isotope Facility (SIF) at the University of California, Davis for dual $\delta^{13}$C and $\delta^{18}$O analysis. At the SIF, samples are dried overnight at 60°C in a drying oven before being weighed into 12-ml Labco Exetainer vials and capped. These vials are placed into an autosampler tray set at 70°C. Using a CTC PAL autosampler device, samples in vials are suffused with helium at 100 ml per minute for 10 minutes. Carbon dioxide ($CO_2$) is released from the powdered samples by manually injecting phosphoric acid (103%) into each vial. Vials are put back into the autosampler tray to equilibrate for 24 hours at 30°C. The liberated $CO_2$ is measured using a ThermoFisherScientific GasBench II device with a 100 µl sample loop connected to a ThermoFisherScientific Delta V Plus gas-isotope ratio mass spectrometer.

Interim delta (δ) values of the sample peak are analyzed using a pure $CO_2$ reference gas. These provisional values are amended considering changes of linearity and instrumental drift until laboratory reference materials (Table 5.3) show correct $\delta^{13}C$ and $\delta^{18}O$ values to produce definitive δ values. This method produces a long-term standard deviation of 0.1 ‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{18}O$. The mean standard deviation for sample and reference replicate material for this project, and the mean absolute accuracy for calibrated reference materials are reported in Table 5.4.

*Table 5. 4 Summary Report of $\delta^{13}C$ and $\delta^{18}O$ Reference Materials for this Project*

| | **N** | **$\delta^{13}C$ (‰)** | **$\delta^{18}O$ (‰)** |
|---|---|---|---|
| Mean SD for sample material replicates | 8 | ± 0.08 | ± 0.12 |
| Mean SD for reference material replicates | 84 | ± 0.10 | ± 0.16 |
| Mean absolute accuracy for calibrated reference materials | 84 | ± 0.06 | ± 0.09 |

*Bone and Dentinal Collagen Extraction:*

Approximately 1 gram of cleaned bone was used for collagen extraction. One half of a previously cut and cleaned tooth, with the enamel previously removed for other analyses, was selected to extract dentinal collagen. Cementum was removed from the tooth roots using a diamond-grit bit drill. Collagen extraction followed a modified Longin (1971) method.

Samples were placed in 0.5 M hydrochloric acid (HCl) in 20 ml glass vials. The HCl solution was replaced every 24 to 48 hours until the sample was demineralized. After demineralization was complete, the HCl solution was decanted and discarded, and samples were rinsed three times using deionized $H_2O$. Sodium hydroxide (NaOH) at 0.125 molarity was added to each sample and allowed to soak for 24 hours to remove humic contaminants. After rinsing the samples three times with deionized $H_2O$, samples were placed in water at pH3 (10–3 M hydrochloric acid) and heated in an oven at 70°C for at least 48 hours to solubilize collagen. The pH3 solution was decanted (and deposited in a clean vial) and replaced every 24–48 hours until samples were solubilized entirely. Solubilized collagen was frozen, followed by freezedrying to isolate the collagen fraction. A subset of the collagen from CA-SAC-107 (4 bone and 10 tooth samples) and CA-SJO-68 (18 bone and 26 tooth samples) was submitted to Direct AMS for radiocarbon dating.

### *$\delta^{13}C$ and $\delta^{15}N$ Analysis of Bone Collagen*

Between 1–4 mg of bone collagen was encapsulated in tin (Sn) capsules, placed in a 96-well tray, and submitted to the Stable Isotope Facility (SIF) at the University of California, Davis for dual $\delta^{13}$C and $\delta^{15}$N analyses. Bone collagen was analyzed using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (IRMS). Samples are introduced to a reactor filled with chromium oxide and silvered copper oxide and combusted at 1000°C. Subsequentially, oxides are separated in a reduction reactor using reduced copper at 650°C. Magnesium perchlorate and phosphorous pentoxide, the helium carrier gas, runs through a water trap, and nitrogen gas ($N_2$) and carbon dioxide ($CO_2$) are separated on a Carbosieve GC column set at 65°C and 65 ml per minute before entering the IRMS.

Several duplicates of laboratory reference materials (Tables 5.5 and 5.6) that have been calibrated against international references are used during analysis. The isotope ratio of each sample is calculated and compared to a reference gas peak, corrected according to known values of laboratory reference materials, and final delta values reported relative to international standards for carbon, Vienna Pee Dee Belemnite (VPDB), and nitrogen, Air. This method produces a long-term standard deviation of 0.2‰ for $\delta^{13}$C and 0.3‰ for $\delta^{15}$N. The mean standard deviation for reference materials replicates and mean absolute accuracy for calibrated reference materials for this project are reported in Table 5.7.

*$\delta^{34}$S Analysis of Bone and Dentinal Collagen:*

Between 9–10 mg of bone and dentinal collagen was encapsulated in tin (Sn) capsules, placed in a 96-well tray, and submitted to the SIF for $\delta^{34}$S analysis. Samples are initially combusted at 1150°C in a reactor filled with tungsten oxide, then reduced with elemental copper at 880°C, and later proceed through a buffering reactor packed with quartz chips set at 900°C. To permit complete separation and optimal focusing, sulfur dioxide ($SO_2$) and carbon dioxide ($CO_2$) are separated by purge and trap. The sample $SO_2$ is introduced to the IRMS for measurement by heating the $SO_2$ absorption trap. An Elementar vario ISOTOPE cube interfaced to a SerCon 20–22 isotope-ratio mass spectrometer measures stable isotope ratios of sulfur-34. To correct for potential variation in drift and linearity, replicates of several laboratory reference materials (that are directly calibrated against IAEA S-1, S-2, and S-3, as well as NBS-127, SO-5, and SO-6) are interspersed with samples during analysis (Table 5.8 and 5.9). Interim $\delta^{34}$S values are corrected relative to known values of laboratory reference materials to produce final $\delta^{34}$S values. This method has a long-term reproducibility of ± 0.4‰.

*Table 5. 5 Stable Isotope Facility (SIF) Laboratory References for $\delta^{13}$C of Bone Collagen*

| SIF Laboratory Reference | % C | $\delta^{13}$C (‰)* | $\delta^{13}$C (‰) Mean† | $\delta^{13}$C (‰) Standard Deviation† | Comments |
|---|---|---|---|---|---|
| Caffeine | 47.64 | -35.05 | -35.05 | 0.02 | Scale Normalization |
| Glutamic Acid (GLAC) | 40.82 | -11.07 | -11.07 | 0.04 | Scale Normalization |
| Alfalfa Flour | 42.62 | -29.67 | NA | NA | Linearity Correction, Elemental Totals |
| Chitin | 44.52 | -19.01 | -18.92 | 0.11 | Linearity Correction, Elemental Totals |
| Glutamic Acid (GLU) | 40.82 | -16.70 | NA | NA | Linearity Correction, Elemental Totals |
| Nylon Powder (NYPOW) | | -24.65 | -24.71 | 0.03 | Drift correction |
| Amaranth Flour | 42.11 | -12.89 | -12.89 | 0.08 | Quality Control |
| Bovine Liver | | -21.69 | -21.66 | 0.04 | Quality Control |
| Keratin | 49.31 | -24.46 | -24.31 | 0.05 | Quality Control |

Notes: *SIF laboratory references are used to calibrate data on the VPDB scale.
†Mean and standard deviation exclude references below limit of quantification (LOQ)

*Table 5. 6 Stable Isotope Facility (SIF) Laboratory References for $\delta^{15}N$ of Bone Collagen*

| **SIF Laboratory Reference** | **% N** | **$\delta^{15}N$ (‰)*** | **$\delta^{15}N$ (‰) Mean†** | **$\delta^{15}N$ (‰) Standard Deviation†** | **Comments** |
|---|---|---|---|---|---|
| Enriched Alanine | 15.72 | 41.13 | 41.13 | 0.02 | Scale Normalization |
| Glutamic Acid (GLAC) | 9.52 | -8.53 | -8.53 | 0.04 | Scale Normalization |
| Alfalfa Flour | 4.68 | 1.81 | NA | NA | Linearity Correction, Elemental Totals |
| Chitin | 6.75 | 2.19 | 2.32 | 0.02 | Linearity Correction, Elemental Totals |
| Glutamic Acid (GLU) | 9.52 | -6.80 | NA | NA | Linearity Correction, Elemental Totals |
| Nylon Powder (NYPOW) |  | -1.06 | -1.05 | 0.03 | Drift correction |
| Amaranth Flour | 2.45 | 2.45 | 2.55 | 0.06 | Quality Control |
| Bovine Liver |  | 7.72 | 7.70 | 0.02 | Quality Control |
| Caffeine | 28.35 | -2.81 | -2.86 | 0.03 | Quality Control |
| Keratin | 14.91 | 4.87 | 4.77 | 0.04 | Quality Control |

Note: *SIF laboratory references are used to calibrate data on the AIR scale.
†Mean and standard deviation exclude references below limit of quantification (LOQ)

*Table 5. 7 Summary Report of $\delta^{15}N$ and $\delta^{13}C$ Reference Materials for Two Batches Ran for this Project*

|  | **$\delta^{15}N$ (‰)** | **$\delta^{13}C$ (‰)** |
|---|---|---|
| **Batch 1*** |  |  |
| Mean SD for reference materials replicates | ± 0.03 | ± 0.05 |
| Mean absolute accuracy for calibrated reference materials | ± 0.05 | ± 0.04 |
| **Batch 2†** |  |  |
| Mean SD for reference materials replicates | ± 0.08 | ± 0.03 |
| Mean absolute accuracy for calibrated reference materials | ± 0.03 | ± 0.06 |

Note: *samples submitted on Tray RAL-S107&S68-C.1
†samples submitted on Tray RAL-S68-C.4

*Table 5. 8 Stable Isotope Facility (SIF) Laboratory References and Summary Report for $\delta^{34}$S of Bone and Dentinal Collagen for Batch 1* Ran for this Project*

| SIF Laboratory Reference | % S | $\delta^{34}$S (‰)[†] | $\delta^{34}$S (‰) Mean[‡] | $\delta^{34}$S (‰) Standard Deviation[‡] | Comments |
|---|---|---|---|---|---|
| Cysteine | 26.40 | 34.24 | 34.19 | 0.44 | Scale Normalization |
| Taurine | 26.40 | -2.47 | -2.49 | 0.32 | Scale Normalization |
| Whale Baleen | 3.20 | 17.50 | 17.68 | 0.17 | Linearity Correction, Elemental Totals |
| Hair | 2.19 | 2.70 | 2.46 | 0.19 | Quality Control |
| Mahi-Mahi Muscle | 1.00 | 19.50 | 19.20 | 0.47 | Quality Control |

| | **$\delta^{34}$S (‰)** |
|---|---|
| Mean SD for reference materials replicates | ± 0.32 |
| Mean absolute accuracy for calibrated reference materials | ± 0.16 |

Note: *Samples submitted on Tray RAL-S107&S68-C.2
[†] SIF laboratory references are used to calibrate data on the VCDT scale.
[‡] Mean and standard deviation exclude references below limit of quantification (LOQ)

*Table 5. 9 Stable Isotope Facility (SIF) Laboratory References and Summary Report for $\delta^{34}$S of Bone and Dentinal Collagen for Batch 2* Ran for this Project*

| SIF Laboratory Reference | % S | $\delta^{34}$S (‰)[†] | $\delta^{34}$S (‰) Mean[‡] | $\delta^{34}$S (‰) Standard Deviation[‡] | Comments |
|---|---|---|---|---|---|
| Cysteine | 26.40 | 34.24 | 34.19 | 0.55 | Scale Normalization |
| Taurine | 26.40 | -2.47 | -2.49 | 0.27 | Scale Normalization |
| Whale Baleen | 3.20 | 17.50 | 17.39 | 0.48 | Linearity Correction, Elemental Totals |
| Hair | 2.19 | 2.70 | 2.30 | 0.59 | Quality Control |
| Mahi-Mahi Muscle | 1.00 | 19.50 | 18.82 | 0.55 | Quality Control |

| | δ34S (‰) |
|---|---|
| Mean SD for reference materials replicates | ± 0.48 |
| Mean absolute accuracy for calibrated reference materials | ± 0.25 |

Note: *Samples submitted on Tray RAL-S107S68-C.3
[†] SIF laboratory references are used to calibrate data on the VCDT scale.
[‡] Mean and standard deviation exclude references below limit of quantification (LOQ)

### *Collection and Preparation of Sr-environmental Background Samples*

Locations for collecting environmental strontium-background samples were selected based on a representative sample of local lithology (Figure 5.4) and proximity (approximately 15-mile radius) to archaeological sites CA-SAC-107 and CA-SJO-68. Based on selection criteria, locations chosen for sampling include Big Break Regional Shoreline (MA/CON-SED-1), Cosumnes River Preserve (MA/CON-SED-2), the Mokelumne River near the Comanche Reservoir (CON-SED-3), and along the El Dorado Trail near Bullard, California (METAVOL-4) (Figure 5.4; Table 5.10). Five samples of either local plant material or snail shell were collected (Table 5.11). Before chemical processing, in preparation for analysis by the mass spectrometer, plant and snail shell samples were dry-ashed using equipment at the Primate Ecology and Molecular Anthropology (PEMA) laboratory at the University of California, Santa Cruz.

### *Preparation of Tooth Enamel for $^{87}Sr/^{86}Sr$ Analysis*

Approximately 50 mg of tooth enamel was separated from the sample fraction for $^{87}Sr/^{86}Sr$ analysis. Samples were soaked in 15% hydrogen peroxide for 24 hours to remove organics. After decanting and rinsing with deionized $H_2O$, 0.1 M acetic acid was added, and samples soaked for 24 hours to remove carbonates. The acetic acid solution was decanted and discarded, and samples were rinsed with deionized $H_20$. Dried powdered samples were submitted to the Primate Ecology and Molecular Anthropology (PEMA) laboratory at the University of California, Santa Cruz for $^{87}Sr/^{86}Sr$ analysis.

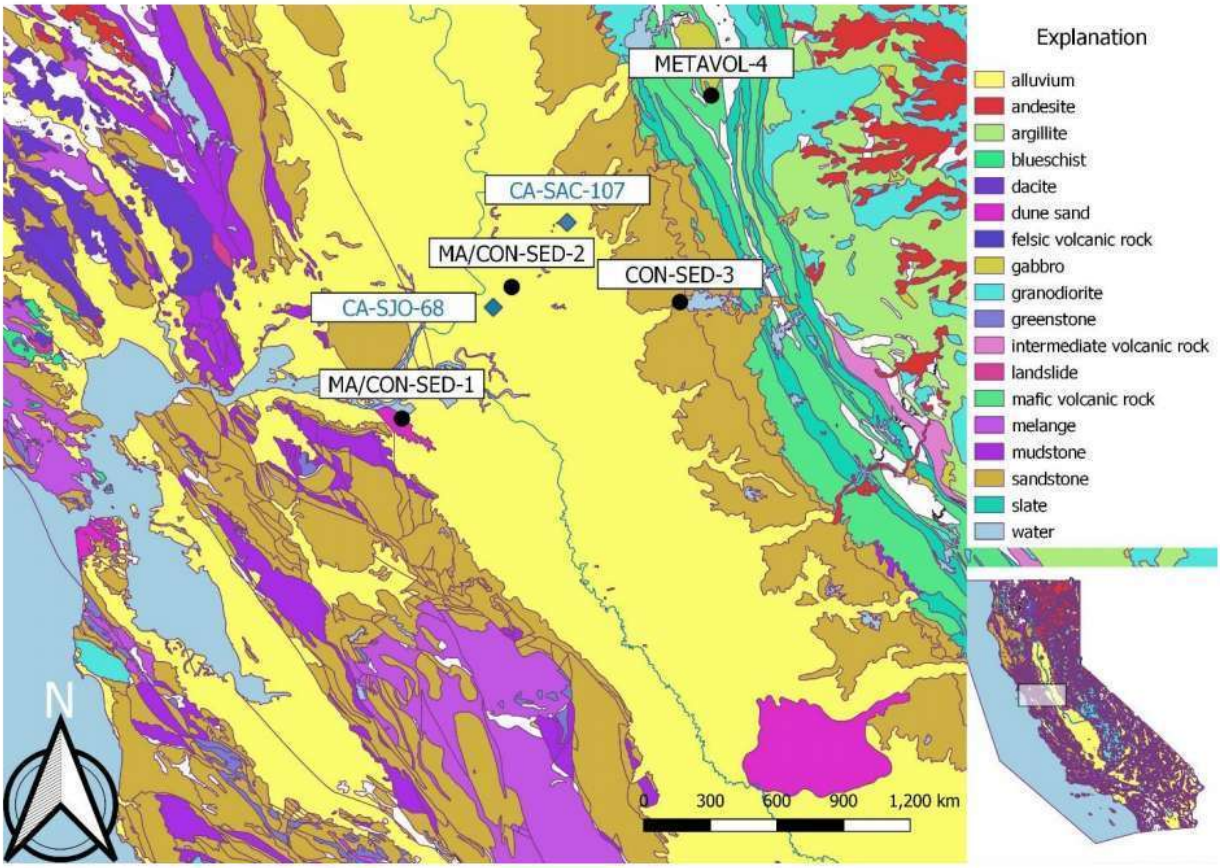

*Figure 5. 4 Geologic map of central California showing Sr-environmental-background sampling locations*

*Table 5. 10 $^{87}Sr/^{86}Sr$ Environmental Background Sampling Sites*

| **Site** | **Area** | **GPS Coordinates** | **General Lithology** | **Age** |
|---|---|---|---|---|
| MA/CON-SED-1 | Big Break Regional Shoreline | 38.011623, -121.725944 | marine and nonmarine (continental) sedimentary rocks | Pleistocene–Holocene |
| MA/CON-SED-2 | Cosumnes River Preserve | 38.259326, -121.429396 | marine and nonmarine (continental) sedimentary rocks | Pleistocene–Holocene |
| CON-SED-3 | Mokelumne River Near Comanche Reservoir | 38.225389, -121.031683 | nonmarine (continental) sedimentary rocks | Pliocene–Pleistocene |
| METAVOL-4 | El Dorado Trail Near Bullard | 38.623173, -120.962995 | metavolcanic rocks | Mesozoic |

*Table 5. 11 $^{87}$Sr/$^{86}$Sr Environmental Background Samples*

| **Area** | **Site** | **Count** | **Coordinates** | **Material** | **Species** |
|---|---|---|---|---|---|
| Cosumnes River Preserve | MA/CON-SED-2 | 1 | 38.25797, -121.43343 | Plant | *Rosa californica* |
| Cosumnes River Preserve | MA/CON-SED-2 | 2 | 38.25794, -121.43347 | Plant | *Quercus sp.* |
| Cosumnes River Preserve | MA/CON-SED-2 | 3 | 38.25777, -121.43380 | Plant | *Quercus sp.* |
| Cosumnes River Preserve | MA/CON-SED-2 | 4 | 38.26197, -121.435 | Plant | *Rubus sp.* |
| Cosumnes River Preserve | MA/CON-SED-2 | 5 | 38.26136, -121.43605 | Plant | *Rubus sp.* |
| Big Break Regional Shoreline | MA/CON-SED-1 | 6 | 38.01033, -121.72475 | Plant | *Rubus sp.* |
| Big Break Regional Shoreline | MA/CON-SED-1 | 7 | 38.01116, -127.72548 | Plant | *Quercus sp.* |
| Big Break Regional Shoreline | MA/CON-SED-1 | 8 | 38.01169, -121.72638 | Plant | Apiaceae |
| Big Break Regional Shoreline | MA/CON-SED-1 | 9 | 38.01124, -121.72718 | Plant | *Rubus sp.* |
| Big Break Regional Shoreline | MA/CON-SED-1 | 10 | 38.01198, -121.72883 | Shell | Gastropoda |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 11 | 38.22541, -121.03106 | Plant | *Quercus sp.* |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 12 | 38.22524, -121.03114 | Plant | *Rubus sp.* |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 13 | 38.22495, -121.03144 | Plant | *Rubus sp.* |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 14 | 38.22494, -121.03158 | Plant | *Quercus sp.* |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 15 | 38.22478, -121.03173 | Plant | *Quercus sp.* |
| El Dorado Trail near Bullard | METAVOL-4 | 16 | 38.62290, -120.96297 | Plant | *Quercus sp.* |
| El Dorado Trail near Bullard | METAVOL-4 | 17 | 38.62385, -120.96346 | Plant | *Quercus sp.* |
| El Dorado Trail near Bullard | METAVOL-4 | 18 | 38.62450, -120.96382 | Plant | *Quercus sp.* |
| El Dorado Trail near Bullard | METAVOL-4 | 19 | 38.62455, -120.96385 | Plant | *Pinus sp.* |
| El Dorado Trail near Bullard | METAVOL-4 | 20 | 38.62285, -120.96282 | Plant | *Arctostaphylos patula* |

### *$^{87}Sr/^{86}Sr$ Analysis of Tooth Enamel and Sr-environmental Background Samples*

Samples were prepared following methods outlined in Deniel and Pin (2001). Powdered tooth enamel and dry-ashed Sr-environmental background samples were transferred to 15 ml perfluoralkoxy (PFA) screw-cap beakers with 1 ml of 29 M hydrofluoric acid (HF) and 0.5 ml of between 7–10 M nitric acid ($HNO_3$). Dissolution of samples was typically complete after a few days on a hot plate set at approximately 80°C. Evaporation of the samples to dryness permitted removing excess HF and volatile silicon tetrafluoride ($SiF_4$). Samples were brought up in 1 ml of 7 M nitric acid ($HNO_3$), warmed for a few hours, and allowed to evaporate to dryness overnight at low temperature. Complete dissolution was achieved by adding between 1–1.5 ml of 2 M nitric acid ($HNO_3$).

Precleaned strontium resin (Sr. Spec. ECM) was added to Teflon columns and washed with approximately 20 ml of 6 M hydrochloric acid (HCl). Columns with resin were subsequentially washed with 2.2 ml of 0.05 M $HNO_3$ before conditioning with 0.3 ml of 2 M $HNO_3$. Dissolved samples are centrifuged, and between 0.5-1 ml of the solution is loaded on the columns, followed by a rinse with 0.4 ml of 2 M $HNO_3$. To elute barium (Ba), samples were washed with 1 ml of between 7–7.5 M $HNO_3$ and two 0.1 ml fractions of 2 M $HNO_3$. Strontium (Sr) was eluted with 1 ml of 0.05 M $HNO_3$. Before eluting lead (Pb) using 1.8–1.5 ml of 5.56–6 M HCL, the Sr. Spec ECM was rinsed three times with 0.1 ml of 2 M HCL. After evaporation to dryness, approximately 2–3 mg of the Sr fraction was loaded with diluted $HNO_3$ and a drop of 3 M phosphoric acid ($H_3PO_4$) onto a single outgassed tantalum filament for mass spectrometric measurements. Table 5.12 reports the PEMA laboratory references for $^{87}Sr/^{86}Sr$ and Table 5.13 reports the Sr concentration of blank ran with samples.

*Table 5. 12 Primate Ecology and Molecular Anthropology (PEMA) Laboratory References for $^{87}Sr/^{86}Sr$ of Tooth Enamel*

| PEMA Standard ID* | $^{87}Sr/^{86}Sr$ | $^{87}Sr/^{86}Sr$ Standard Deviation | $^{87}Sr/^{86}Sr$ Standard Error |
|---|---|---|---|
| 1 | 0.71018 | 0.00690 | 0.0006 |
| 2 | 0.71021 | 0.00700 | 0.0006 |
| 4 | 0.71018 | 0.00710 | 0.0006 |
| 5 | 0.71019 | 0.00670 | 0.0006 |
| 6 | 0.71021 | 0.00770 | 0.0006 |
| Mean | 0.71019 | 0.00708 | 0.0006 |
| Note: *standard SRM 987 | | | |

*Table 5. 13 Summary Report of Procedural Blanks Ran with each Batch* at the Primate Ecology and Molecular Anthropology Laboratory*

| PEMA Blank ID | Sr concentration (ppm) | Sr concentration (ppb) |
|---|---|---|
| B2 | 0.37 | 0.00037 |
| B3 | 0.15 | 0.00015 |
| B4 | 1.88 | 0.00188 |
| B5 | 1.06 | 0.00106 |
| Note: *procedural blanks run with each batch of 10 to 15 samples during sample preparation as part of column chromatography | | |

**Statistical Tests of Hypotheses**

The following section reviews the statistical tests used to address this study's central research question: does the sexual division of labor, and more specifically, the sex-biased subsistence contribution to the overall diet, influence postmarital residence for Early Period populations in the Central Valley of California? This research question relies on the assumption that populations from CA-SAC-107 and CA-SJO-68 resided in relatively sedentary villages and routinely acquired marriage partners from other communities. To investigate the relationship between subsistence practice/diet and postmarital residence patterns using the previously isotopic techniques described above, it is necessary first to evaluate whether populations from CA-SAC-107 and CA-SJO-68 were practicing exogamous marriage. If populations from CA-SAC-107 and CA-SJO-68 practiced exogamous marriage, there should be observable differences between the isotopic mobility profiles representative of childhood/adolescent years versus adulthood (Table 5.14). In cases where both viable bone and tooth data is available (i.e., sulfur and oxygen), a Levene's test for equality of variance will be conducted to test this hypothesis. Since $^{87}Sr/^{86}Sr$ analysis was only conducted on tooth enamel, a Levene's test will be used to compare general mobility between childhood and adolescent/early adulthood. As well, summary statistics, including the population variance and mean, will be presented.

The null hypothesis for hypothesis 1 is that there is no statistically significant difference between the variance of bone [var(bone)] isotopic values compared to those of teeth [var(teeth)] (Table 5.14). If the Levene's test reveals that var(bone) is statistically equivalent to var(teeth) and the variance of isotopic values within each of these categories is high, it is likely that individuals foraged in diverse landscapes with variable sources of available sulfur and oxygen throughout their lifespans. This behavioral correlate is consistent with highly mobile groups that frequently move residential camps.

If the var(bone) and var(teeth) are statistically equivalent, but the variance of isotopic values within each of these categories is low, individuals likely foraged within the same range during the timeframes in which sampled tissues developed. If mean teeth values converge onto mean bone values, this suggests that individuals foraged in or consumed resources from the same locales in adulthood as they had in their youth. Low inter-individual variation and lack of evidence for individuals migrating to the site—as evidenced by comparable mean bone and teeth values—would be consistent with a population with low mobility that lived in sedentary villages and practiced village-endogamy.

The alternative hypothesis for hypothesis 1 is that var(bone) is not statistically equivalent to var(teeth) (Table 5.14). If isotopic values of bone show high variance while the isotopic values of teeth show low variance, it is likely that individuals foraged in environments with the same source of available sulfur and oxygen, while as adults they foraged in diverse landscapes with variable sources of the isotopic systems investigated. Another possibility is that the isotopic values of teeth show high variance while the isotopic values of bone show low variance. In this case, the time frame during which dental tissues developed represent individuals foraging in diverse landscapes with variable sources of sulfur and oxygen. As adults, individuals forage in landscapes with similar isotopic sources. This is consistent with a sedentary population with individuals migrating to the site as adults. If the null hypothesis is rejected and bone values show low variance while teeth values show high variance, this suggests a sedentary, exogamous population; this is the result best suited for testing for sex-biased mobility patterns in hypothesis 2.

*Table 5.14 Null and Alternative Hypotheses of Hypothesis 1 using Levene's Test for Equality of Variance*

| **Hypothesis 1** | Populations from CA-SAC-107 and CA-SJO-68 practiced exogamous marriage causing significant difference between isotopic mobility profiles in childhood/adolescence versus adulthood years. |
|---|---|
| $HO_1$: var(bone) = var(teeth) | Isotope values of both bone and teeth show high variance but are not significantly different. |
| *Behavioral correlates of* $HO_1$: | Individuals forage in diverse landscapes with variable sources of available sulfur and oxygen throughout their lifespans. This is consistent with highly mobile groups who frequently move residential camps. |
| $HO_2$: var(bone) = var(teeth) | Isotope values of both bone and teeth show low variance but are not significantly different. |
| *Behavioral correlates of* $HO_2$: | Individuals forage within the same range during the timeframes in which sampled tissues developed. If mean teeth values converge onto mean bone values, this suggests that individuals forage in or consume resources from the same locales in adulthood as they had in their youth. Low inter-individual variation and lack of evidence for individuals migrating to the site (as evidenced by comparable mean bone and teeth values) is consistent with a population with low mobility, sedentary villages and village-endogamy. |
| $HA_1$: var(bone) ≠ var(teeth) | Isotope values of bone show high variance while isotope values of teeth show low variance. Variance of isotope values of bone and teeth are significantly different. |
| *Behavioral correlates of* $HA_1$: | During the time frame in which dental tissues developed, individuals forage in environments with the same source of available sulfur and oxygen. As adults, individuals forage in diverse landscapes with variable sources of available oxygen, strontium, and sulfur. |
| $HA_2$: var(bone) ≠ var(teeth) | Isotope values of teeth show high variance while isotope value of bone show low variance. Variance of isotope values of bone and teeth are significantly different. |
| *Behavioral correlates of* $HA_2$: | During the time frame in which dental tissues develop, individuals forage in diverse landscapes with variable sources of available sulfur and oxygen. As adults, individuals forage in similar landscapes with similar isotopic sources. This is consistent with a sedentary population with individuals migrating to the site as adults. If the null hypothesis is rejected and bone values show low variance while teeth values show high variance, this suggests a sedentary, exogamous population; this is the result best suited for testing for sex-biased mobility patterns in Hypothesis 2. |

Once the degree of relative mobility is established by testing hypothesis 1, potential unilocal postmarital residence patterns can be evaluated. If populations from CA-SAC-107 and CA-SJO-68 practiced unilocal postmarital residence (e.g., matrilocality or patrilocality), there will be a significant difference between isotopic mobility profiles between males and females (Table 5.15). The Fisher's exact test of independence will be used to statistically compare the relative proportion of non-locals for males versus females. In cases where there is isotopic evidence for both bone and teeth (i.e., sulfur and oxygen), "local" individuals will be defined as those whose tooth isotopic values fall within two standard deviations around mean bone values (the local range), while "non-local" individuals are those whose tooth isotopic values fall outside of the local range. The null hypothesis for this test is that the relative proportion of non-locals is independent of sex and, therefore, mobility profiles are not sex-biased. If the null hypothesis is rejected, the relative proportion of non-locals is dependent on sex, and either: (1) the proportion of male non-locals is significantly higher than female non-locals, or (2) the proportion of female non-locals is significantly higher than male non-locals. These patterns are consistent with matrilocality in the case of the former, and patrilocality for the latter. The $^{87}Sr/^{86}Sr$ of tooth enamel will be compared to those of modern samples from central California to evaluate human geolocation. Additionally, comparisons of general mobility between childhood and adolescence/early adulthood for females *versus* males will be assessed.

*Table 5. 15 Null and Alternative Hypotheses of Hypothesis 2 using Fisher's Exact Test of Independence*

| | |
|---|---|
| **Hypothesis 2:** If populations from CA-SAC-107 and CA-SJO-68 practiced unilocal postmarital residence (e.g., matrilocality or patrilocality), then there will be a significant difference between isotopic mobility profiles of males versus females. | |
| *H0:* The relative proportion of non-locals is independent of sex. | *Behavioral correlates of H0:* Mobility is not sex-biased. |
| If the null hypothesis is rejected, the relative proportion of non-locals is dependent on sex. Either: | |
| (1): The proportion of male non-locals is significantly higher than female non-locals. | *Behavioral correlates:* Mobility is biased towards male dispersal, which is consistent with matrilocality. |
| (2): The proportion of female non-locals is significantly higher than male non-locals. | *Behavioral correlates:* Mobility is biased towards female dispersal, which is consistent with patrilocality. |

If the relative economic importance of male versus female subsistence contributions influences postmarital residence practices, then dietary isotopic signatures consistent with "female labor" should associate with matrilocality while dietary isotopic signatures consistent with "male labor" should associate with patrilocality (hypothesis 3). If certain food resources are economically important, they should comprise the bulk of a population's diet. Therefore, these economically important foods will drive the dietary isotopic signatures for those populations. The ethnographic record for California shows that female subsistence labor is associated with the gathering and processing of plant foods; subsistence based on acorn economies is particularly important. On the other hand, male subsistence practices are associated with hunting and fishing. If female contributions to the subsistence-economy are important and the foods that women procured and processed contribute the bulk to the population's diets, then dietary isotopic signatures should show reliance on low-trophic level, terrestrial resources (Figure 5.5). Conversely, if male contributions to the subsistence-economy are important and the foods that men traditionally acquire contribute to the bulk of a population's diet, then dietary isotopic signatures for that population should show reliance on high-trophic level, terrestrial resources and/or freshwater resources (Figure 5.5).

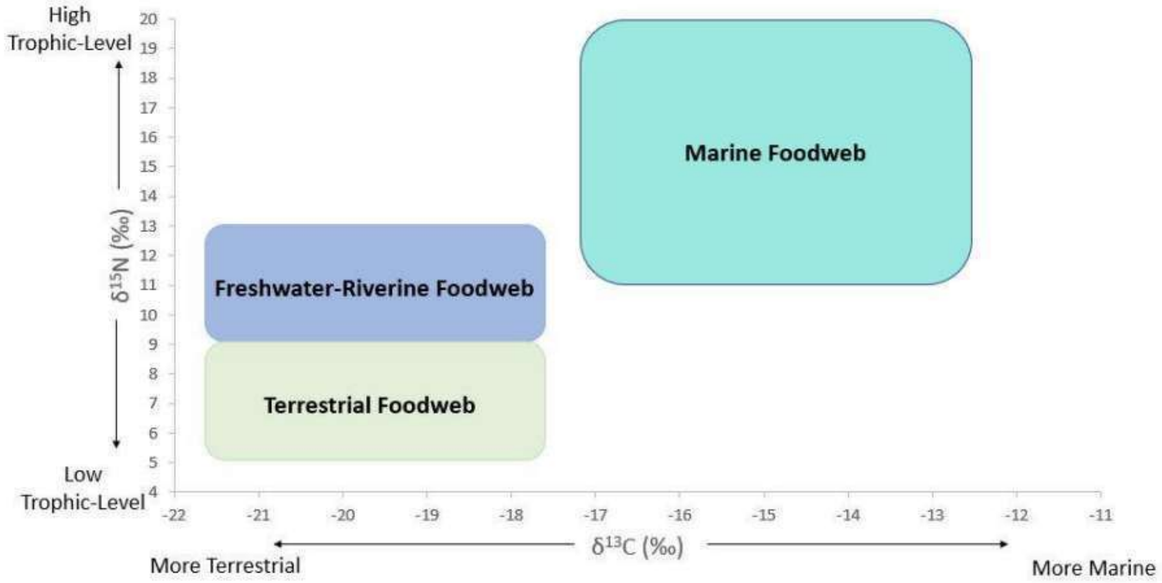

*Figure 5. 5 Approximate $\delta^{15}N$ and $\delta^{13}C$ ranges for terrestrial, freshwater-riverine, and marine food web*

# CHAPTER VI. RESULTS

The objective of this dissertation research is to examine the relationship between the sexual division of labor, and more specifically, the sex-biased contributions to the overall diet, and postmarital residence for two burial populations from CA-SAC-107 and CA-SJO-68 using isotopic evidence. The Windmiller Mound (CA-SAC-107) is a multi-component site with burials associated with the Early through Late Periods; temporal affiliation is predominantly based on diagnostic artifacts and burial position. As noted in Chapter 2, two radiocarbon dates from burials recovered from between 1.0 and 1.5 meters below the surface range between about 2600 and 3200 BP (Breschini et al. 1996; Ragir 1972; Schulz 1981). Based on the reported provenience of burials in records at the PAHMA, samples that likely dated to the Early Period were selected from CA-SAC-107.

Four bone collagen and ten dentinal collagen samples from CA-SAC-107 were submitted to DirectAMS for radiocarbon dating and calibrated using CALIB 8.2 (http://calib.org; Stuiver et al. 2021). Interestingly, radiocarbon dating results reveal assays ranging from about 3427 to 135 BP (Table 6.1). Two bone collagen samples (12-5598(0) and 12-5610.1) show a median probability consistent with the Early Period (Table 6.1). Two bone collagen samples (12-5589.1 and 12-5600(0)) and a first molar dentinal collagen sample (12-7874(0)) reveal median probabilities dating to the Early/Middle Transition (Table 6.1); they are combined with Early Period samples for analysis below. Only one first molar dentinal collagen sample (12-5615(0)) firmly dates to the Middle Period (1411–1569 cal BP), and two dentinal collagen samples (12-7789(0) and 12-7867(0)) with median probabilities dating to the Late Period (Table 6.1). Of particular interest are six burials with radiocarbon assays (median probability < 140 BP) that suggest the Windmiller Mound was continuously used into the Historic Period (Table 6.1). In short, while this study sought to focus on individuals from the Early Period, over half the samples appear to date to later periods.

Eighteen bone collagen and 26 dentinal collagen samples were radiocarbon dated from CA-SJO-68 with median probabilities ranging from 4898 to 3288 cal BP (Table 6.2). All these dates are within the Early Period and are currently the oldest directly dated samples from the Blossom Mound (Table 6.2).

The following sections report the results of isotopic analysis of human skeletal tissues at CA-SAC-107 and CA-SJO-68. First, paleodietary reconstruction focused on bone $\delta^{13}C$ and $\delta^{15}N$, including general patterns and sex comparisons, is presented. Then, the results of analysis of paleomobility using $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ at each site are discussed, including comparisons of female and male mobility profiles, and, in the case of CA-SAC-107, diachronic assessment.

*Table 6. 1 Radiocarbon Dates from CA-SAC-107, Windmiller Mound*

| PAHMA # | D-AMS Code | Material | Radiocarbon age BP | 1-sigma error | Calibrated BP age ranges* | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1-sigma (68.3%)† | 2-sigma (95.4%)† | Median Probability |
| 12-5589.1 | 037957 | Bone collagen | 2506 | 25 | 2347–2432 | 2339–2494 | 2406 |
| 12-5598(0) | 037954 | Bone collagen | 3409 | 28 | 3452–3496 | 3439–3572 | 3493 |
| 12-5600(0) | 037956 | Bone collagen | 2391 | 28 | 2178–2236 | 2153–2270 | 2239 |
| 12-5610.1 | 037955 | Bone collagen | 3427 | 26 | 3487–3573 | 3460–3637 | 3540 |
| 12-5615(0) | 040676 | $M^1$ dentinal collagen | 1741 | 21 | 1510–1543 | 1411–1569 | 1498 |
| 12-7787(0) | 040678 | $M_3$ dentinal collagen | 309 | 21 | 71–115 | 168–278 | 140 |
| 12-7789(0) | 040672 | $M^1$ dentinal collagen | 452 | 22 | 350–413 | 309–469 | 386 |
| 12-7791(0) | 040673 | $P_3$ dentinal collagen | 135 | 20 | ‡ | ‡ | ‡ |
| 12-7830(0) | 040674 | $P^3$ dentinal collagen | 293 | 19 | 60–118 | 0–152 | 116 |
| 12-7835(0) | 040680 | $P^4$ dentinal collagen | 149 | 21 | ‡ | ‡ | ‡ |
| 12-7867(0) | 040675 | $P^3$ dentinal collagen | 426 | 21 | 356–432 | 306–462 | 385 |
| 12-7874(0) | 040679 | $M^1$ dentinal collagen | 2450 | 22 | 2304–2349 | 2295–2355 | 2317 |
| 12-7878(0) | 040671 | $M^1$ dentinal collagen | 354 | 22 | 62–118 | 0–153 | 127 |
| 12-7885(0) | 040677 | $M^1$ dentinal collagen | 164 | 19 | ‡ | ‡ | ‡ |

Notes:

* Calibrated using mixed Marine and NH Atmosphere curve with a reservoir correction of 365 ± 50 (CALIB 8.2; Stuiver et al. 2021). Estimated % marine for each sample is reported in Table 6.3.

† Age ranges with the highest probability are reported here in cases with more than one 1-sigma and 2-sigma intervals.

‡ Valid radiocarbon ages (adjusted for $\Delta$ R) must be between 172 and 50,2000 years BP.

*Table 6. 2 Radiocarbon Dates from CA-SJO-68, Blossom Mound*

| PAHMA # | D-AMS Code | Material | Radiocarbon age BP | 1-sigma error | Calibrated BP age ranges‡ | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1-sigma† (68.3%) | 2-sigma† (95.4%) | Median Probability |
| 12-5824(0) | 038951 | Bone collagen | 3580 | 30 | 3685–3728 | 3619–3834 | 3722 |
| 12-5833(0) | 041235 | Bone collagen | 3571 | 26 | 3614–3696 | 3564–3728 | 3657 |
| 12-5833(0) | 041252 | $M_1$ dentinal collagen | 3657 | 24 | 3823–3885 | 3716–3921 | 3831 |
| 12-5833(0) | 041253 | $M_3$ dentinal collagen | 3658 | 27 | 3723–3797 | 3695–3897 | 3793 |
| 12-6472(0) | 037953 | Bone collagen | 3453 | 27 | 3482–3566 | 3452–3595 | 3528 |
| 12-7575(0) | 038942 | Bone collagen | 3687 | 25 | 3721–3802 | 3691–3892 | 3783 |
| 12-7577 | 041236 | $M^1$ dentinal collagen | 3610 | 23 | 3621–3721 | 3573–3732 | 3677 |
| 12-7568(0) | 041238 | $M^1$ dentinal collagen | 3648 | 24 | 3825–3892 | 3813–3925 | 3843 |
| 12-7581.1 | 041233 | Bone collagen | 3470 | 25 | 3556–3638 | 3484–3644 | 3582 |
| 12-7582(0) | 041234 | Bone collagen | 3776 | 24 | 3883–3978 | 3835–3998 | 3930 |
| 12-7591(0) | 041245 | $M_3$ dentinal collagen | 3132 | 24 | 3242–3308 | 3210–3365 | 3288 |
| 12-7603(0) | 041248 | $M_1$ dentinal collagen | 3536 | 24 | 3578–3646 | 3556 – 3722 | 3633 |
| 12-7603(0) | 041249 | $M_3$ dentinal collagen | 3545 | 24 | 3615–3695 | 3566–3725 | 3655 |
| 12-7638.1 | 041237 | $M_3$ dentinal collagen | 4419 | 25 | 4832–4874 | 4827– 4958 | 4859 |
| 12-7613(0) | 038943 | Bone collagen | 3359 | 26 | 3453–3495 | 3444–3568 | 3490 |
| 12-7614.1 | 038944 | Bone collagen | 3457 | 26 | 3484–3573 | 3457–3637 | 3538 |

| PAHMA # | D-AMS Code | Material | Radiocarbon age BP | 1-sigma error | Calibrated BP age ranges[‡] | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1-sigma[†] (68.3%) | 2-sigma[†] (95.4%) | Median Probability |
| 12-7614.1 | 041258 | $M_1$ dentinal collagen | 3462 | 25 | 3566–3639 | 3548–3691 | 3607 |
| 12-7614.1 | 041259 | $M_3$ dentinal collagen | 3428 | 25 | 3567–3638 | 3548–3650 | 3606 |
| 12-7621(0) | 037952 | Bone collagen | 3493 | 25 | 3550–3637 | 3482–3646 | 3580 |
| 12-7621(0) | 041243 | $M_1$ dentinal collagen | 3508 | 26 | 3613–3648 | 3559–3723 | 3638 |
| 12-7621(0) | 041244 | $M^3$ dentinal collagen | 3444 | 22 | 3489–3572 | 3465–3637 | 3539 |
| 12-7622.1 | 037951 | Bone collagen | 4319 | 28 | 4697–4759 | 4615– 4840 | 4730 |
| 12-7624(0).1 | 041239 | $M_1$ dentinal collagen | 4443 | 25 | 4847–4887 | 4836–4975 | 4898 |
| 12-7624(0).1 | 041240 | $M_3$ dentinal collagen | 4497 | 27 | 4843–4888 | 4831–4976 | 4895 |
| 12-7634(0) | 038946 | Bone collagen | 3583 | 26 | 3581–3651 | 3550–3726 | 3641 |
| 12-7634(0) | 041260 | $M^1$ dentinal collagen | 3510 | 24 | 3573–3642 | 3549–3716 | 3622 |
| 12-7634(0) | 041261 | $M_3$ dentinal collagen | 3562 | 25 | 3617–3717 | 3570–3728 | 3666 |
| 12-7640.1 | 041241 | $M_1$ dentinal collagen | 4318 | 26 | 4519–4646 | 4501–4724 | 4593 |
| 12-7640.1 | 041242 | $M^3$ dentinal collagen | 4219 | 24 | 4465–4517 | 4352–4571 | 4466 |
| 12-7646(0) | 041254 | $M_1$ dentinal collagen | 4180 | 27 | 4506–4572 | 4417–4622 | 4513 |
| 12-7646(0) | 041255 | $M_3$ dentinal collagen | 4194 | 27 | 4506–4576 | 4418–4625 | 4523 |
| 12-7652.1 | 038945 | Bone collagen | 3245 | 25 | 3359–3405 | 3336–3451 | 3388 |
| 12-7652.1 | 041256 | $M_1$ dentinal collagen | 3247 | 24 | 3326–3376 | 3226–3398 | 3330 |

| PAHMA # | D-AMS Code | Material | Radiocarbon age BP | 1-sigma error | Calibrated BP age ranges* | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1-sigma† (68.3%) | 2-sigma† (95.4%) | Median Probability |
| 12-7652.1 | 041257 | $M_3$ dentinal collagen | 3255 | 25 | 3325–3376 | 3223–3398 | 3328 |
| 12-7569(0) | 038947 | Bone collagen | 3696 | 28 | 3827–3920 | 3817–3934 | 3863 |
| 12-7569(0) | 041250 | $M_1$ dentinal collagen | 3769 | 26 | 3908–3991 | 3882–4087 | 3976 |
| 12-7569(0) | 041251 | $M_3$ dentinal collagen | 3714 | 27 | 3850–3928 | 3827–3987 | 3905 |
| 12-7588(0) | 038948 | Bone collagen | 3475 | 28 | 3549–3636 | 3481–3646 | 3577 |
| 12-7588(0) | 041246 | $M_1$ dentinal collagen | 3394 | 23 | 3445–3495 | 3437–3562 | 3474 |
| 12-7588(0) | 041247 | $M_3$ dentinal collagen | 3344 | 23 | 3377–3414 | 3345–3464 | 3407 |
| 12-7598(0) | 038950 | Bone collagen | 3508 | 26 | 3567–3642 | 3546–3695 | 3611 |
| 12-7608(0) | 038949 | Bone collagen | 3474 | 25 | 3492–3542 | 3480–3641 | 3563 |
| 12-8024(0) | 037950 | Bone collagen | 3415 | 28 | 3484–3566 | 3454–3594 | 3529 |
| 12-8022(0) | 041232 | Bone collagen | 3469 | 25 | 3483–3576 | 3459–3638 | 3542 |

Notes:

* Calibrated using mixed Marine and NH Atmosphere curve with a reservoir correction of 365 ± 50 (CALIB 8.2; Stuiver et al. 2021). Estimated % marine for each sample is reported in Table 6.5

† Age ranges with the highest probability are reported here in cases with more than one 1-sigma and 2-sigma intervals.

## Paleodietary Analysis at CA-SAC-107, Windmiller Mound

Only five individuals from the Windmiller Mound had bone that met the PAHMA sampling criteria to conduct isotopic analysis for this project (Table 6.3). Four of the bone samples (Table 6.1) were radiocarbon dated and reveal assays dating to the Early Period and Early/Middle transition (3540–2239 cal BP). The mean human bone collagen $\delta^{13}C$ ($\delta^{13}C_{col}$) of the CA-SAC-107 burial population is -19.7‰ (SD = 0.2) and ranges from -20.1 to -19.6‰ (Table 6.3; Table 6.4). These values are consistent with $C_3$-terrestrial diets. For instance, economically important nuts, seeds, and fruits in central California show mean $\delta^{13}C$ of about -24.7‰ (Bartelink 2006: Table 5.1). Once the diet-to-tissue offset (~5 ‰) reported in the literature (Ambrose and Norr 1993; Tieszen and Fagre 1993) is considered, this value aligns with those reported at CA-SAC-107.

*Table 6. 3 $\delta^{15}C$ and $\delta^{15}N$ Values at CA-SAC-107*

| PAHMA # | Sex | $\delta^{13}C_{col}$ | $\delta^{13}C_{ap}$ | Apatite-Collagen Spacing | $\delta^{15}N$ | % Marine | % Terrestrial | C/N Ratio |
|---|---|---|---|---|---|---|---|---|
| 12-5589.1* | Female | -19.71 | -14.73 | 4.98 | 8.25 | 15 | 85 | 3.3 |
| 12-5598(0)† | Male | -19.62 | -15.04 | 4.58 | 9.13 | 16 | 84 | 3.3 |
| 12-5600(0) * | Male | -19.56 | -15.62 | 3.94 | 8.93 | 16 | 84 | 3.3 |
| 12-5610.1† | Female | -20.13 | -14.06 | 6.07 | 9.56 | 12 | 88 | 3.3 |
| 12-5616.3‡ | Female | -19.71 | -11.76 | 7.95 | 9.07 | 15 | 85 | 3.2 |

Notes:
* Early/Middle Transition
† Early Period
‡ Not directly dated

The human bone apatite $\delta^{13}C$ ($\delta^{13}C_{ap}$) values span from -15.6 to -11.8‰ with a mean of -14.2‰ (SD = 1.5) (Table 6.3; Table 6.4). As discussed in Chapter V, apatite-collagen spacing is influenced by whether dietary protein is relatively enriched, or depleted, in $^{13}C$ relative to the whole diet (including carbohydrates and fats). Because marine resources are more enriched in $^{13}C$ (higher $\delta^{13}C$), an apatite-collagen spacing of less than 4.4‰ can be used as a proxy for marine-based dietary protein. Since the Windmiller Mound is located inland, marine-based protein sources are not anticipated to significantly influence $\delta^{13}$C at CA-SAC-107. However, other $^{13}$C-enriched resources may drive $\delta^{13}$C values. For example, pine tends to grow in environments with deficient water retention and water-stressed plants are relatively enriched in $^{13}$C (Hull et al. 2016; Picon et al. 1996). Individuals living at CA-SAC-107 may have engaged in logistical forays into the nearby foothills of the Sierra Nevada and incorporated pine nuts into the diet, which would shape their $\delta^{13}$C values. The apatite-collagen spacing of the CA-SAC-107 burial population ranges from 3.9 to 8.0‰ with a mean of 5.5‰ (SD = 1.6). Therefore, on average the population from the Windmiller Mound seems to be not reliant on marine-based protein sources. However, one male (12-5600(0)) shows an apatite-collagen spacing of 3.9‰, which is consistent with contributions of at least some marine-based, or other $^{13}$C-enriched resource, to the protein portion of the diet. When a marine-carbon-mixing model (MCM), based on data from Bartelink (2006: Table 5.1; Table 5.2), is used to analyze $\delta^{13}C_{col}$, it suggests that approximately 16% of this male's diet is derived from marine resources. This is consistent with the rest of the CA-SAC-107 burial population (mean = 15%). However, this model assumes that any enrichment in $^{13}$C is derived from marine sources and does not consider other $^{13}$C resources (e.g., pine nuts).

*Table 6. 4 Summary Statistics of $\delta^{13}$C and $\delta^{15}$N at CA-SAC-107*

| | *n* | **Mean** | **SD** | **Range** |
|---|---|---|---|---|
| **Collagen $\delta^{13}$C** | | | | |
| Population | 5 | -19.7 | 0.2 | 0.6 |
| Female | 3 | -19.9 | 0.2 | 0.4 |
| Male | 2 | -19.6 | 0.0 | 0.1 |
| **Apatite $\delta^{13}$C** | | | | |
| Population | 5 | -14.2 | 1.5 | 3.9 |
| Female | 3 | -13.5 | 1.6 | 3.0 |
| Male | 2 | -15.3 | 0.4 | 0.6 |
| **Apatite-Collagen Spacing** | | | | |
| Population | 5 | 5.5 | 1.6 | 4.0 |
| Female | 3 | 6.3 | 1.5 | 3.0 |
| Male | 2 | 4.3 | 0.5 | 0.6 |
| **Collagen $\delta^{15}$N** | | | | |
| Population | 5 | 9.0 | 0.5 | 1.3 |
| Female | 3 | 9.0 | 0.7 | 1.3 |
| Male | 2 | 9.0 | 0.1 | 0.2 |

$\delta^{15}N$ values of bone collagen for the CA-SAC-107 population ranges from 8.3 to 9.6‰ with a mean of 9.0‰ (SD = 0.5) (Table 6.3: Table 6.4). The mean $\delta^{15}N$ value at CA-SAC-107 is approximately 6.5 to 7.0‰ greater than that reported for economically important nuts, seeds, and fruits in central California (Bartelink 2006: 5.1). Sedges and rushes (e.g., tule, California bulrush) in central California show mean $\delta\ ^{15}N$ of 8.3‰ (Bartelink 2006: Table 5.1). A mean $\delta^{15}N$ value of about 5‰ is expected if the CA-SAC-107 population subsisted on a purely herbivorous diet, once the trophic effect is taken into account (between 2–4‰ increase with each trophic level). Mean $\delta^{15}N$ value at CA-SAC-107 are more consistent with those of omnivores (7.1 ± 2.5‰) and obligate carnivores (8.8 ± 1.7‰) in California (Bartelink 2006: Table 5.2).]. Figure 6.1 illustrates a biplot depicting $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen at CA-SAC-107. These values are consistent with a diet focused on terrestrial-game, freshwater fish, and $C_3$ plants.

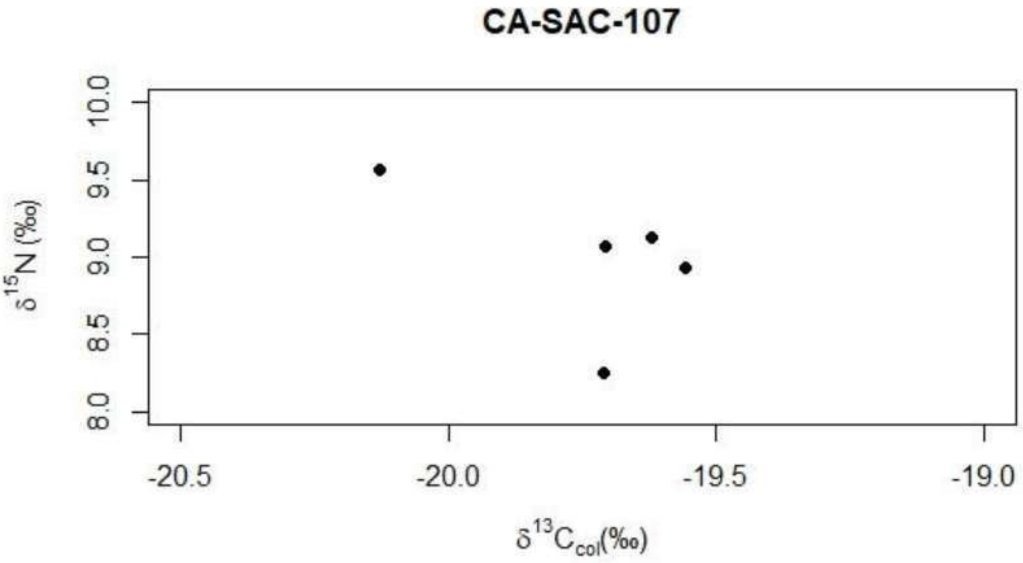

*Figure 6. 1 Biplot showing $\delta^{13}C$ and $\delta^{15}N$ of bone collagen at CA-SAC-107*

Of the five individuals from CA-SAC-107 from whom bone samples were available, three are female and two are male (Table 6.3; Table 6.4). Female and male mean $\delta^{13}C_{col}$ are similar (-19.9‰ and -

19.6‰, respectively) while female mean $\delta^{13}C_{ap}$ (-13.5‰) is 1.8‰ greater than males' (-15.3‰) (Figure 6.2; Figure 6.3; Table 6.3; Table 6.4). One female's (12-5616.3) $\delta^{13}C_{ap}$ value (-11.8‰) is significantly more enriched in $^{13}C$ compared to the rest of the population (2.4‰ greater than population mean $\delta^{13}C_{ap}$ at -14.2‰) (Table 6.3; Table 6.4). This value drives the greater $\delta^{13}C_{ap}$ and variation in the female subset (range = 3.0; SD = 1.6) compared to the males (range = 0.6; SD = 0.4) (Table 6.4; Figure 6.2; Figure 6.3).

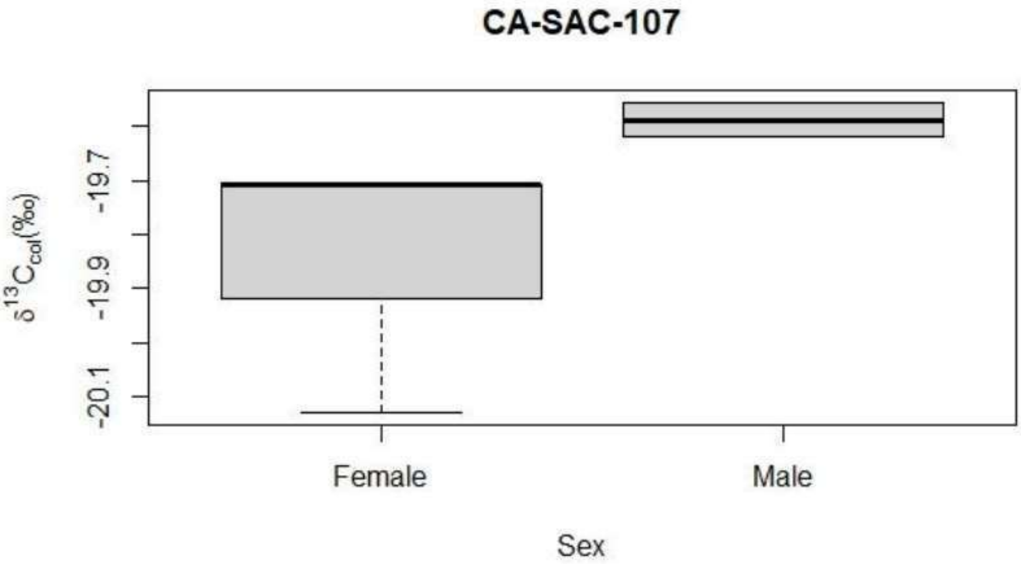

*Figure 6. 2 Boxplot comparing female and male $\delta^{13}C$ of bone collagen at CA-SAC-107*

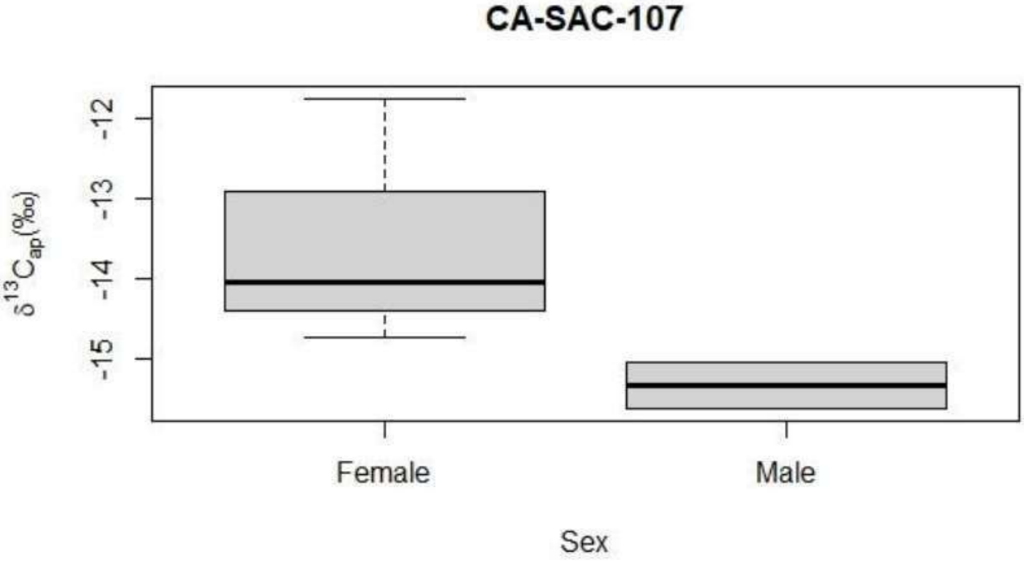

*Figure 6. 3 Boxplot comparing female and male $\delta^{13}C$ of bone apatite at CA-SAC-107*

The aforementioned pattern is reflected in the mean $\delta^{13}C_{ap\text{-}col}$ at CA-SAC-107, with females showing higher average spacing (6.3‰) and variation (range = 3.0; SD = 1.5) than males ($\delta^{13}C_{ap\text{-}col}$ = 4.3‰, range = 0.6; SD = 0.5) (Table 6.4). A marine-carbon-mixing model indicates that the percent-marine contribution of one female (12-5610.1; 12%) is 2.8% lower than the average predicted for the Windmiller Mound population (14.8%) (Table 6.3). Interestingly, this female reveals the highest $\delta^{15}N$ (9.6‰) of the population (Table 6.3). The mean $\delta^{15}N$ of females and males at CA-SAC-107 is the same (9.0‰), although female values are more variable (Table 6.4; Figure 6.4). Although the sample size is small, overall dietary isotopes at the Windmiller Mound indicate relatively homogenous diets for the three females and two males.

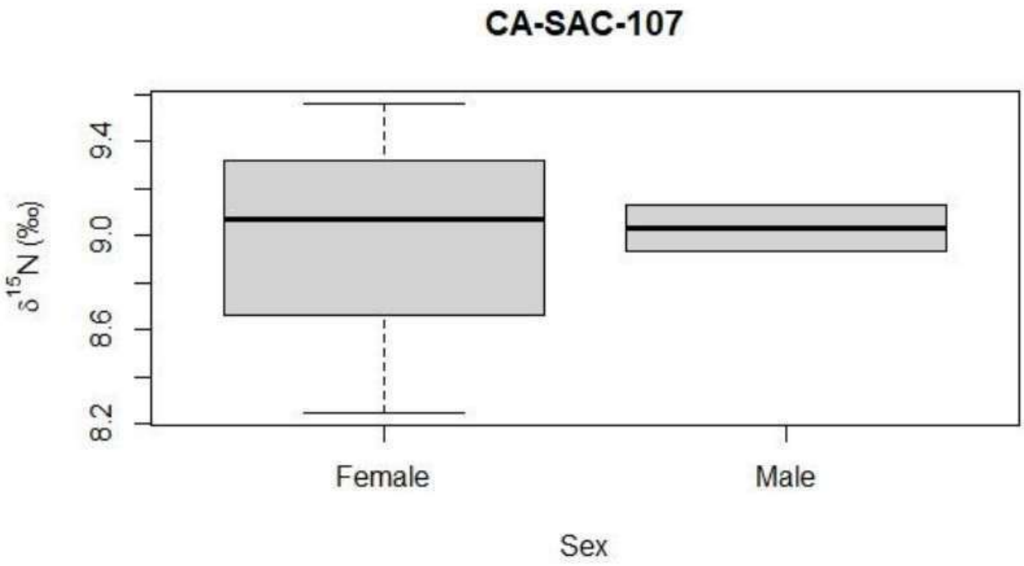

*Figure 6. 4 Boxplot comparing female and male $\delta^{15}N$ of bone collagen at CA-SAC-107*

**Paleodietary Analysis at CA-SJO-68, Blossom Mound**

The $\delta^{13}C_{col}$ values of the CA-SJO-68 population (n = 24) range from -20.6 to -17.7‰ with a mean of -19.5‰ (SD = 0.6) (Table 6.5; Table 6.6). The mean $\delta^{13}C_{ap}$ is -13.4‰ (SD = 1.0) and values span -15.1 to -11.6‰ (Table 6.5; Table 6.6). Therefore, $\delta^{13}C_{ap}$ shows greater variation than the values reported for $\delta^{13}C_{col}$ at the Blossom Mound. The $\delta^{13}C_{ap\text{-}col}$ at CA-SJO-68, averaging 6.1‰ (SD = 1.1) and ranging from 4.7 to 8.0 ‰, suggest that the population likely relied on $^{13}C$ depleted dietary protein sources. A marine-carbon-mixing model indicates that about 17% of the population's diet is derived from marine resources (Table 6.5). Therefore, a small portion of the diet was shaped by $^{13}C$ enriched marine-protein sources. Mean $\delta^{15}N$ of the Blossom Mound population is 11.2‰ (SD =1.3) and spans 8.8 to 13.8‰ (Table 6.5; Table 6.6). $\delta^{15}N$ values at CA-SJO-68 suggest that the population foraged in environments with several trophic levels (e.g., freshwater, estuarine, and marine ecosystems). When taken together with the relatively low $\delta^{13}C$ values, dietary isotopes at the Blossom Mound are particularly consistent with freshwater resources. Although, resources acquired in marine and/or brackish-water environments through logistical forays or trade may also have played a role. Figure 6.5 depicts a biplot of $\delta^{13}C_{col}$ and $\delta^{15}N$ at CA-SJO-68 and illustrate that values are consistent with expectations for freshwater-riverine food webs.

*Table 6. 5 $\delta^{13}C$ and $\delta^{15}N$ Values at CA-SJO-68*

| PAHMA # | Sex | $\delta^{13}C_{col}$ | $\delta^{13}C_{ap}$ | Apatite-Collagen Spacing | % Marine | % Terrestrial | $\delta^{15}N$ | C/N Ratio |
|---|---|---|---|---|---|---|---|---|
| 12-5824(0) | Male | -19.75 | -14.90 | 4.85 | 15 | 85 | 11.3 | 3.2 |
| 12-5833(0) | Male | -19.15 | -13.25 | 5.89 | 19 | 81 | 12.2 | 3.2 |
| 12-6472(0) | Female | -19.48 | — | — | 17 | 83 | 10.1 | 3.2 |
| 12-7569(0) | Female | -19.54 | -13.50 | 6.04 | 16 | 84 | 11.6 | 3.2 |
| 12-7575(0) | Female | -18.78 | — | — | 21 | 79 | 12.2 | 3.2 |
| 12-7577 | Female | -18.83 | -12.66 | 6.18 | 21 | 79 | 12.0 | 3.2 |
| 12-7581.1 | Female | -19.97 | -13.22 | 6.74 | 14 | 86 | 10.6 | 3.2 |
| 12-7582(0) | Male | -19.12 | — | — | 19 | 81 | 12.9 | 3.2 |
| 12-7588(0) | Female | -19.72 | -15.05 | 4.67 | 15 | 85 | 9.9 | 3.2 |
| 12-7598(0) | Female | -19.67 | — | — | 16 | 84 | 11.5 | 3.3 |
| 12-7603(0) | Male | -19.00 | — | — | 20 | 80 | 12.7 | 3.2 |
| 12-7608(0) | Female | -19.58 | -11.63 | 7.95 | 16 | 84 | 10.6 | 3.2 |
| 12-7613(0) | Male | -20.44 | — | — | 10 | 90 | 10.3 | 3.2 |
| 12-7614.1 | Male | -19.60 | -14.21 | 5.38 | 16 | 84 | 11.5 | 3.2 |
| 12-7621(0) | Male | -19.41 | -11.68 | 7.73 | 17 | 83 | 11.8 | 3.2 |
| 12-7622.1 | Female | -19.70 | -13.37 | 6.33 | 15 | 85 | 8.8 | 3.3 |
| 12-7634(0) | Male | -18.74 | -13.84 | 4.9 | 22 | 78 | 13.8 | 3.2 |
| 12-7638.1 | Female | -19.57 | — | — | 16 | 84 | 9.8 | 3.2 |
| 12-7640.1 | Male | -17.72 | -12.89 | 4.83 | 29 | 71 | 13.6 | 3.2 |
| 12-7646(0) | Male | -19.36 | -14.19 | 5.17 | 18 | 82 | 10.3 | 3.2 |
| 12-7652.1 | Male | -20.57 | -13.24 | 7.33 | 10 | 90 | 9.8 | 3.2 |
| 12-8022(0) | Male | -19.46 | -12.39 | 7.06 | 17 | 83 | 12.1 | 3.2 |
| 12-8024(0) | Female | -20.13 | -14.34 | 5.79 | 12 | 88 | 10.3 | 3.2 |
| 12-8025(0) | Female | -20.13 | -12.76 | 7.37 | 12 | 88 | 9.9 | 3.2 |

*Table 6. 6 Summary Statistics of $\delta^{13}C$ and $\delta^{15}N$ Values at CA-SJO-68*

| | *n* | Mean | SD | Range |
|---|---|---|---|---|
| **Collagen $\delta^{13}C$** | | | | |
| Population | 24 | -19.5 | 0.6 | 2.9 |
| Female | 12 | -19.6 | 0.4 | 1.4 |
| Male | 12 | -19.4 | 0.7 | 2.9 |
| **Apatite $\delta^{13}C$** | | | | |
| Population | 17 | -13.4 | 1.0 | 3.4 |
| Female | 8 | -13.3 | 1.0 | 3.4 |
| Male | 9 | -13.4 | 1.0 | 3.2 |
| **Apatite-Collagen Spacing** | | | | |
| Population | 17 | 6.1 | 1.1 | 3.3 |
| Female | 8 | 6.4 | 1.0 | 3.3 |
| Male | 9 | 5.9 | 1.2 | 2.9 |
| **Collagen $\delta^{15}N$** | | | | |
| Population | 24 | 11.2 | 1.3 | 5.0 |
| Female | 12 | 10.6 | 1.0 | 3.4 |
| Male | 12 | 11.9 | 1.3 | 4.0 |

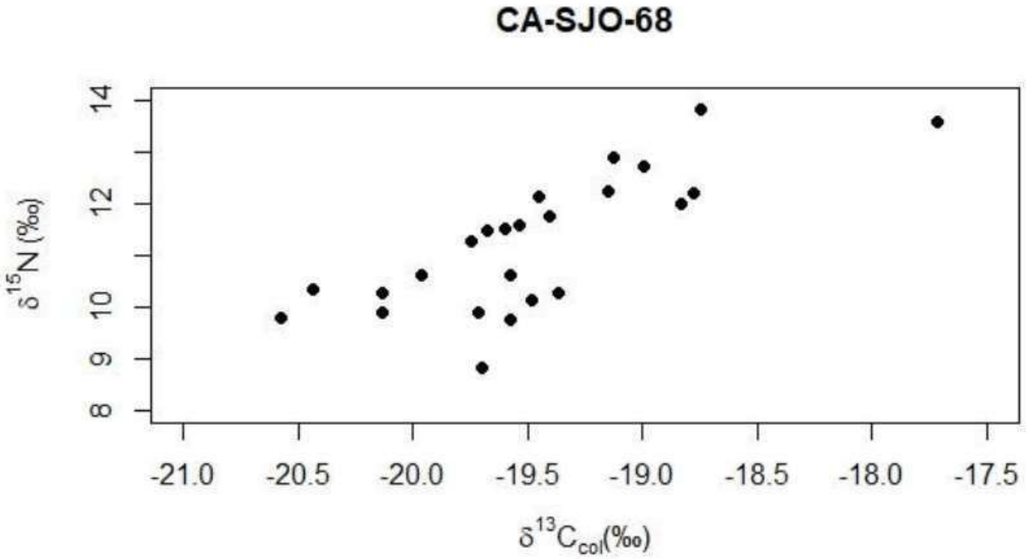

*Figure 6. 5 Biplot showing $\delta^{13}C$ and $\delta^{15}N$ of bone collagen at CA-SJO-68*

Female (n = 12) $\delta^{13}C_{col}$ ranges from -20.1 to -18.8‰ with a mean of -19.6‰ (SD = 0.4) (Table 6.5; Table 6.6). Male (n = 12) $\delta^{13}C_{col}$ are comparable, averaging -19.4‰ (SD = 0.7) and spanning from -20.6 to

-17.7‰ (Table 6.5; Table 6.6). However, males (range = 2.9) exhibit greater variation in $\delta^{13}C_{col}$ than females (range = 1.4) (Table 6.6; Figure 6.6). Female and male $\delta^{13}C_{ap}$ values are consistent, with a mean of -13.3‰ and -13.4‰, respectively (Table 6.6). The variation in $\delta^{13}C_{ap}$ is also comparable between the sexes, with females ranging from -15.1 to -11.6‰ (SD = 1.0) and males spanning -14.9 to -11.7‰ (SD = 1.0) (Table 6.6; Figure 6.7). Therefore, the protein portion of the diet for males likely originates from a broader array of resources that vary in their underlying $\delta^{13}C$.

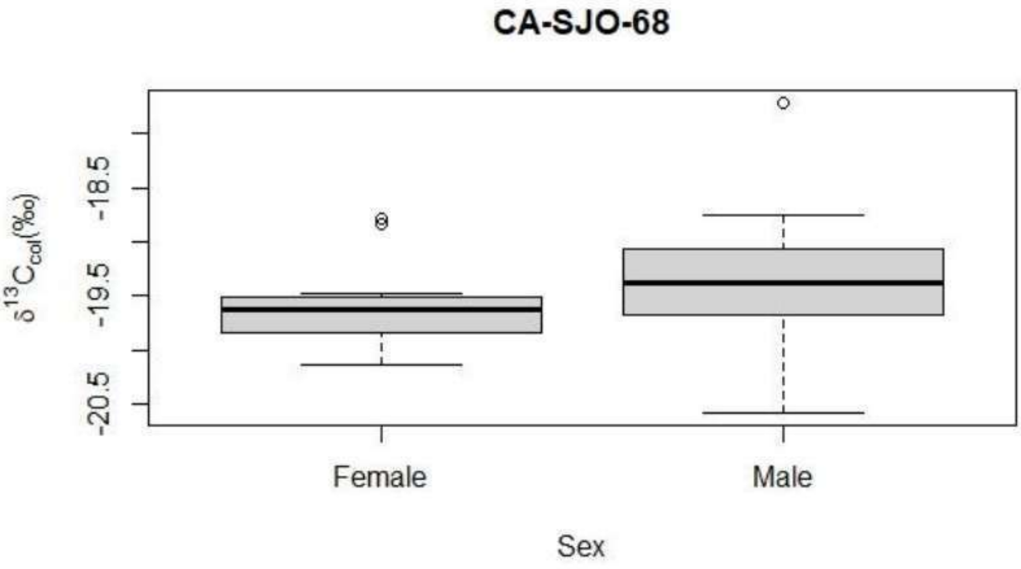

*Figure 6. 6 Boxplot comparing female and male $\delta^{13}C$ of bone collagen at CA-SJO-68*

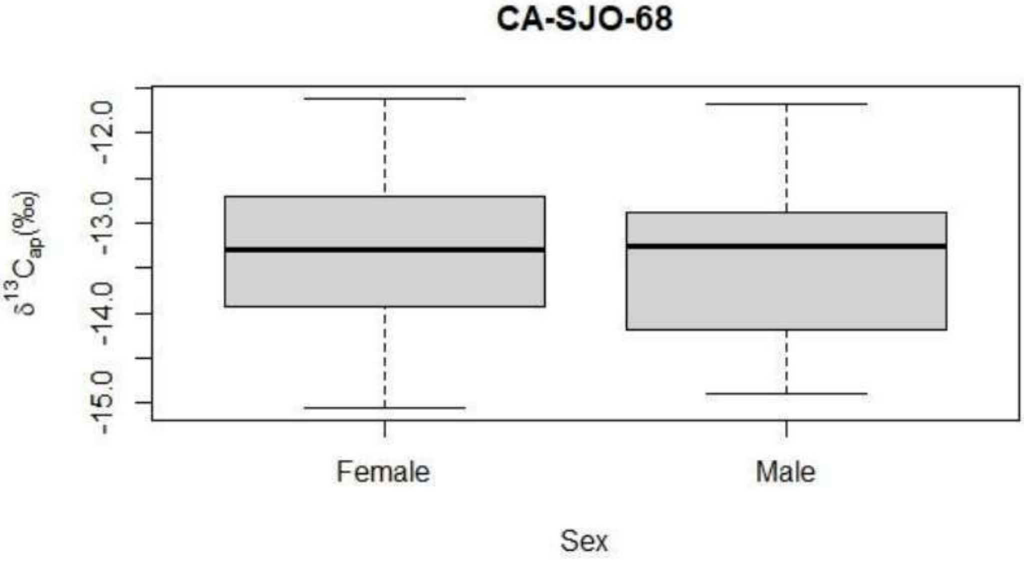

*Figure 6. 7 Boxplot comparing female and male $\delta^{13}C$ of bone apatite at CA-SJO-68*

Female $\delta^{13}C_{ap\text{-}col}$ (6.4‰; SD = 1.0) is 0.5‰ greater than the male mean value (5.9‰; SD = 1.2) and exhibits a greater range (female range = 3.3; male range = 2.9) (Table 6.6). This is supported by a marine-carbon-mixing model's predictions for percent marine contributions to the diet with males (17.6%) averaging 1.7% higher than females (15.9%) (Table 6.5). The highest predicted value comes from one male (12-7640.1), for whom 29% marine contribution is projected for the protein portion of the diet (Table 6.5). Interestingly, two males (12-7613(0) and 12-7652.1) are predicted to have only 10% marine-based diet, 7% lower than the population's average (Table 6.5). Two females (12-7575(0) and 12-7577) show expected percent marine contribution to the diet as high as 21%, which is 4% greater than the population mean (Table 6.5).

Males at CA-SJO-68 show greater enrichment of $^{15}N$ and greater variation in $\delta^{15}N$ than females (Table 6.5; Figure 6.8). The male mean $\delta^{15}N$ (11.9‰; SD = 1.3) is 1.3‰ greater than females (10.6‰; SD = 1.0) (Table 6.6). Male $\delta^{15}N$ values range from 9.8 to 13.8‰ while female $\delta^{15}N$ values span 8.8 to 12.2‰ (Table 6.5; Figure 6.8). Table 5 reports results of a Mann-Whitney test comparing female *versus* male mean $\delta^{13}C_{col}$, $\delta^{13}C_{ap}$, $\delta^{13}C_{ap\text{-}col}$, and $\delta^{15}N$. Of these comparisons, only $\delta^{15}N$ reveals a significant (*p* = 0.02) difference between female and male mean values (α = 0.05; Table 6.7). As expected, individuals for whom a higher percent marine contribution to the diet was predicted using the marine carbon mixing model also show higher $\delta^{15}N$ (Table 6.5). For instance, among males, the two (12-7613(0) and 12-7652.1) for whom only 10% of the diet is predicted to come from marine contributions show the lowest $\delta^{15}N$ (10.3‰ and 9.8‰) (Table 6.5). Likewise, the two males (12-7634(0) and 12-7640.1) with the highest $\delta^{15}N$ are predicted to have between 22-29% marine contribution to the diet, the two highest predictions for the population (Table 6.5).

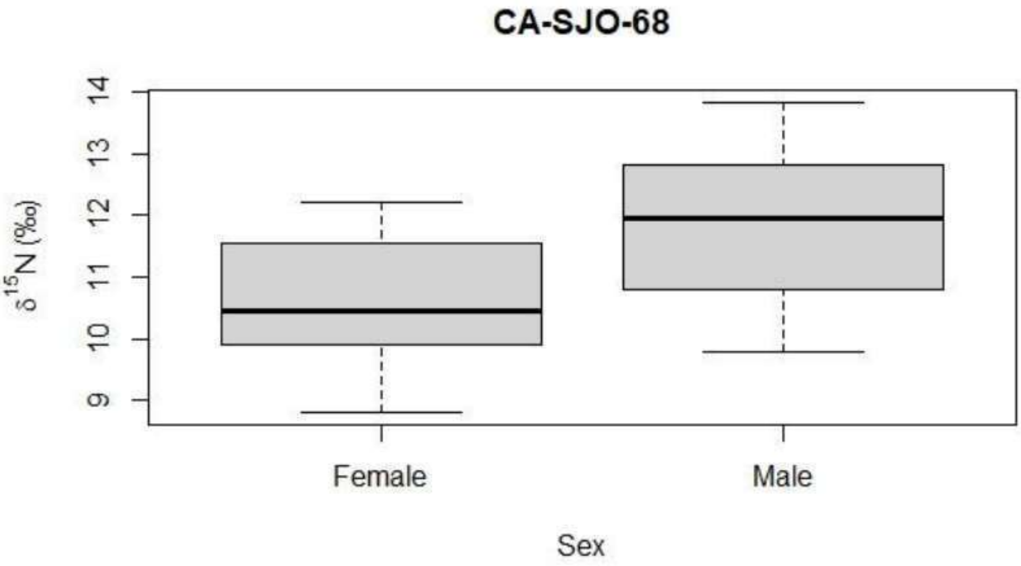

*Figure 6. 8 Boxplot comparing female and male $\delta^{15}N$ of bone collagen at CA-SJO-68*

*Table 6. 7 Mann-Whitney Test Results of Female vs. Male Dietary Isotopic Values at CA-SJO-68*

| | *N* | *Z* | *p*-value |
|---|---|---|---|
| Collagen $\delta^{13}C$ | 24 | -1.17 | 0.24 |
| Apatite $\delta^{13}C$ | 17 | -0.14 | 0.89 |
| Apatite-Collagen Spacing | 17 | -0.90 | 0.37 |
| Collagen $\delta^{15}N$ | 24 | -2.25 | ***0.02** |
| *significant at α = 0.05 | | | |

Dietary isotopes at the Blossom Mound suggests some distinction between female and male diets. In particular, males, on average, consume higher trophic-level resources than females, which indicates that men likely relied more on terrestrial-game and freshwater fish. As well, a marine-carbon-mixing model predicts that males had greater access to marine resources than females. Female diets are more similar to one another than males for whom greater variation in isotope values, $\delta^{15}N$ in particular, indicates differential access to types of protein sources.

### Paleodietary Comparison of the Windmiller and Blossom Mounds using Isotopic Evidence

Mean $\delta^{13}C_{col}$ at the Windmiller (-19.7 ‰) and Blossom (-19.5‰) mounds are nearly identical, while the CA-SJO-68 population shows slightly higher mean $\delta^{13}C_{ap}$ (-13.4‰) than the CA-SAC-107 (-14.2‰) (Table 6.4; Table 6.6). Figure 6.9 shows a biplot of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ at these two sites, and marine-protein and $C_3$-protein regression lines based on controlled feeding experiments carried out by Froehle et al. (2010). The Froehle et al. (2010) model effectively illustrates how $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values can be used to interpret likely dietary contributions, particularly, the source (e.g., marine; $C_3$) of protein vs. carbohydrates and fats (Bartelink et al. 2020; Barton et al. 2020; Eerkens et al. 2013). The 'marine-protein-line' (illustrated in blue in Figure 6.9) represents the upper threshold expected for diets characterized by marine-protein consumption. The '$C_3$-protein-line' (depicted as green in Figure 6.9) expresses the parameters of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values expected for diets characterized by $C_3$-protein consumption. Furthermore, relative position of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values to these protein-regression-lines informs on the approximate contribution of marine or $C_3$ dietary sources of carbohydrates and fats. In other words, the furthest left end (more negative $\delta^{13}C$) of each line represents all carbohydrates and fats derived from $C_3$ sources, while the furthest right end (more positive $\delta^{13}C$) represents all carbohydrates and fats derived from marine sources (Figure 6.9).

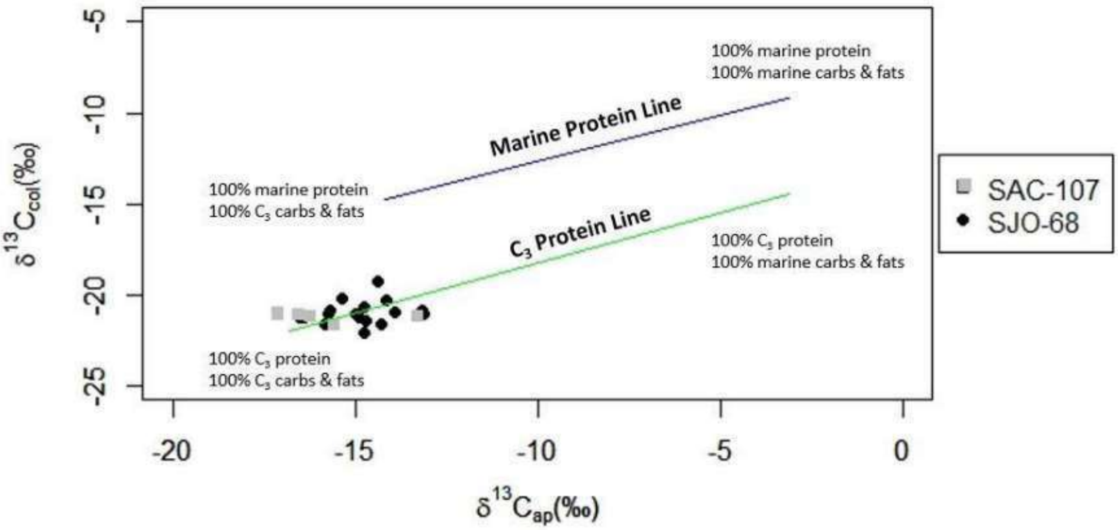

*Figure 6. 9 Comparison of $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values at CA-SAC-107 and CA-SJO-68*

When compared to this model, the $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values of the CA-SAC-107 and CA-SJO-68 populations are consistent with largely freshwater and $C_3$ sources of dietary protein, carbohydrates, and fats (Figure 6.9). The CA-SJO-68 population does show greater variation and is slightly more biased towards the right along the $C_3$-protein line than the CA-SAC-107 population. This suggests consumption of at least some marine-based dietary carbohydrates and fats by individuals at the Blossom Mound and is consistent with predictions using the marine-carbon-mixing model that reveal a greater percent marine contribution at CA-SJO-68 (17%) compared to CA-SAC-107 (15%).

The mean $\delta^{15}N$ at CA-SJO-68 (11.2‰) is 2.2‰ higher than that at CA-SAC-107 (9.0‰), suggesting that the Blossom Mound population generally consumed higher trophic-level resources than the Windmiller Mound population (Table 6.4; Table 6.6). Figure 6.10 depicts a biplot of $\delta^{15}N$ and $\delta^{13}C$ values from CA-SAC-107, CA-SJO-68, and five other archaeological sites with Early Period components (CA-ALA-307, CA-CCO-295, CA-CCO-696, CA-SJO-112, and CA-YOL-171). Dietary isotope values at the Windmiller Mound are consistent with other populations (e.g., CCO-696 and SJO-112) that likely forage within a $C_3$-terrestrial food web (Figure 6.10). The higher $\delta^{15}N$ and range of $\delta^{13}C_{col}$ at the Blossom Mound are consistent with populations (e.g., YOL-171) that likely foraged within freshwater-riverine systems

(Figure 10). Dietary isotope values at CA-SAC-107 and CA-SJO-68 are clearly distinct from populations (e.g., ALA-307 and CCO-295) that likely foraged within a marine-based food web, although at least one individual (12-7640.1) at the Blossom Mound is approaching isotope values expected for dietary sources from brackish environments (Figure 6.10; Table 6.6).

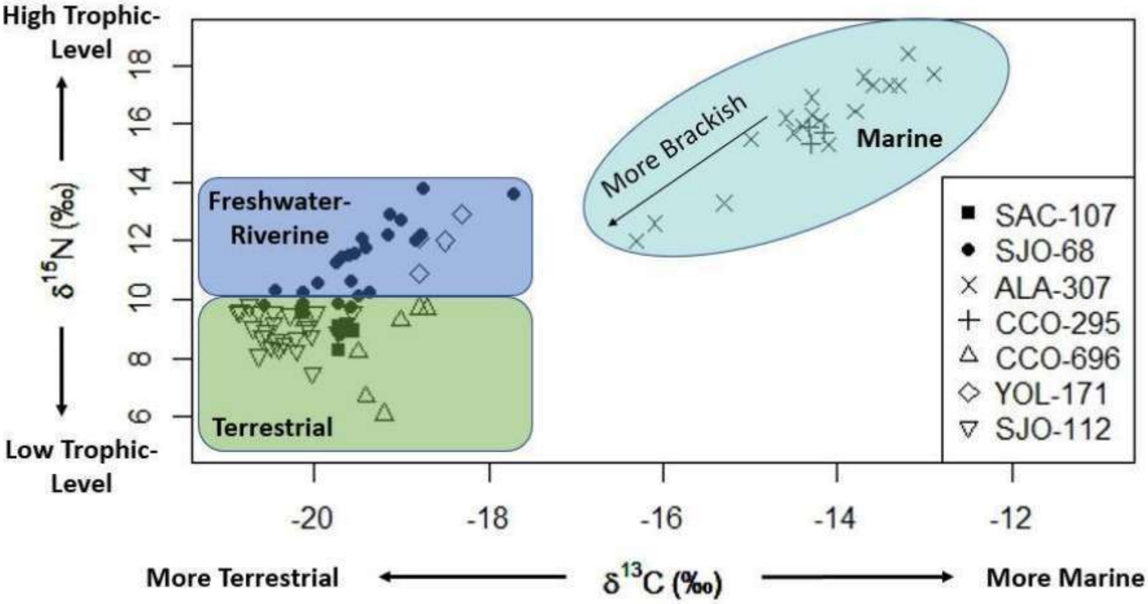

*Figure 6. 10 $\delta^{13}C$ and $\delta^{15}N$ values of CA-SAC-107 and CA-SJO-68 samples reported in this study, and other Early Period components of sites in central California reported in the literature (Bartelink 2009 [CA-ALA-307]; Barton et al. 2020 [CA-SJO-112]; Beasley et al. 2013 [CA-CCO-295]; Eerkens et al. 2015 [CA-YOL-171]; and Ralston et al. 2016 [CA-CCO-696]*

## Environmental-Strontium Results

Reconstruction of human geolocation at CA-SAC-107 and CA-SJO-68 relies, in part, on $^{87}Sr/^{86}Sr$ analysis of human tooth enamel and modern samples from central California. Table 6.8 reports $^{87}Sr/^{86}Sr$ of plant and snail samples (n =20) from the four locations used to collect strontium environmental-background data. The $^{87}Sr/^{86}Sr$ values for samples collected from the Cosumnes River Preserve (MA/CON-SED-2) range from 0.70717 to 0.70735 (range = 16.7 X $10^{-5}$) and have a mean of 0.70726 (SD

=6.0 X $10^{-5}$) (Table 6.8; Table 6.9). At the Big Break Regional Shoreline (MA/CON-SED-1), $^{87}Sr/^{86}Sr$ span from 0.70688 to 0.70708 (range = 20.1 X $10^{-5}$) with a mean of 0.70696 (SD = 8.0 X $10^{-5}$). Samples collected along the Mokelumne River (CON-SED-3) show the greatest variation of the environmental-strontium sampling locations and range from 0.70673 to 0.70716 (range = 42.7 X $10^{-5}$) with a mean $^{87}Sr/^{86}Sr$ of 0.70695 (SD =20.0 X $10^{-5}$). The $^{87}Sr/^{86}Sr$ of samples collected from along the El Dorado Trail (METAVOL-4) vary from 0.70559 to 0.70603 (range = 44.2 X $10^{-5}$) and have a mean of 0.70577 (SD = 18.0 X $10^{-5}$) (Table 6.8; Table 6.9). Figure 6.11 shows boxplots comparing $^{87}Sr/^{86}Sr$ of samples collected from MA/CON-SED-2, MA/CON-SED-1, CON-SED-3, and METAVOL-4.

*Table 6. 8 $^{87}Sr/^{86}Sr$ of Samples from Environmental-Strontium Collection Locations*

| **Area** | **Site** | **Count** | **Species** | **$^{87}Sr/^{86}Sr$** |
|---|---|---|---|---|
| Cosumnes River Preserve | MA/CON-SED-2 | 1 | *Rosa californica* | 0.707236 |
| Cosumnes River Preserve | MA/CON-SED-2 | 2 | *Quercus sp.* | 0.707271 |
| Cosumnes River Preserve | MA/CON-SED-2 | 3 | *Quercus sp.* | 0.707345 |
| Cosumnes River Preserve | MA/CON-SED-2 | 4 | *Rubus sp.* | 0.707272 |
| Cosumnes River Preserve | MA/CON-SED-2 | 5 | *Rubus sp.* | 0.707178 |
| Big Break Regional Shoreline | MA/CON-SED-1 | 6 | *Rubus sp.* | 0.706924 |
| Big Break Regional Shoreline | MA/CON-SED-1 | 7 | *Quercus sp.* | 0.706882 |
| Big Break Regional Shoreline | MA/CON-SED-1 | 8 | Apiaceae | 0.706984 |
| Big Break Regional Shoreline | MA/CON-SED-1 | 9 | *Rubus sp.* | 0.706942 |
| Big Break Regional Shoreline | MA/CON-SED-1 | 10 | Gastropoda | 0.707083 |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 11 | *Quercus sp.* | 0.706766 |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 12 | *Rubus sp.* | 0.706728 |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 13 | *Rubus sp.* | 0.706950 |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 14 | *Quercus sp.* | 0.707138 |
| Mokelumne River near Comanche Reservoir | CON-SED-3 | 15 | *Quercus sp.* | 0.707155 |
| El Dorado Trail near Bullard | METAVOL-4 | 16 | *Quercus sp.* | 0.705626 |
| El Dorado Trail near Bullard | METAVOL-4 | 17 | *Quercus sp.* | 0.706031 |
| El Dorado Trail near Bullard | METAVOL-4 | 18 | *Quercus sp.* | 0.705589 |
| El Dorado Trail near Bullard | METAVOL-4 | 19 | *Pinus sp.* | 0.705792 |
| El Dorado Trail near Bullard | METAVOL-4 | 20 | *Arctostaphylos patula* | 0.705831 |

*Table 6. 9 Summary Statistics of $^{87}Sr/^{86}Sr$ at Environmental-Strontium Background Locations*

| **$^{87}Sr/^{86}Sr$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| MA/CON-SED-1 | 5 | 0.70696 | $8.0 \times 10^{-5}$ | $20.1 \times 10^{-5}$ |
| MA/CON-SED-2 | 5 | 0.70726 | $6.0 \times 10^{-5}$ | $16.7 \times 10^{-5}$ |
| CON-SED-3 | 5 | 0.70695 | $20.0 \times 10^{-5}$ | $42.7 \times 10^{-5}$ |
| METAVOL-4 | 5 | 0.70577 | $18.0 \times 10^{-5}$ | $44.2 \times 10^{-5}$ |

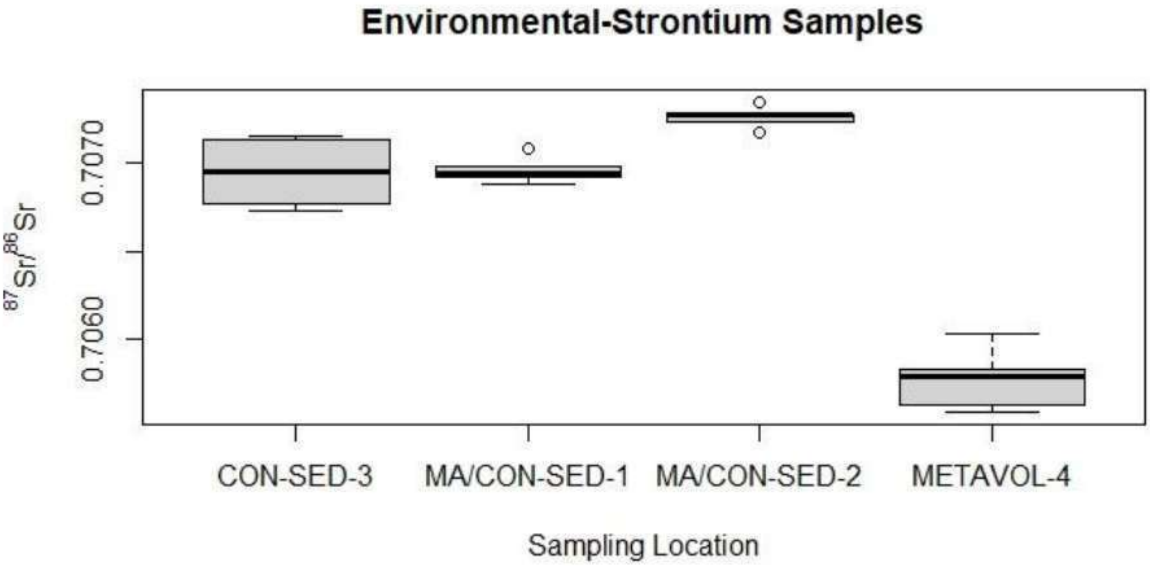

*Figure 6. 11 Boxplot comparing $^{87}Sr/^{86}Sr$ of samples from environmental-strontium collection locations*

**Isotopic Indicators of Mobility at CA-SAC-107**

Analysis of paleomobility using three isotopic indicators—stable sulfur, stable oxygen, and radiogenic strontium—was conducted on samples from the Windmiller Mound (CA-SAC-107) as outlined in Chapter 5. As previously mentioned, radiocarbon assays generated for this study confirm that CA-SAC-107 is a multi-component site with burials dating from the Early Period to the Historic Period (Table 6.1). Statistical comparisons across variables, including elements sampled, sex, and time periods, are reported in the following sections.

*Table 6. 10 Results of Isotopic Analysis of Bone and Teeth Samples from CA-SAC-107 Used to Study Paleomobility*

| **PAHMA #** | **Sex** | **Element Sampled** | **$\delta^{34}$S** | **$\delta^{18}$O** | **$^{87}$Sr/$^{86}$Sr** | **Period** |
|---|---|---|---|---|---|---|
| 12-5589.1 | Female | Bone | 6.1 | -5.2 | — | Early |
| | | $C_1$ | 5.9 | -5.5 | 0.706911 | |
| 12-5598(0) | Male | Bone | 6.5 | -6.8 | — | Early |
| 12-5600(0) | Male | Bone | 6.0 | -6.1 | — | Early |
| | | $I_2$ | 4.6 | -5.4 | — | |
| | | $M_3$ | 5.0 | -6.1 | 0.707050 | |
| 12-5610.1 | Female | Bone | 5.9 | -6.9 | — | Early |
| 12-5615(0) | Female | $M^1$ | 4.4 | -6.2 | 0.706957 | Middle |
| 12-5616.3 | Female | Bone | 6.1 | -6.4 | — | — |
| 12-7787(0) | Male | $M_3$ | 3.3 | -7.2 | 0.707000 | Historic |
| 12-7789(0) | Female | $M^1$ | 2.6 | -6.9 | 0.706715 | Late |
| 12-7791(0) | Female | $P_3$ | 3.9 | -4.9 | — | Historic |
| 12-7830(0) | Male | $P^3$ | 1.9 | — | — | Historic |
| 12-7835(0) | Female | $P^4$ | 3.8 | -5.1 | 0.707006 | Historic |
| 12-7867(0) | Female | $P^3$ | 3.5 | -6.5 | — | Late |
| | | $M^3$ | 5.5 | -6.3 | 0.707010 | |
| 12-7874(0) | Male | $M^1$ | 2.2 | — | — | Early |
| 12-7878(0) | Female | $M^1$ | 5.3 | -4.3 | 0.706967 | Historic |
| 12-7885(0) | Female | $M^1$ | 3.9 | -3.6 | 0.706983 | Historic |
| 12-7893(0) | Male | $M^1$ | 5.3 | -5.6 | 0.706996 | — |

Note: — insufficient material for analysis

### *Overview of $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr Patterns*

The $\delta^{34}$S population mean for bone collagen is 6.1‰ (SD = 0.2), and ranges from 5.9 to 6.5‰ (range = 0.6) (Table 6.10, Table 6.11). Some individuals from CA-SAC-107 did not have first molars available for analysis and, therefore, other teeth that develop during childhood (i.e., crown forms between 3 mo. and 7 yrs. with root completed between 10 and 14 yrs.) were alternatively selected and are herein referred to as "early-forming" teeth (Table 6.10). The $\delta^{34}$S of dentinal collagen from "early-forming" teeth span 1.9 to 5.9‰ (range = 4.0) and from first molars range from 2.2 to 5.3‰ (range = 3.1) (Table 6.10; Table 6.11; Figure 6.12). The mean $\delta^{34}$S is 3.9‰ (SD = 1.3) for both "early-forming" teeth and first molars (Table 6.11). The $\delta^{34}$S population mean of third molar dentinal collagen is 4.6‰ (SD = 1.1) and spans 3.3 to 5.5‰ (range = 2.2) (Table 6.10; Table 6.11; Figure 6.12).

*Table 6. 11 Summary Statistics of $\delta^{34}S$ at CA-SAC-107*

| **$\delta^{34}S$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Bone Collagen $\delta^{34}S$ | 5 | 6.1 | 0.2 | 0.6 |
| M1 Collagen $\delta^{34}S$ | 6 | 3.9 | 1.3 | 3.1 |
| M3 Collagen $\delta^{34}S$ | 3 | 4.6 | 1.1 | 2.2 |
| "Early-Forming" Tooth Collagen $\delta^{34}S$ | 6 | 3.9 | 1.3 | 4.0 |

Ideally, since people are likely interred near places they lived immediately before death, bone $\delta^{34}S$ values can represent a site's "local" signature, which is typically set at two standard deviations around the mean $\delta^{34}S$ of bone. However, since the bone sampled for analysis from CA-SAC-107 dates to the Early Period (Table 6.1; Table 6.11) due to sampling limitations, a "local" signature useful for temporal comparisons cannot be confidently established. Mean bone $\delta^{34}S$ is 2.2‰ greater than that of first molars and other "early-forming" teeth, and 1.5‰ greater than mean $\delta^{34}S$ of third molars. While first molars and "early-forming" teeth have the same mean $\delta^{34}S$, first molars have a slightly greater range. Bone values are more tightly clustered with a smaller range and standard deviation relative to teeth.

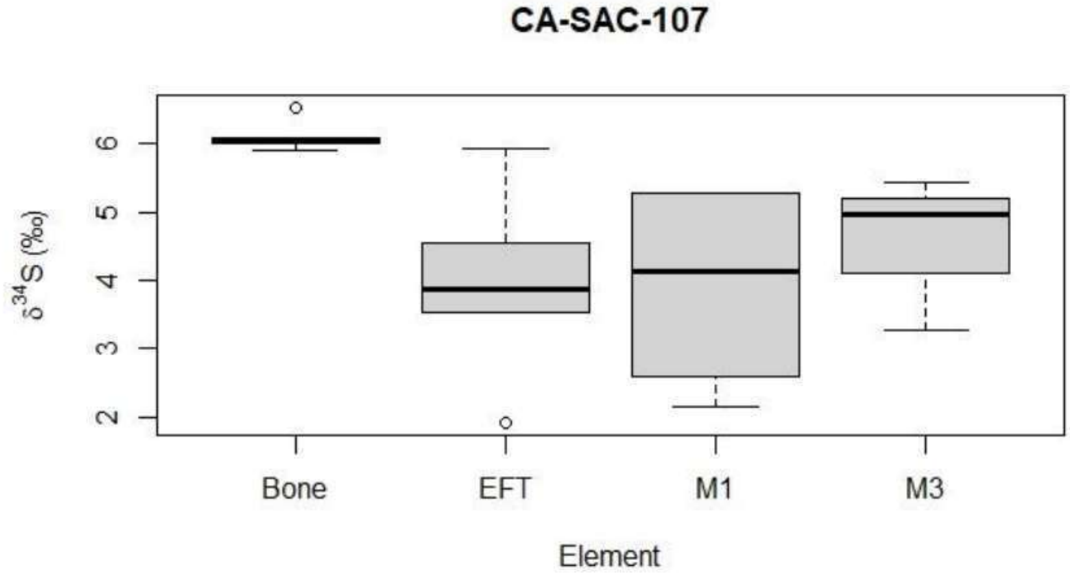

*Figure 6. 12 Boxplot comparing $\delta^{34}S$ of bone collagen, first molar (M1), third molar (M3), and "early-forming" tooth (EFT) dentinal collagen from CA-SAC-107*

Results of the one-tailed Levene's test for equality of variance comparing $\delta^{34}$S in bone and teeth are presented in Table 6.12. Only three third molars produced sufficient collagen for $\delta^{34}$S analysis precluding inclusion in the Levene's test. Comparisons of var(bone) vs. var(M1) show significant *p*-values at an alpha of 0.05 using both the mean and the median as the center (Table 6.12). Therefore, we can reject the null hypothesis that bone and first molar variance are equal at the p = 0.05 level. The Levene's test reveals no statistically significant differences in var(bone) versus var(EFT), and var(EFT) versus var(M1) (Table 6.12).

If the population from CA-SAC-107 practiced exogamous marriage, then greater variation in $\delta^{34}$S is expected for teeth than bone. Although summary statistics support this expectation, statistical analysis using the Levene's test only reveals significance in one case: var(bone) versus var(M1). However, since bone sampling is heavily biased towards the Early Period, time is a confounding variable and is taken into consideration later in this section.

*Table 6.12 Levene's Test (One-Tailed) Results for Comparison of $\delta^{34}$S at CA-SAC-107*

| **Type** | ***df*** | **F** | | ***p* value** | |
|---|---|---|---|---|---|
| | | Median | Mean | Median | Mean |
| *var*(bone) vs. *var*(M1) | 1<br>9 | 8.59 | 9.40 | **0.02** | **0.01** |
| *var*(bone) vs. *var*(EFT) | 1<br>9 | 2.85 | 2.87 | 0.13 | 0.12 |
| *var*(M1) vs. *var(*EFT) | 1<br>10 | 0.21 | 0.20 | 0.66 | 0.66 |
| α = 0.05 | | | | | |

As mentioned in Chapter 5, biogenic oxygen in bone apatite is susceptible to diagenesis and should be evaluated with caution. However, the mean $\delta^{18}$O of bone apatite and third molar enamel from CA-SAC-107 are comparable, with bone showing a negligibly greater range (Figure 6.13). This may suggest that bone $\delta^{18}$O values are minimally affected at CA-SAC-107. Bone apatite ranges from -6.9 to -5.2‰ (range = 1.6) with a mean of -6.3‰ (SD = 0.7), while third molar enamel spans -7.2 to -6.1‰

(range = 1.1) and averages -6.5‰ (SD = 0.6) (Table 6.10; Table 6.13). Both $\delta^{18}O$ of enamel for first molars and other "early-forming teeth" are relatively more enriched in $^{18}O$ (about 1.0 ‰ greater) than bone apatite and third molar enamel, which is expected for a breastfeeding child as $\delta^{18}O$ is higher in breastmilk. The $\delta^{18}O$ of "early-forming" tooth enamel ranges from -6.5 to -4.9‰ (range = 1.7) and averages -5.4‰ (SD = 0.6), while first molar enamel spans -6.9 to -3.6‰ (range = 3.3) with a mean of -5.3‰ (SD = 1.3) (Table 6.10; Table 6.13; Figure 6.13). The one-tailed Levene's test for equality of variance comparing bone versus teeth is presented in Table 6.14. Based on this test, the null hypothesis that bone and teeth variance are equal at an alpha of 0.05 cannot be rejected (Table 6.14).

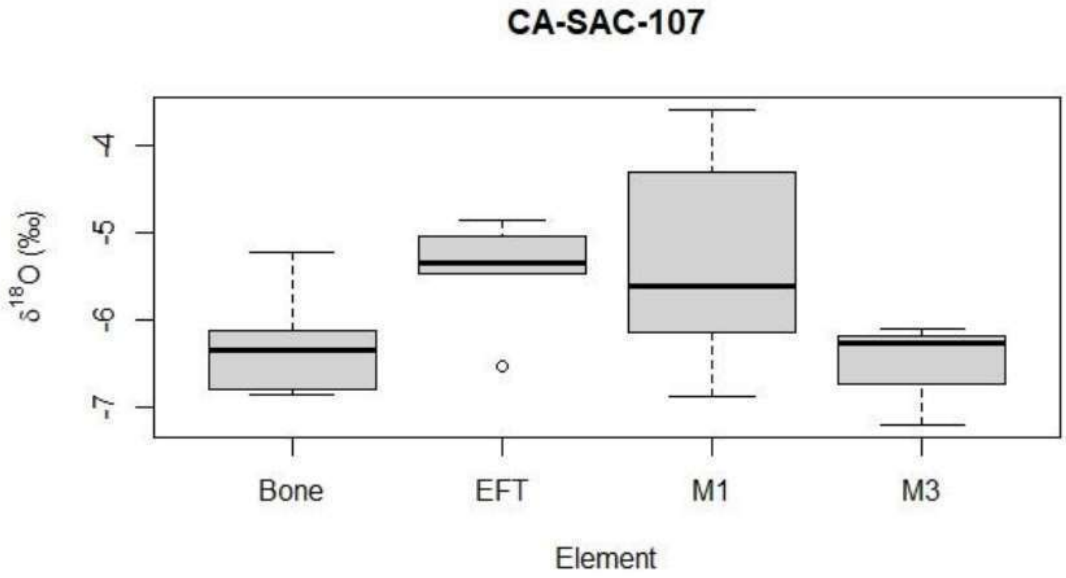

*Figure 6. 13 Boxplot comparing $\delta^{18}O$ of bone apatite, first molar (M1), third molar (M3), and "early-forming" tooth (EFT) enamel from CA-SAC-107*

*Table 6. 13 Summary Statistics of $\delta^{18}O$ at CA-SAC-107*

| **$\delta^{18}O$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Bone apatite $\delta^{18}O$ | 5 | -6.3 | 0.7 | 1.6 |
| M1 enamel $\delta^{18}O$ | 5 | -5.3 | 1.3 | 3.3 |
| M3 enamel $\delta^{18}O$ | 3 | -6.5 | 0.6 | 1.1 |
| "Early-forming" tooth enamel $\delta^{18}O$ | 5 | -5.4 | 0.6 | 1.7 |

*Table 6. 14 Levene's Test (One-Tailed) Results for Comparison of $\delta^{18}$O at CA-SAC-107*

| **Type** | ***df*** | **F** | | ***p* value** | |
|---|---|---|---|---|---|
| | | Median | Mean | Median | Mean |
| *var*(Bone) vs. *var*(M1) | 1 8 | 2.06 | 3.89 | 0.19 | 0.08 |
| *var*(Bone) vs. *var*(EFT) | 1 8 | 0.02 | 0.02 | 0.89 | 0.88 |
| *var*(M1) *vs. var*(EFT) | 1 8 | 2.27 | 4.13 | 0.17 | 0.08 |

The $^{87}$Sr/$^{86}$Sr of tooth enamel at CA-SAC-107 ranges from 0.70672 to 0.70700 (range = 28.0 X 10$^{-5}$) for first molars (n = 5), from 0.70691 to 0.70701 (range = 10.0 X 10$^{-5}$) for "early-forming" teeth (n = 2), and 0.70700 to 0.70705 (range = 5.0 X 10$^{-5}$) for third molars (n = 3) (Table 6.10; Table 6.15; Figure 6.14). The $^{87}$Sr/$^{86}$Sr population mean for first molar enamel is 0.70692 (SD = 12.0 X 10$^{-5}$), 0.70696 for "early-forming" teeth (SD = 7.0 X 10$^{-5}$), and 0.70702 third molars (SD = 2.0 X 10$^{-5}$) (Table 6.15; Figure 6.14). The population's $^{87}$Sr/$^{86}$Sr are comparable across teeth, however, sample sizes from each tooth category are too small to run meaningful statistical tests.

Figure 6.15 shows a visual representation of how the $^{87}$Sr/$^{86}$Sr of tooth enamel at CA-SAC-107 relates to the environmental sampling location's $^{87}$Sr/$^{86}$Sr signatures (set at two standard deviations around the mean for each location). None of the samples from the Windmiller Mound fall within the MA/CON-SED-2 or METAVOL-4 parameters (Table 6.10; Table 6.15; Figure 6.15). The mean $^{87}$Sr/$^{86}$Sr of samples at MA/CON-SED-2 are between 0.00024 and 0.00034 greater than those reported for tooth enamel at CA-SAC-107 (Table 6.15; Table 6.9).

*Table 6. 15 Summary Statistics of $^{87}$Sr/$^{86}$Sr at CA-SAC-107*

| **$^{87}$Sr/$^{86}$Sr Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| "Early-forming" tooth enamel $^{87}$Sr/$^{86}$Sr | 2 | 0.70696 | 7.0 X 10$^{-5}$ | 10.0 X 10$^{-5}$ |
| M1 enamel $^{87}$Sr/$^{86}$Sr | 5 | 0.70692 | 12.0 X 10$^{-5}$ | 28.0 X 10$^{-5}$ |
| M3 enamel $^{87}$Sr/$^{86}$Sr | 3 | 0.70702 | 2.0 X 10$^{-5}$ | 5.0 X 10$^{-5}$ |

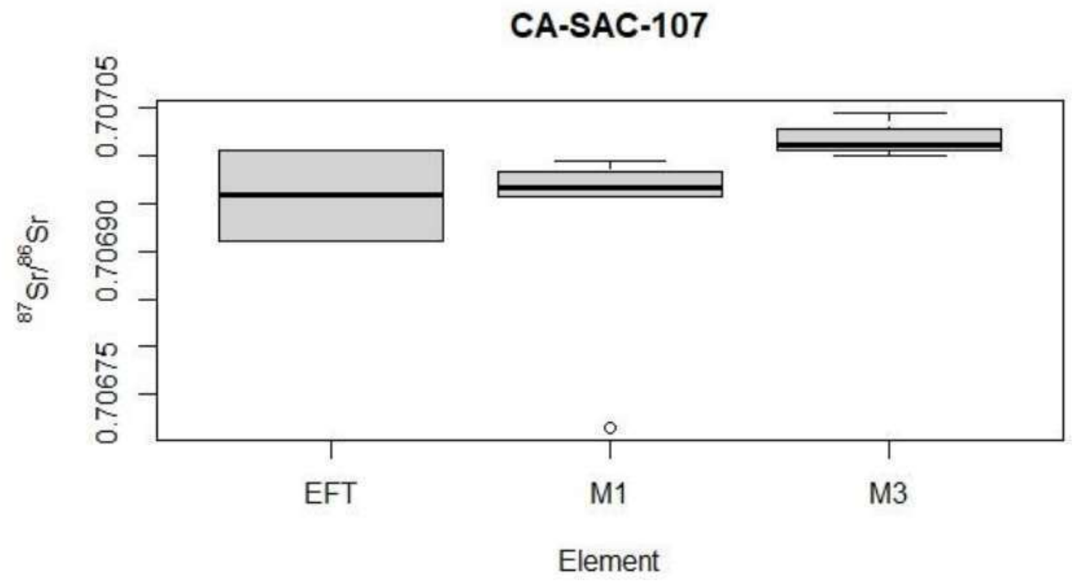

*Figure 6. 14 . Boxplot comparing $^{87}Sr/^{86}Sr$ of first molar (M1), third molar (M3), and "early-forming" tooth (EFT) enamel from CA-SAC-107*

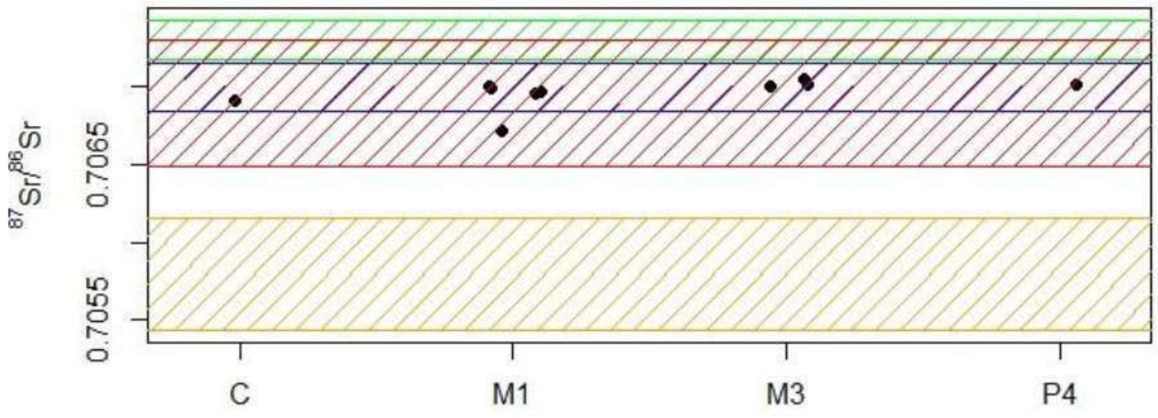

*Figure 6. 15 Stripchart showing $^{87}Sr/^{86}Sr$ of canine (C), second premolar (P4), first molar (M1), and third molar (M3) enamel at CA-SAC-107. Shaded region represents two standard deviations around the mean of MA/CON-SED-1 (blue), MA/CON-SED-2 (green), CON-SED-3 (red), and METAVOL-4 (yellow).*

### *Sex Comparison of $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr at CA-SAC-107*

Isotopic data of human skeletal tissues can elucidate sex-biased dispersal patterns necessary to interpret past postmarital residence practices. This study attempted to generate and compare female versus male mobility profiles using sulfur, oxygen, and strontium isotopes. However, sampling limitations, including small sample sizes and the temporal bias of sampled elements, make this task difficult. Therefore, a diachronic assessment of isotopic tracers of geography at CA-SAC-107 will be more informative and is discussed in the following section. Despite this, comparisons of female and male $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr can still be informative.

The $\delta^{34}$S values for females from CA-SAC-107 for bone range from 5.9 to 6.1‰ (range = 0.2; n = 3) with a mean of 6.0‰ (SD = 0.1) (Table 6.10; Table 6.16; Figure 6.16). First molar values span 2.6 to 5.3‰ (range = 2.7; n = 4) with a mean of 4.0‰ (SD = 1.1), while only one female produced a third molar adequate for sampling and yielded a value of 5.4‰ (Table 6.10; Table 6.16; Figure 6.16). The $\delta^{34}$S values for females from CA-SAC-107 for collagen from "early-forming" teeth range from 3.5 to 5.9‰ (range = 2.4; n = 4) with a mean of 4.3‰ (SD = 1.1) (Table 6.16; Figure 6.16).

Bone $\delta^{34}$S values for males at CA-SAC-107 span from 6.0 to 6.5‰ (range = 0.5; n = 2) with a mean of 6.3‰ (SD = 0.4) (Table 6.10; Table 6.16; Figure 6.16). First molar values vary from 2.2 to 5.3‰ (range = 3.1; n = 2) with a mean of 3.7‰ (SD = 2.2), and "early-forming" teeth range from 1.9 to 4.6‰ (range = 2.6; n = 2) with a mean of 3.2‰ (SD = 1.9) (Table 6.10; Table 6.16; Figure 6.16). Male third molar $\delta^{34}$S spans 3.3 to 5.0‰ (range = 1.7, n = 2) with a mean of 4.1‰ (SD = 1.2) (Table 6.10; Table 6.16; Figure 6.16). Female and male $\delta^{34}$S of bone and dentinal collagen are largely consistent; however, sample sizes are too small to run meaningful statistical comparison between the sexes.

Table 6. 16 Summary Statistics of $\delta^{34}S$ Comparing Females and Males at CA-SAC-107

| **$\delta^{34}S$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| *Bone collagen $\delta^{34}S$* | | | | |
| Female | 3 | 6.0 | 0.1 | 0.2 |
| Male | 2 | 6.3 | 0.4 | 0.5 |
| *"Early-forming" tooth collagen* | | | | |
| Female | 4 | 4.3 | 1.1 | 2.4 |
| Male | 2 | 3.2 | 1.9 | 2.6 |
| *M1 collagen $\delta^{34}S$* | | | | |
| Female | 4 | 4.0 | 1.1 | 2.7 |
| Male | 2 | 3.7 | 2.2 | 3.1 |
| *M3 Collagen $\delta^{34}S$* | | | | |
| Female | 1 | 5.4 | NA | NA |
| Male | 2 | 4.1 | 1.2 | 1.7 |

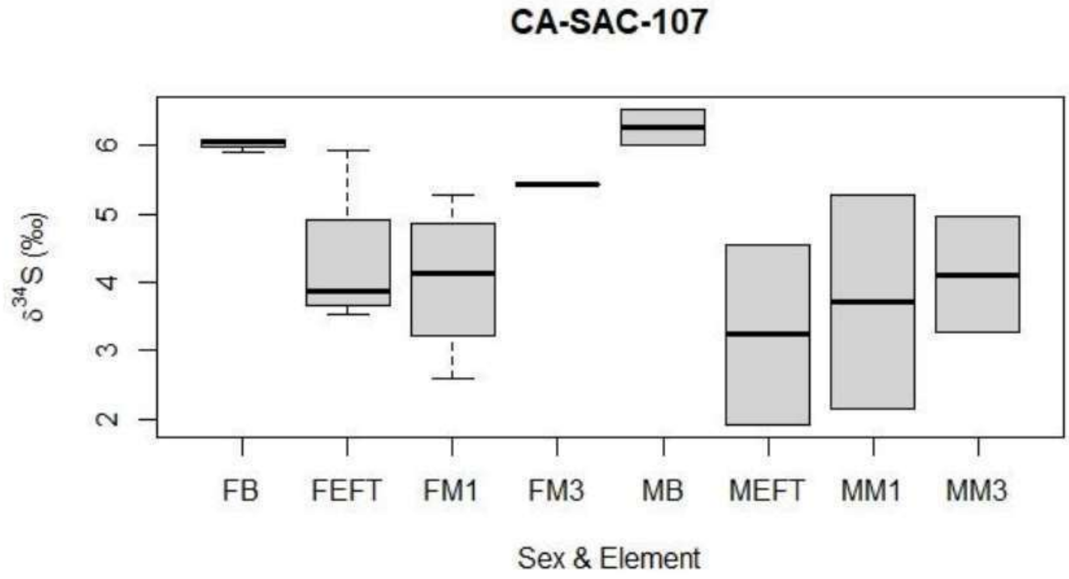

Figure 6. 16 Boxplots comparing female (F) versus male (M) $\delta^{34}S$ of "early-forming" tooth (EFT), first molar (M1) and third molar (M3) dentinal collagen from CA-SAC-107

The $\delta^{18}O$ values for females from CA-SAC-107 for bone vary from -6.9 to -5.2‰ (range = 1.6; n = 3), -6.9 to -3.6‰ for first molars (range = 3.3; n =4), and -6.5 to -4.9‰ (range = 1.7; n = 4) for "early-forming" tooth enamel (Table 6.10; Table 6.17; Figure 6.17). Only one female produced enough enamel for sampling from a third molar, a $\delta^{18}O$ value of -6.3‰. The mean $\delta^{18}O$ values for females are -6.1‰ (SD

= 0.8), -5.2‰ (SD = 1.5), and -5.5‰ (SD = 0.7) for bone, first molars, and “early-forming” teeth, respectively.

Comparatively, the $\delta^{18}O$ values for males from CA-SAC-107 span from -6.8 to -6.1‰ for bone (range = 0.7; n = 2), and -7.2 to -6.1‰ for third molars (range = 1.1, n = 2) (Table 6.10; Table 6.17, Figure 6.17). For both first molar and “early-forming” tooth samples—in this case, a mandibular-second incisor—only one male for each had sufficient enamel for sampling and produced $\delta^{18}O$ values of -5.6‰ and -5.4‰, respectively. For males, the mean $\delta^{18}O$ of bone is -6.5‰ (SD = 0.5), and third molars is -6.7‰ (SD = 0.8). Overall, like $\delta^{34}S$, male and female $\delta^{18}O$ are comparable, but samples sizes are too small to make meaningful statistical comparisons.

*Table 6. 17 Summary Statistics of $\delta^{18}O$ Comparing Females and Males at CA-SAC-107*

| **$\delta^{18}O$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| *Bone apatite $\delta^{18}O$* | | | | |
| Female | 3 | -6.1 | 0.8 | 1.6 |
| Male | 2 | -6.5 | 0.5 | 0.7 |
| *“Early-forming” tooth enamel $\delta^{18}O$* | | | | |
| Female | 4 | -5.5 | 0.7 | 1.7 |
| Male | 1 | -5.4 | NA | NA |
| *M1 enamel $\delta^{18}O$* | | | | |
| Female | 4 | -5.2 | 1.5 | 3.3 |
| Male | 1 | -5.6 | NA | NA |
| *M3 enamel $\delta^{18}O$* | | | | |
| Female | 1 | -6.3 | NA | NA |
| Male | 2 | -6.7 | 0.8 | 1.1 |

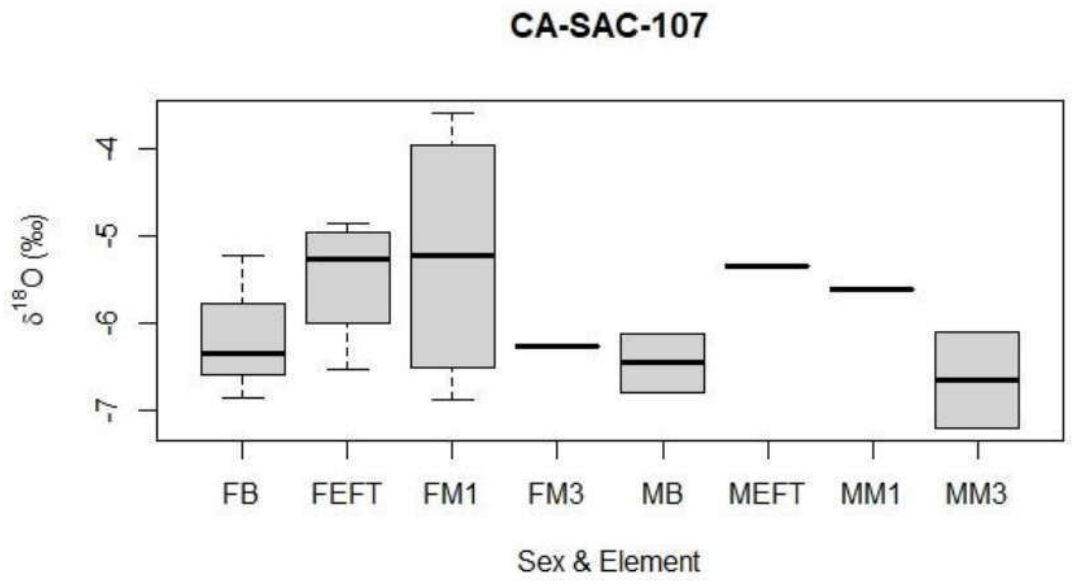

*Figure 6. 17 Boxplots comparing female (F) versus male (M) $\delta^{18}O$ of "early-forming" tooth (EFT), first molar (M1) and third molar (M3) enamel from CA-SAC-107*

Only ten individuals from the Windmiller Mound had enough enamel to conduct $^{87}Sr/^{86}Sr$ analysis. Female (n = 7) $^{87}Sr/^{86}Sr$ values range from 0.70672 to 0.70701 (range = 29.8 X $10^{-5}$) with a mean of 0.70694 (SD = 10.3 X $10^{-5}$) (Table 6.10; Table 6.18; Figure 6.18). Male (n = 3) $^{87}Sr/^{86}Sr$ values range from 0.70700 to 0.70705 (range = 5.0 X $10^{-5}$) with a mean of 0.70701 (SD = 2.7 X $10^{-5}$) (Table 6.10; Table 6.18; Figure 6.18). Males have $^{87}Sr/^{86}Sr$ that are relatively, but minimally, more enriched in $^{87}Sr$ than females. Females show greater variation than males; however, this is likely a product of females having a larger sample size. As well, the female range is largely shaped by one female (12-7789(0)) who shows relatively low $^{87}Sr/^{86}Sr$ (0.70672) compared to the rest of the CA-SAC-107 population. The very small sample size of males for $^{87}Sr/^{86}Sr$ analysis makes meaningful statistical comparisons impossible.

*Table 6. 18 Summary Statistics of $^{87}Sr/^{86}Sr$ Comparing Females and Males at CA-SAC-107*

| **$^{87}Sr/^{86}Sr$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Female | 7 | 0.70694 | 10.3 X $10^{-5}$ | 29.8 X $10^{-5}$ |
| Male | 3 | 0.70701 | 2.7 X $10^{-5}$ | 5.0 X $10^{-5}$ |

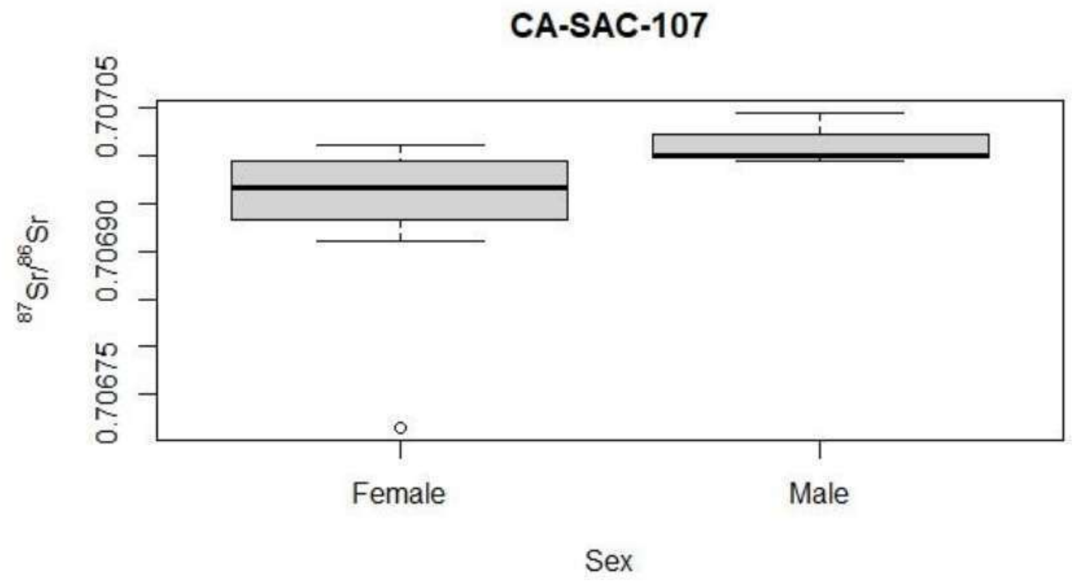

*Figure 6. 18 Boxplot comparing female versus male $^{87}$Sr/$^{86}$Sr of tooth enamel from CA-SAC-107*

Overall, the crosscutting of a multitude of factors, including the type of element sampled, sex, and chronology, introduce confounding variables. Appraisal of $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr across different temporal periods is discussed in the next section.

### *Chronological Comparisons of $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr at CA-SAC-107*

The $\delta^{34}$S of sampled elements (n = 8) dating to the Early Period (2239–3540 cal BP) from CA-SAC-107 ranges from 2.2 to 6.5‰ (range = 4.4) with a mean of 5.3‰ (SD = 1.4) (Table 6.10; Table 6.19). Only one radiocarbon dated sample (first molar dentinal collagen from 12-5615(0)) dates to the Middle Period (1411–1569 cal BP) with $\delta^{34}$S of 4.4‰ (Table 6.10; Table 6.19). The $\delta^{34}$S of sampled elements (n = 3) dating to the Late Period (*circa* 385 cal BP) ranges from 2.6 to 5.5‰ (range = 2.9) with a mean of 3.9‰ (SD = 1.5) (Table 6.10; Table 6.19). Six radiocarbon-dated samples from CA-SAC-107 date to the Historic period (median probability less than 140 cal BP); $\delta^{34}$S values of these samples range from 1.9 to 5.3‰ (range = 3.4) with a mean of 3.7‰ (SD = 1.1). Late and Historic Period samples show less variation than the Early Period (Table 6.19; Figure 6.19). As well, the mean $\delta^{34}S$ of Early Period samples is 1.3‰ and 1.5‰ greater than those reported for the Late and Historic Periods, respectively (Table 6.19; Figure 6.19). The sample sizes of the Early and Historic periods are sufficient for statistical comparison.

*Table 6. 19 Summary Statistics of Chronological Comparisons of $\delta^{34}S$ Values at CA-SAC-107*

| **$\delta^{34}S$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Early Period | 8 | 5.3 | 1.4 | 4.4 |
| Middle Period | 1 | 4.4 | *NA* | *NA* |
| Late Period | 3 | 3.9 | 1.5 | 2.9 |
| Historic | 6 | 3.7 | 1.1 | 3.4 |

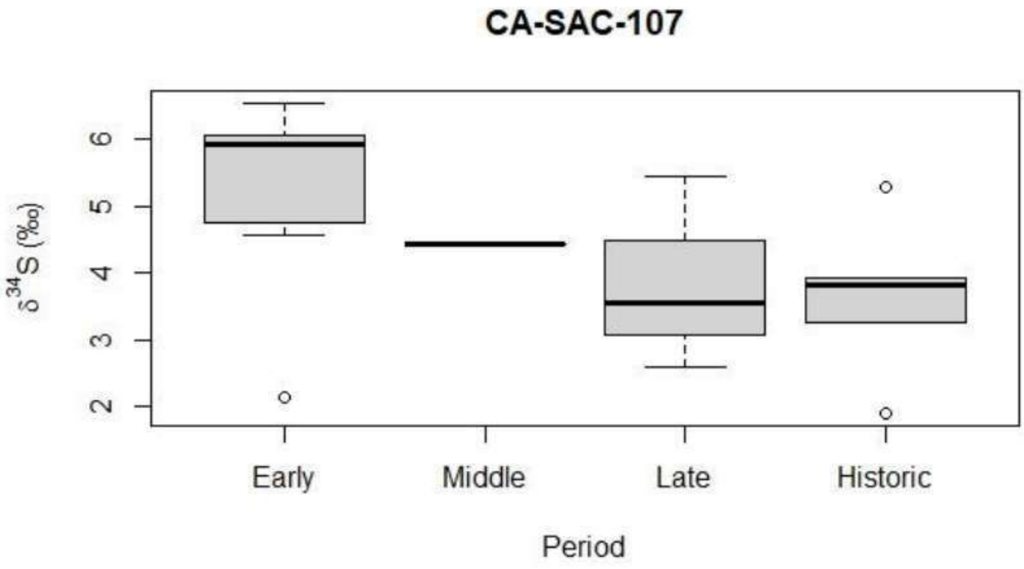

*Figure 6. 19 Boxplot showing comparisons of $\delta^{34}S$ based on chronology at CA-SAC-107*

Results of the one-tailed Levene's test for equality of variance showing temporal comparisons of $\delta^{34}S$ and $\delta^{18}O$ at CA-SAC-107 are presented in Table 6.20. Greater variation of $\delta^{34}S$ for the Early Period subset compared to those with younger dates is consistent with decreasing general mobility in central California. However, comparison of *var*(Early Period) vs. *var*(Historic) does not show a significant difference at an alpha of 0.05 due to small sample size. Statistical comparison of each period's mean $\delta^{34}$S values using the Mann-Whitney test demonstrates a significant difference ($p = 0.03$) between Early and Historic period mean values at the 0.05 level (Table 6.21). This suggests that during the Early Period, individuals from the CA-SAC-107 population were foraging in locales with distinct sources of available sulfur from those who lived during the Historic Period. However, none of the Historic Period samples include bone collagen. Therefore, this distinction may be driven more by differences in mobility and diet of children/adolescents and adults than diachronic trends in mobility.

*Table 6. 20 Levene's Test (One-Tailed) Results for Chronological Comparison of $\delta^{34}$S and $\delta^{18}$O at CA-SAC-107*

| **Type** | ***df*** | **F** | | ***p* value** | |
|---|---|---|---|---|---|
| | | Median | Mean | Median | Mean |
| *var*(Early) vs. *var*(Historic) | | | | | |
| $\delta^{34}$S | 1<br>12 | 0.11 | 0.48 | 0.75 | 0.50 |
| $\delta^{18}$O | 1<br>10 | 0.75 | 0.94 | 0.41 | 0.36 |

*Table 6. 21 Mann-Whitney Results for Chronological Comparison of $\delta^{34}$S and $\delta^{18}$O at CA-SAC-107*

| **Type** | ***N*** | ***Z*** | ***p* value** |
|---|---|---|---|
| Early Period vs. Historic | | | |
| $\delta^{34}$S | 14 | -2.18 | **0.03*** |
| $\delta^{18}$O | 12 | -1.62 | 0.11 |
| *significant at α = 0.05 | | | |

The $\delta^{18}$O values for the CA-SAC-107 population dating to the Early Period range from -6.9 to -5.2‰ (range = 1.6), -6.9 to -6.3‰ (range = 0.6) for those dating to the Late Period, and from -7.2 to -3.6‰ (range = 3.6) for Historic samples (Table 6.10; Table 6.22). The on Middle Period samples reveals a $\delta^{18}$O value of -6.2‰. The $\delta^{18}$O population mean is -6.0‰ (SD = 0.7) for the Early Period, -6.6‰ (SD = 0.3) for the Late Period, and -5.0‰ (SD = 1.4) for the Historic Period (Table 6.22; Figure 6.20).

The mean $\delta^{18}$O of the Historic samples shows a 1.0‰ and 1.8% enrichment compared to the Early and Late Period, respectively. Historic samples also exhibit the highest standard deviation and range for the CA-SAC-107 population (Table 6.22; Figure 6.20). However, comparisons of Early and Historic Period mean $\delta^{18}O$ (Table 6.21) and variation (Table 6.20) do not show significant chronological differences of $\delta^{18}O$ values at CA-SAC-107. Variation during the Historic Period is driven by one male's (12-7787(0)) third-molar enamel whose $\delta^{18}O$ is 2.2‰ lower than the Historic mean (Table 6.10; Table 6.22). Since $\delta^{18}O$ becomes progressively more negative the further inland in California (Kendall and Copeland 2001), this suggests that 12-7787(0) likely lived further east as a late adolescent/early adult than the rest of the population living at Windmiller Mound during the Historic Period. Additionally, when this male is excluded from the Historic mean $\delta^{18}O$, the values illustrate even greater enrichment in $^{18}O$ compared to older periods (Table 6.22; Figure 6.20). This suggests that throughout their lives, those living near the Windmiller Mound between the Early and Late periods spent more time in environs further east compared to those who were buried at the site after about 150 years ago.

*Table 6. 22 Summary Statistics of Chronological Comparisons of $\delta^{18}O$ Values at CA-SAC-107*

| **$\delta^{18}O$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Early Period | 7 | -6.0 | 0.7 | 1.6 |
| Middle Period | 1 | -6.2 | NA | NA |
| Late Period | 3 | -6.6 | 0.3 | 0.6 |
| Historic | 5 | -5.0 | 1.4 | 3.6 |

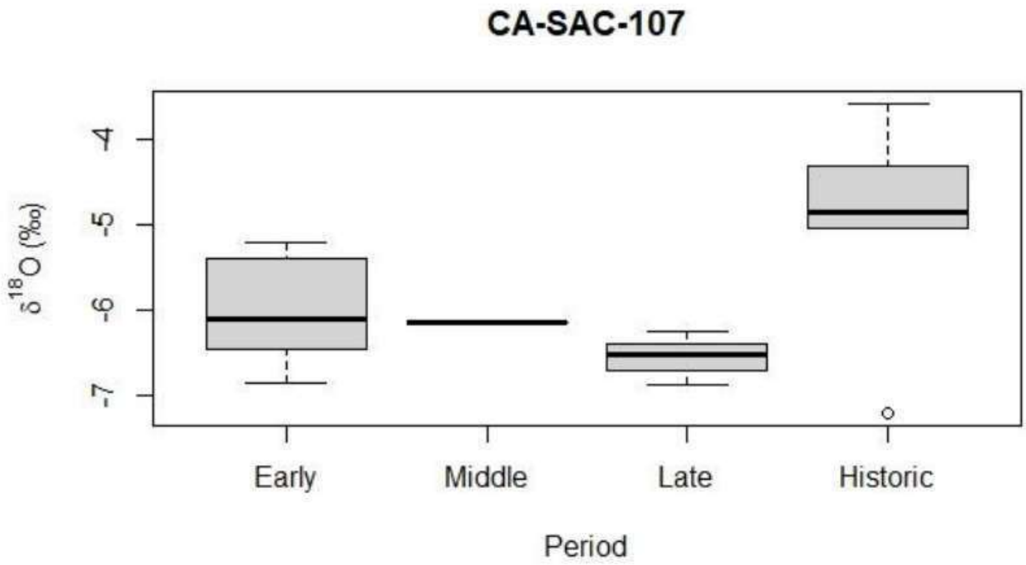

*Figure 6. 20 Boxplot showing comparisons of $\delta^{18}O$ based on chronology at CA-SAC-107*

Most of the directly dated samples used for $^{87}Sr/^{86}Sr$ analysis at CA-SAC-107 are Historic (n = 4). These samples' $^{87}Sr/^{86}Sr$ range from 0.70697 to 0.70701 (range = 3.9 X $10^{-5}$) with a mean of 0.70699 (SD = 1.8 X $10^{-5}$) (Table 6.10; Table 6.23). Samples dating to the Early Period (n =2) range from 0.70691 to 0.70705 (range = 13.39 X $10^{-5}$) and from 0.70672 to 0.70701 (range = 29.8 X $10^{-5}$) for the Late Period (n = 2) (Table 6.10; Table 6.23). Only one sample directly dates to the Middle Period with a $^{87}Sr/^{86}Sr$ value of 0.70696. Thus, mean $^{87}Sr/^{86}Sr$ is consistent across all time periods. Late Period samples show the greatest variation, although this is largely driven by one individual (12-7789(0)) who is comparably less enriched in $^{87}Sr$ (0.70672) (Table 6.10; Table 6.23). The small sample sizes reported for each time period makes meaningful statistical comparisons not possible.

*Table 6. 23 Summary Statistics of Chronological Comparisons of $^{87}Sr/^{86}Sr$*

| **$^{87}Sr/^{86}Sr$ Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| Early Period | 2 | 0.70698 | 9.5 X $10^{-5}$ | 13.39 X $10^{-5}$ |
| Middle Period | 1 | 0.70696 | NA | NA |
| Late Period | 2 | 0.70686 | 21.0 X $10^{-5}$ | 29.8 X $10^{-5}$ |
| Historic | 4 | 0.70699 | 1.8 X $10^{-5}$ | 3.9 X $10^{-5}$ |

## Isotopic Indicators of Mobility at CA-SJO-68

*Table 6. 24 Results of Isotopic Analysis of Bone and Teeth Samples from CA-SJO-68 Used to Study Paleomobility*

| PAHMA # | Sex | Element Sampled | $\delta^{34}S$ | $\delta^{18}O$ | $^{87}Sr/^{86}Sr$ |
|---|---|---|---|---|---|
| 12-5824(0) | Male | Bone | 3.4 | -8.1 | NA |
| 12-5833(0) | Male | Bone | 4.5 | -8.9 | NA |
| | | $M_1$ | 3.2 | — | — |
| | | $M_3$ | 4.3 | -8.0 | 0.706950 |
| 12-6472(0) | Female | Bone | 4.0 | NA | NA |
| | | $M_1$ | 2.1 | -6.5 | 0.706907 |
| 12-7568(0) | Male | $M^1$ | 1.8 | -5.7 | 0.706897 |
| 12-7569(0) | Female | Bone | 3.9 | -7.7 | NA |
| | | $M_1$ | 3.6 | -7.1 | 0.706646 |
| | | $M_3$ | 3.2 | -7.7 | 0.706780 |
| 12-7575(0) | Female | Bone | 4.9 | NA | NA |
| | | $M_1$ | 6.3 | -6.5 | 0.706981 |
| | | $M_3$ | 6.3 | -6.0 | 0.709450 |
| 12-7577 | Female | Bone | 6.1 | -8.4 | NA |
| | | $M^1$ | 6.3 | -5.9 | 0.706862 |
| 12-7581.1 | Female | Bone | 2.7 | -8.2 | NA |
| | | $M^1$ | 5.3 | -7.4 | 0.706874 |
| 12-7582(0) | Male | Bone | 4.6 | -8.0* | NA |
| | | $I_2$ | 5.0 | -6.6 | 0.706994 |
| 12-7588(0) | Female | Bone | 4.4 | -7.2 | NA |
| | | $M_1$ | 5.4 | — | 0.706873 |
| | | $M_3$ | 6.3 | -6.2 | 0.707030 |
| 12-7591(0) | Male | Bone | — | -6.6* | NA |
| | | $I_2$ | 1.6 | -5.8 | 0.706971 |
| | | $M_3$ | 1.2 | -6.9 | 0.707010 |
| 12-7598(0) | Female | Bone | 3.8 | -7.8 | NA |
| | | $M^1$ | 5.1 | -7.1 | 0.706910 |
| 12-7603(0) | Male | Bone | 4.7 | NA | NA |
| | | $M_1$ | 4.1 | -6.9 | 0.706825 |
| | | $M_3$ | 4.4 | -7.4 | 0.710000 |
| 12-7608(0) | Female | Bone | 4.6 | -8.1 | NA |
| | | $M_1$ | 4.2 | -6.8 | 0.706881 |
| | | $M_3$ | 4.3 | -7.0 | 0.707000 |
| 12-7613(0) | Male | Bone | 2.8 | NA | NA |
| | | $M_1$ | — | -5.8 | 0.706821 |
| | | $M_3$ | 2.6 | -6.1 | 0.706880 |
| 12-7614.1 | Male | Bone | 4.8 | -7.5 | NA |
| | | $M_1$ | 3.0 | -6.3 | 0.706949 |
| | | $M_3$ | 2.5 | -6.3 | 0.706950 |
| 12-7621(0) | Male | Bone | 4.6 | -8.4 | NA |

| PAHMA # | Sex | Element Sampled | $\delta^{34}$S | $\delta^{18}$O | $^{87}$Sr/$^{86}$Sr |
|---|---|---|---|---|---|
| | | $M_1$ | 3.7 | -7.1 | 0.706905 |
| | | $M^3$ | 4.3 | -6.7 | 0.706890 |
| 12-7622.1 | Female | Bone | 5.3 | -7.1 | NA |
| | | $M^1$ | 5.9 | -5.9 | 0.706744 |
| 12-7624(0).1 | Male | $M_1$ | 3.4 | -7.1 | 0.706828 |
| | | $M_3$ | 5.6 | -6.0 | 0.706850 |
| 12-7634(0) | Male | Bone | 5.6 | -8.2 | NA |
| | | $M^1$ | 4.5 | -6.6 | 0.707000 |
| | | $M_3$ | 4.9 | -6.1 | — |
| 12-7638.1 | Female | Bone | 4.9 | -8.5 | NA |
| | | $I_2$ | 5.7 | — | --- |
| | | $M_3$ | 5.2 | -6.8 | 0.706830 |
| 12-7640.1 | Male | Bone | 5.6 | -7.9 | NA |
| | | $M_1$ | 6.2 | -7.6 | 0.706867 |
| | | $M^3$ | 6.8 | -8.3 | 0.706920 |
| 12-7646(0) | Male | Bone | 6.5 | -6.6 | NA |
| | | $M_1$ | 5.5 | -4.78 | 0.706965 |
| | | $M_3$ | 6.8 | -5.2 | 0.707010 |
| 12-7652.1 | Male | Bone | 2.4 | -7.5 | NA |
| | | $M_1$ | 2.0 | -6.0 | 0.709000 |
| | | $M_3$ | 1.3 | -5.5 | 0.706970 |
| 12-8022(0) | Male | Bone | 3.2 | -7.6 | NA |
| | | $M_1$ | 3.8 | -5.3 | 0.706840 |
| | | $M_3$ | 2.6 | -7.0 | 0.706760 |
| 12-8024(0) | Female | Bone | 3.6 | -7.8 | NA |
| | | $M_1$ | 2.1 | -6.1 | 0.707000 |
| 12-8025(0) | Female | Bone | 3.5 | -7.8 | NA |
| | | $M_1$ | 2.5 | -5.2 | 0.707000 |

Note:
— insufficient material for analysis
NA not applicable; not submitted for analysis.
* unusually high % carbonate

### *$\delta^{34}$S Results*

The $\delta^{34}$S values of bone collagen for the CA-SJO-68 population range from 2.4 to 6.5‰ (range = 4.1), 1.8 to 6.4‰ (range = 4.6) for first molar dentinal collagen, and 1.2 to 6.8‰ (range = 5.6) for third molar dentinal collagen (Table 6.24, Table 6.25). The $\delta^{34}$S population mean for bone collagen is 4.3‰ (SD = 1.1), 4.1‰ (SD = 1.5) for first molar dentinal collagen, and 4.3‰ (SD = 1.8) for third molar dentinal collagen (Table 6.25).

Bone $\delta^{34}$S values represent the "local" signature at CA-SJO-68 since individuals are most likely buried in areas near to where they lived prior to death, and bone collagen reflects diet and mobility for the last five to 25 years of life (Hedges et al. 2007). Thus, two standard deviations around the mean $\delta^{34}$S of bone (2.1‰ to 6.5‰) delimit the "local" range for the area surrounding and including archaeological site CA-SJO-68.

*Table 6. 25 Summary Statistics of $\delta^{34}$S Values at CA-SJO-68*

| **$\delta^{34}$S Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| *Bone Collagen* **$\delta^{34}$S** | | | | |
| Population | 24 | 4.3 | 1.1 | 4.1 |
| Female | 12 | 4.3 | 0.9 | 3.4 |
| Male | 12 | 4.4 | 1.2 | 4.1 |
| *M1 Collagen* **$\delta^{34}$S** | | | | |
| Population | 23 | 4.1 | 1.5 | 4.6 |
| Female | 11 | 4.4 | 1.6 | 4.2 |
| Male | 12 | 3.7 | 1.4 | 4.6 |
| *M3 Collagen* **$\delta^{34}$S** | | | | |
| Population | 17 | 4.3 | 1.8 | 5.6 |
| Female | 5 | 5.1 | 1.4 | 3.1 |
| Male | 12 | 3.9 | 1.9 | 5.6 |

The mean $\delta^{34}$S values of bone, first molars, and third molars are similar, with third molars values at 4.3‰ and first molars showing a slightly lower mean $\delta^{34}$S values at 4.1‰ (Table 6.25; Figure 6.21). Both first and third molars exhibit a greater range of $\delta^{34}$S values than bone (4.1‰), 4.6‰ and 5.6‰, respectively (Table 6.25; Figure 6.21). This suggests that compared to later in life, the population from CA-SJO-68 foraged from marginally more varied environments in their childhood with greater heterogeneity in available sulfur. The $\delta^{34}$S of teeth suggests that people were most mobile during their teenage years, followed by early childhood, and were more sedentary as adults.

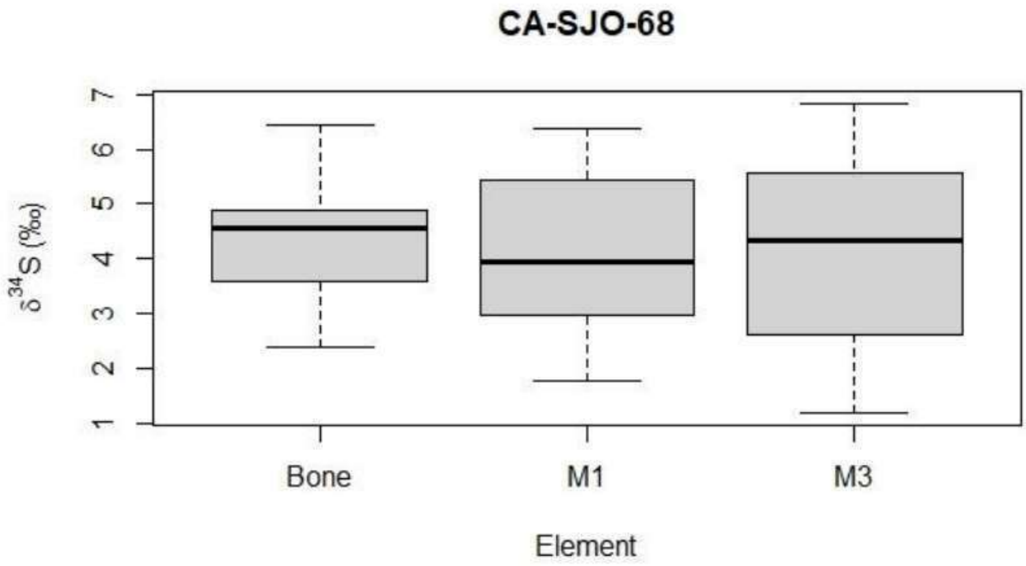

*Figure 6. 21 Boxplot comparing $\delta^{34}S$ in bone collagen, first molar dentinal collagen (M1), and third molar dentinal collagen (M3) from CA-SJO-68*

Results of the one-tailed Levene's test for equality of variance comparing $\delta^{34}$S in bone and teeth are presented in Table 6.26. Greater variation is expected for teeth than bone values for populations that practice exogamous marriage. Comparison of *var*(bone) and *var*(M3) reveals a significant *p*-value (0.03) at an alpha level of 0.05 (Table 6.26). Therefore, we can reject the null hypothesis that bone and third molar variance are equal at the *p* = 0.05 level. A comparison of *var*(bone) and *var*(M1) shows the same pattern, but only approaches significance (*p* = 0.06) (Table 6.26). The Levene's test reveals no statistically significant difference in *var*(M1) *versus* *var*(M3) (Table 6.26).

*Table 6. 26 Levene's* Test (One-Tailed) Results for Comparison of $\delta^{34}S$ Values at CA-SJO-68*

| **Type** | ***df*** | **F** | ***p* value**[†] |
|---|---|---|---|
| *var*(bone) vs. *var*(M1) | 1<br>44 | 3.889 | 0.055[‡] |
| *var*(bone) vs. *var*(M3) | 1<br>39 | 5.101 | **0.030**[‡] |
| var(M1) vs. *var*(M3) | 1<br>37 | 0.358 | 0.553 |
| Note:<br>*center = median<br>[†] α = 0.05<br>[‡]significant results at α = 0.1 | | | |

Taken together, results of the Levene's test and review of summary statistics suggest that in the time during which first and third molar dentinal collagen formed, individuals from CA-SJO-68 foraged in environments with a greater range of available sulfur isotope ratios. This implies that at least some individuals originated from other locales in their youth and migrated to the proximate area of the site later in life. This pattern is consistent with a population that permits at least some marriage exogamy. Overall, the low standard deviations reported for the CA-SJO-68 population (and comparable ranges for bone and first molars) suggest a relatively low inter-individual variation (Table 6.25; Figure 6.21). Although, the Levene test comparing bone and third molar values and the comparably higher range reported for third molars indicates that as teenagers, individuals from the Blossom Mound were living in a broader range of locales (Table 6.25; Table 6.26). Accordant mean $\delta^{34}$S bone and teeth values suggest that this population, on average, foraged in, or consumed resources from, similar environs during childhood, teenage, and later adult years.

The CA-SJO-68 $\delta^{34}$S values for female bone range from 2.5 to 6.1‰ (range = 3.4; n = 12) with a mean of 4.3‰ (SD = 0.9) (Table 6.25; Figure 6.22). First molar values span 1.8 to 6.3‰ (range = 4.2; n = 11) with a mean of 4.4‰ (SD = 1.6), while the limit of third molar values falls within 3.2 to 6.3‰ (range = 3.1; n = 5) with a mean of 5.1‰ (SD = 1.4) (Table 6.25; Figure 6.22).

Bone $\delta^{34}$S values for males span from 1.8 to 6.5‰ (range = 4.1; n = 12) with a mean of 4.4‰ (SD = 1.2) (Table 6.25; Figure 6.22). First molar values vary from 1.8 to 6.4‰ (range = 4.6; n = 12) with a mean of 3.7‰ (SD = 1.4) and third molar $\delta^{34}$S range from 1.2 to 6.8‰ (range = 5.6, n = 12) with a mean of 3.9‰ (SD = 1.9) (Table 6.25; Figure 6.22). Figure 6.23 indicates where female and male $\delta^{34}$S of bone, first, and third molars fall relative to the "local" range (2.1 to 6.5%).

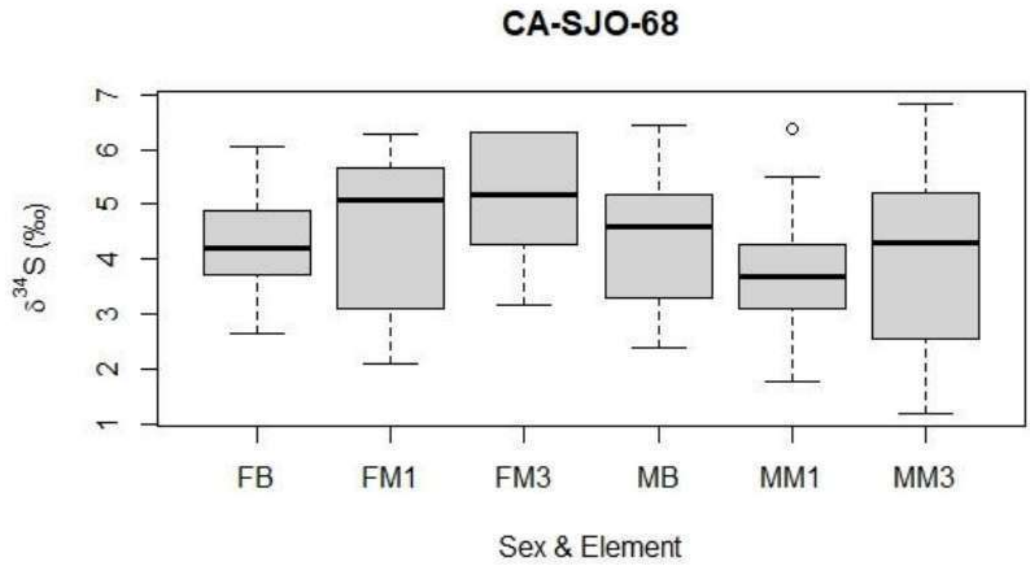

*Figure 6. 22 Boxplots comparing female (F) versus male (M) $\delta^{34}S$ in bone collagen (B), 1st molar dentinal collagen (M1), and 3rd molar dentinal collagen (M3) from CA-SJO-68*

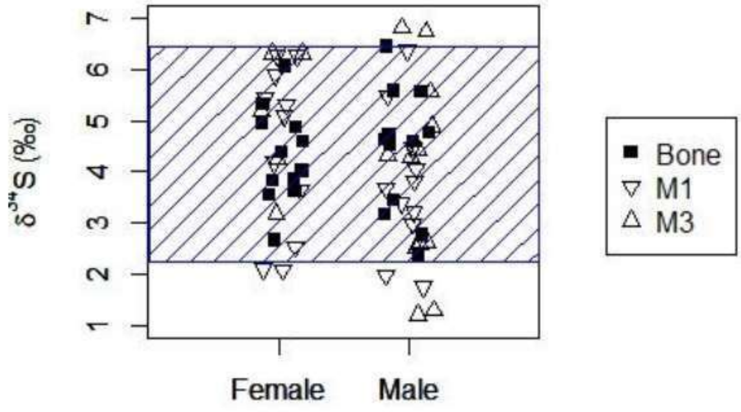

*Figure 6. 23 Comparison of female versus male $\delta^{34}S$ in bone collagen, 1st molar dentinal collagen, and 3rd molar dentinal collagen from CA-SJO-68 ("local" site range indicated by shaded section)*

On average, males show slightly higher $\delta^{34}S$ of bone than females, but a slightly lower $\delta^{34}S$ of first molars (Table 6.25; Figure 6.22). However, these distinctions are minor, representing only a 0.1‰ and 0.7‰ difference for bone and first molars, respectively. Females show third molar $\delta^{34}S$ values greater than those observed for males by 1.2‰ (Table 6.25). This data are skewed towards male third molars (n = 12) due to the lack of available third molars for sampling from females (n = 5).

As well, the lower mean $\delta^{34}S$ of third molars for males is driven mainly by two males (12-7591(0) and 12-7652.1) with "nonlocal" signatures that are comparably depleted in $^{34}S$ (Table 6.1; Figure 6.23). Statistical comparison of female *versus* male mean $\delta^{34}S$ values across all elements sampled demonstrates no meaningful difference at the 0.05 level (Table 6.27). Overall, males show greater inter-individual variation compared to females (Table 6.25; Figure 6.22).

*Table 6. 27 Mann-Whitney U Results for Comparison of Mean $\delta^{34}S$ Values of Females Versus Males at CA-SJO-68.*

| **Type** | ***N*** | ***Z*** | ***p* value*** |
|---|---|---|---|
| Bone Collagen $\delta^{34}S$ | 25 | -0.14 | 0.80 |
| M1 Collagen $\delta^{34}S$ | 23 | -0.97 | 0.33 |
| M3 Collagen $\delta^{34}S$ | 17 | -0.87 | 0.38 |
| * $\alpha = 0.05$ | | | |

Reconstruction of individual-level mobility patterns at CA-SJO-68 using $\delta^{34}S$ reveals that seven individuals (two females and five males) show evidence for mobility or migration (Table 6.28). Two patterns emerge: (1) "nonlocal $\delta^{34}S$" of one or both teeth with "local $\delta^{34}S$" of bone, and (2) "local $\delta^{34}S$" of the first molar, "nonlocal $\delta^{34}S$" of the third molar, and "local $\delta^{34}S$" of bone. The first pattern is consistent with individuals living elsewhere during their early childhood and teenage/early adult years and then migrating to the vicinity of archaeological site CA-SJO-68 as later adults. Two females, 12-6472(0) and 12-8024(0) reflect this first pattern. Unfortunately, neither of them had available third molars for testing. Therefore, we cannot conclude whether they resided in an environment with distinct $\delta^{34}S$ values from the CA-SJO-68 location during their teenage/early adult years or migrated to the site during that time. One female's, 12-8024(0), $\delta^{34}$S of the first molar (2.1‰) is on the lower edge of the "local" range for the site (Table 6.24; Figure 6.23).

*Table 6. 28 Select Mobility Patterns Observed at CA-SJO-68 Based on $\delta^{34}$S analysis*

| **PAHMA #** | **Sex** | **Mobility Pattern** |
|---|---|---|
| 12-6472(0) | Female | NL --> (—) --> L |
| 12-8024(0) | Female | NL --> (—) --> L* |
| 12-7568(0) | Male | NL --> (—) --> (L?) |
| 12-7591(0) | Male | NL --> NL --> (L?)$^{\dagger}$ |
| 12-7640.1 | Male | L --> NL --> L |
| 12-7646(0) | Male | L --> NL --> L$^{\pm}$ |
| 12-7652.1 | Male | NL --> NL --> L |

Note:
NL = "nonlocal"
L = "local"
(—) tooth unavailable for analysis
(L?) insufficient collagen for sulfur analysis; presumed local based on burial location
*on edge of "local" range
$^{\dagger}$ $I_2$ sampled in place of first molar
$^{\pm}$ upper limit of "local" range

Three males, 12-7568(0), 12-7591(0), and 12-7652.1, show "nonlocal" tooth $\delta^{34}$S values but likely resided locally as adults (Table 6.24; Figure 6.23). One male, 12-7568(0), only had a first molar available for study (Table 6.24). Bone from 12-7591(0) did not produce enough collagen for sulfur analysis to interpret residence as an adult (Table 6.24; Figure 6.23). Presumably, both of these individuals lived at or near the site later in life since they were interred at CA-SJO-68. One male, 12-7652.1, likely migrated to the site as an adult based on "nonlocal" $\delta^{34}$S values of first and third molars and "local" $\delta^{34}$S of bone. Two males (12-7640.1 and 12-7646(0)) show "local" $\delta^{34}$S of first molars and bone but "nonlocal" $\delta^{34}$S of third molars (Figure 6.23). This pattern is consistent with living locally at the site as children, migrating to a different locale during their teenage or early adult years, and then returning to the site as older adults.

Based on first molars and other early forming teeth, about 17% of females and 21% of males show "nonlocal" $\delta^{34}S$ (Table 6.29). In comparison, 100% of females show "local" $\delta^{34}S$ of third molars, while about 33% of males show "nonlocal" values (Table 6.29). For both males and females, 100% of bone $\delta^{34}S$ falls within the "local" range (Table 6.29; Figure 6.23). Despite a slight bias of males within the proportion of nonlocals, statistical significance cannot be demonstrated at the 0.05 level using the Fisher's exact test (Table 6.29). However, the third molar data should be interpreted with caution due to the small sample size available for females (n = 5).

*Table 6. 29 Fisher's Exact Test Results for Comparison of "Local" Versus "Nonlocal" Status of Females and Males Based on $\delta^{34}S$ Values at CA-SJO-68.*

| **$\delta^{34}S$ Breakdown** | **Local** | **Nonlocal** | **% Nonlocal** | ***p*-value*** |
|---|---|---|---|---|
| *M1 Collagen $\delta^{34}S^{\dagger}$* | | | | |
| Female | 10 | 2 | 16.7 | 1.00 |
| Male | 11 | 3 | 21.4 | |
| *M3 Collagen $\delta^{34}S$* | | | | |
| Female | 5 | 0 | 0.0 | 0.26 |
| Male | 8 | 4 | 33.3 | |

Notes:
*$\alpha = 0.05$
$^{\dagger}$ includes other early-forming teeth (e.g., second incisors) of individuals for which first molars are unavailable for analysis (Table 6.24)

In summary, $\delta^{34}S$ results are most consistent with a sedentary population mostly practicing village (or within the immediate area) marriage-endogamy, with a few migrants. The small number of individuals migrating to the site includes both females and males, with several males showing an interesting pattern of leaving the area of CA-SJO-68 as teenagers or young adults and returning to the site later in life.

### *$\delta^{18}O$ Results*

Two individuals, 12-7582(0) and 12-7591(0), have unusual % carbonate of bone apatite (14.2 and 16.1%, respectively) that fall outside of the typical range (about 2–6%) and therefore were not included in the following analysis of bone $\delta^{18}O$. The $\delta^{18}O$ values for the CA-SJO-68 population range from

-8.9 to -7.1‰ (range = 2.3) for bone apatite, -7.4 to -4.8‰ (range = 2.8) for first molar enamel, and -8.3 to -5.2‰ (range = 2.8) for third molar enamel (Table 6.30; Figure 6.24). The $\delta^{18}$O population mean is -7.9‰ (SD = 0.6) for bone apatite, -6.4‰ (SD = 0.8) for first molar enamel, and -6.7‰ (SD = 0.9) for third molar enamel (Table 6.30; Figure 6.24). The mean $\delta^{18}$O of bone is relatively depleted in $^{18}$O by 1.2 and 1.5‰ compared to first and third molars, respectively (Table 6.30; Figure 6.24). However, this result should be interpreted with caution since $\delta^{18}$O of bone apatite is susceptible to diagenesis. The first molar and third molar $\delta^{18}$O are comparable; however, first molar $\delta^{18}$O values are slightly elevated which is consistent with enrichment expected for the tissues of breast-feeding infants (Table 6.30; Figure 6.24). Third molars show the greatest range and standard deviation (Table 6.30; Figure 6.24).

These results, including lower variation reported for bone values, are consistent with patterns observed from $\delta^{34}$S of sampled tissues from CA-SJO-68. Like the $\delta^{34}$S results, $\delta^{18}$O of bone, first molars, and third molars imply that during childhood and as teenagers, the Blossom Mound population drank water from moderately more varied environments with more diverse sources of available oxygen than as adults. As anticipated, the bone $\delta^{18}$O values, as a whole, show a clear offset from the tooth values (Figure 6.24) and likely represent altered biogenic oxygen. What is clear is that the $\delta^{18}$O results of first and third molars, like those of $\delta^{34}$S, indicate greater mobility as teenagers at CA-SJO-68.

*Table 6. 30 Summary Statistics of $\delta^{18}$O Values at CA-SJO-68*

| **$\delta^{18}$O Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| *Bone Apatite* **$\delta^{18}$O*** | | | | |
| Population | 19 | -7.9 | 0.6 | 2.3 |
| Female | 10 | -7.8 | 0.5 | 1.4 |
| Male | 8 | -7.9 | 0.7 | 2.3 |
| *M1 Enamel* **$\delta^{18}$O** | | | | |
| Population | 21 | -6.4 | 0.8 | 2.8 |
| Female | 10 | -6.4 | 0.7 | 2.2 |
| Male | 11 | -6.3 | 0.9 | 2.8 |
| *M3 Enamel* **$\delta^{18}$O** | | | | |
| Population | 17 | -6.7 | 0.9 | 3.1 |
| Female | 5 | -6.7 | 0.7 | 1.7 |
| Male | 12 | -6.6 | 1.0 | 3.1 |
| *excludes bone samples with unusual % carbonate | | | | |

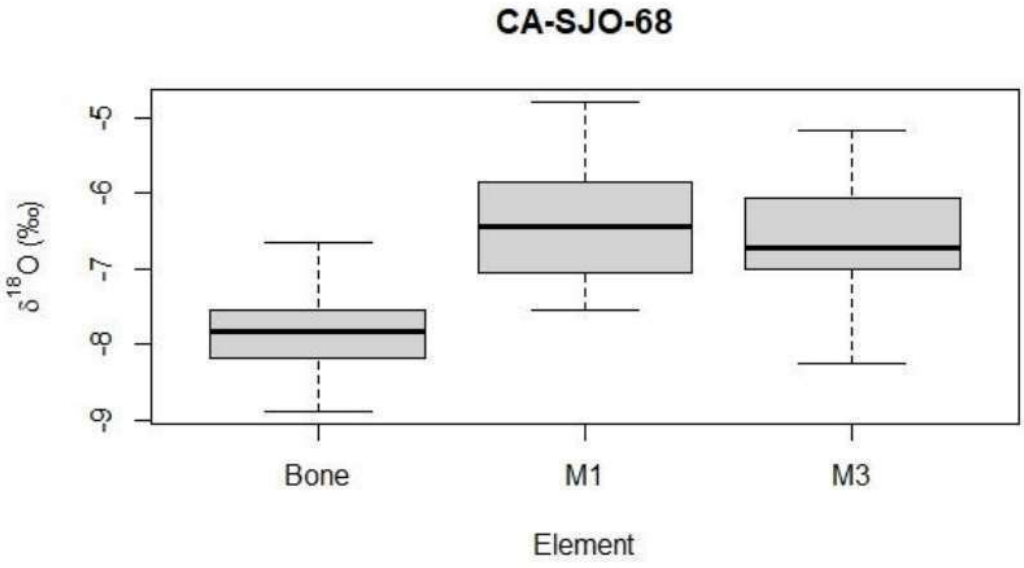

*Figure 6. 24 Boxplot comparing $\delta^{18}O$ of bone apatite, first molar enamel (M1), and third molar enamel (M3) from CA-SJO-68*

Summary statistics of $\delta^{18}O$ of bone apatite, first molar enamel, and third molar enamel at CA-SJO-68 show a greater variation of tooth values (Table 6.30; Figure 6.24); this result is consistent with exogamous marriage where some originate from other locales in their youth but then marry and move to and later live at the site as adults. The one-tailed Levene's test for equality of variance comparing bone versus teeth is presented in Table 6.31. None of the *p*-values are significant at an alpha of 0.05 using the median as the center; however, the low *p*-values comparing var(bone) and var(M3) is interesting (Table 6.31). When the Levene test is conducted using the mean as the center, var(bone) versus var(M3) is statistically different at an alpha of 0.05.

*Table 6. 31 Levene's Test (One-Tailed) Results for Comparison of $\delta^{18}$O Values at CA-SJO-68*

| **Type** | ***df*** | **F** | | ***p* value** | |
|---|---|---|---|---|---|
| | | mean | median | mean | median |
| *var*(bone) vs. *var*(M1) | 1<br>38 | 2.97 | 2.70 | 0.09$^{\dagger}$ | 0.11 |
| *var*(bone) vs. *var*(M3) | 1<br>34 | 4.17 | 3.88 | ***0.05**** | 0.06† |
| var(M1) vs. *var*(M3) | 1<br>36 | 0.28 | 0.26 | 0.51 | 0.62 |

*α = 0.05; †α = 0.1

The $\delta^{18}$O values for females from CA-SJO-68 for bone vary from -8.5 to -7.1‰ (range = 1.4; n = 10), -7.4 to -5.2‰ for first molars (range = 2.2; n = 10), and -7.7 to -6.0‰ for third molars (range = 1.7; n = 5) (Table 6.24; Table 6.30; Figure 6.25). As well, the mean $\delta^{18}$O values for females are -7.8‰ (SD = 0.5), -6.4‰ (SD = 0.7), and -6.7‰ (SD = 0.7) for bone, first molars, and third molars, respectively. Comparatively, the $\delta^{18}$O values for males from CA-SJO-68 span from -8.9 to -6.6‰ for bone (range = 2.3; n = 8), -7.6 to -4.8‰ for first molars (range = 2.8; n = 11), and -8.3 to -5.2‰ for third molars (range = 3.1, n = 12) (Table 6.30, Figure 6.25). For males, the mean $\delta^{18}$O of bone is -7.9‰ (SD = 0.7), of first molars is -6.3‰ (SD = 0.9), and of third molars is -6.6‰ (SD = 1.0).

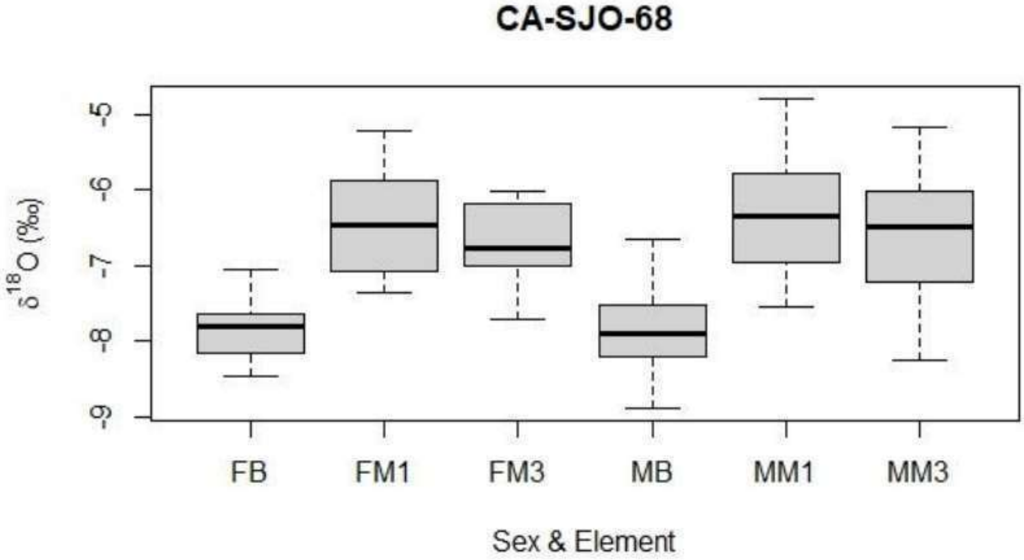

*Figure 6. 25 Boxplots comparing female (F) versus male (M) $\delta^{18}O$ of bone apatite (B), 1st molar enamel (M1), and 3rd molar enamel (M3) from CA-SJO-68*

Males and females at CA-SJO-68 show comparable mean $\delta^{18}O$ values across all sampled elements, with males showing evidence for greater inter-individual variation, particularly within the third molar results (Table 6.30; Figure 6.25). The Mann-Whitney U test reveals no statistical difference between female and male $\delta^{18}O$ values (Table 6.32). One male, 12-7646(0), shows $\delta^{18}O$ of the first molar (-4.8‰) that is relatively enriched in $^{18}O$ compared to the rest of the male population (Table 6.24; Table 6.30; Figure 6.26). Another male, 12-7640.1, shows $\delta^{18}O$ of the first molar (-7.6‰) that is relatively depleted in $^{18}O$ (Table 6.24; Table 6.30; Figure 6.26). These observations also hold for their third molar values, -5.2‰ and -8.3‰ for 12-7646(0) and 12-7640.1, respectively (Table 6.24). Interestingly, both of these males show "nonlocal" third molar $\delta^{34}S$, but "local" first molar $\delta^{34}S$ (Table 6.24; Figure 6.26). In the absence of an appropriate proxy for a "local" $\delta^{18}O$ range, it is difficult to ascertain whether the oxygen values of these males are indeed unusual compared to the rest of the population. However, the fact that their values fall on the edge of the observed range is telling. Since $\delta^{18}O$ generally decreases from west to the east in California, it may suggest that they were living somewhere with similarly available sulfur during their early childhood years but further east and west from the Blossom Mound as evidenced by the lower $\delta^{18}O$ of 12-7646(0) and the higher $\delta^{18}O$ of 12-7640.1.

*Table 6. 32 Mann-Whitney U Results for Comparison of Mean $\delta^{18}O$ Values of Females Versus Males at CA-SJO-68.*

| Type | *N* | *Z* | *p* value* |
|---|---|---|---|
| Bone Apatite $\delta^{18}O$ | 19 | -0.04 | 0.97 |
| M1 Enamel $\delta^{18}O$ | 21 | -0.45 | 0.65 |
| M3 Enamel $\delta^{18}O$ | 17 | -0.36 | 0.72 |
| *α = 0.05 | | | |

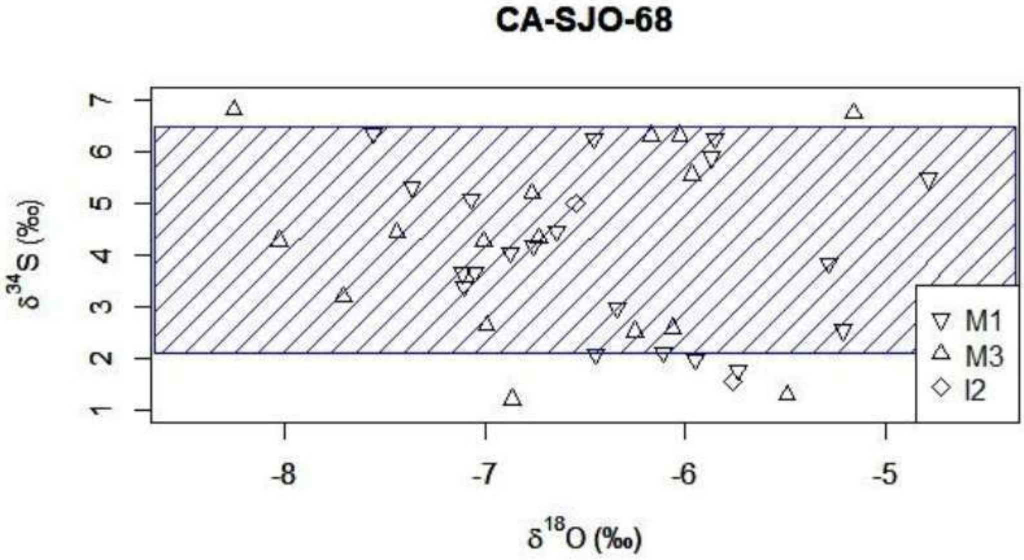

*Figure 6. 26 Biplot showing $\delta^{34}S$ and $\delta^{18}O$ of first molars (M1), third molars (M3), and second incisors (I2) at CA-SJO-68. Shaded region represents "local" $\delta^{34}S$ range.*

Another male, 12-7652.1, shows relatively elevated $\delta^{18}O$ (-5.5‰) of the third molar (Table 6.24; Table 6.30; Figure 6.26). This individual's $\delta^{34}S$ values of first and third molars fall within the "nonlocal" range. An additional male, 12-5833(0), shows relatively lower $\delta^{18}O$ values of the third molar (-8.0‰) and one female, 12-8025(0), has relatively elevated $\delta^{18}O$ (-5.2‰) of the first molar (Table 6.24; Table 6.30; Figure 6.26); neither of these individuals demonstrates evidence as "nonlocals" using $\delta^{34}S$.

In summary, it is challenging to ascertain individual-level mobility patterns using $\delta^{18}$O alone due to a lack of trusted bone data to establish a site "local" range. However, some interesting patterns are still captured using $\delta^{18}$O, particularly when comparing female and male tooth data. While mean $\delta^{18}$O of first and third molars are similar for males and females, males show greater inter-individual variation, consistent with $\delta^{34}$S findings. More significant variation in $\delta^{18}$O of males indicates that they likely lived in a broader array of locations as children and teenagers when compared to females. Like the $\delta^{34}$S results, this suggests a slight bias towards greater male mobility throughout life. As well, the $\delta^{18}$O data shows that three males (12-7640.1, 12-7646(0), and 12-7652.1) with "nonlocal $\delta^{34}$S" of teeth have $\delta^{18}$O values that fall on the edge of the population range. This result lends credence to their "nonlocal" status, previously established using the $\delta^{34}$S data, during childhood and as teenagers.

### *$^{87}$Sr/$^{86}$Sr Results*

The $^{87}$Sr/$^{86}$Sr of tooth enamel at CA-SJO-68 ranges from 0.70665 to 0.70900 (range = 0.00235) for first molars (n = 22), and 0.70676 to 0.71000 (range = 0.00324) for third molars (n = 16) (Table 6.24; Table 6.33). The $^{87}$Sr/$^{86}$Sr population mean for first molar enamel is 0.70698 (SD = 0.00046), and 0.70727 (SD = 0.00097) for third molar enamel (Table 6.24; Table 6.33). On average, third molar enamel shows a greater enrichment of $^{87}$Sr and greater variation than first molar enamel and suggests that the Blossom Mound population lived in a more diverse range of locations during their teenage years (Table 6.33; Figure 6.27). The Levene's test using the median as the center indicate that var(M1) and var(M3) are not statistically different at $\alpha = 0.05$ (Table 6.34). However, comparing var(M1) and var(M3) using the mean as the center reveals a statistically significant *p*-value of 0.03 (Table 6.34).

*Table 6. 33 Summary Statistics of $^{87}Sr/^{86}Sr$ Values at CA-SJO-68*

| **$^{87}$Sr/$^{86}$Sr Breakdown** | ***n*** | **Mean** | ***SD*** | **Range** |
|---|---|---|---|---|
| *M1 Enamel $^{87}Sr/^{86}Sr$* | | | | |
| Population | 22 | 0.70698 | 0.00046 | 0.00235 |
| Female | 11 | 0.70688 | 0.00011 | 0.00035 |
| Male | 11 | 0.70708 | 0.00064 | 0.00218 |
| *M3 Enamel $^{87}Sr/^{86}Sr$* | | | | |
| Population | 16 | 0.70727 | 0.00097 | 0.00324 |
| Female | 5 | 0.70742 | 0.00114 | 0.00266 |
| Male | 11 | 0.70720 | 0.00093 | 0.00324 |

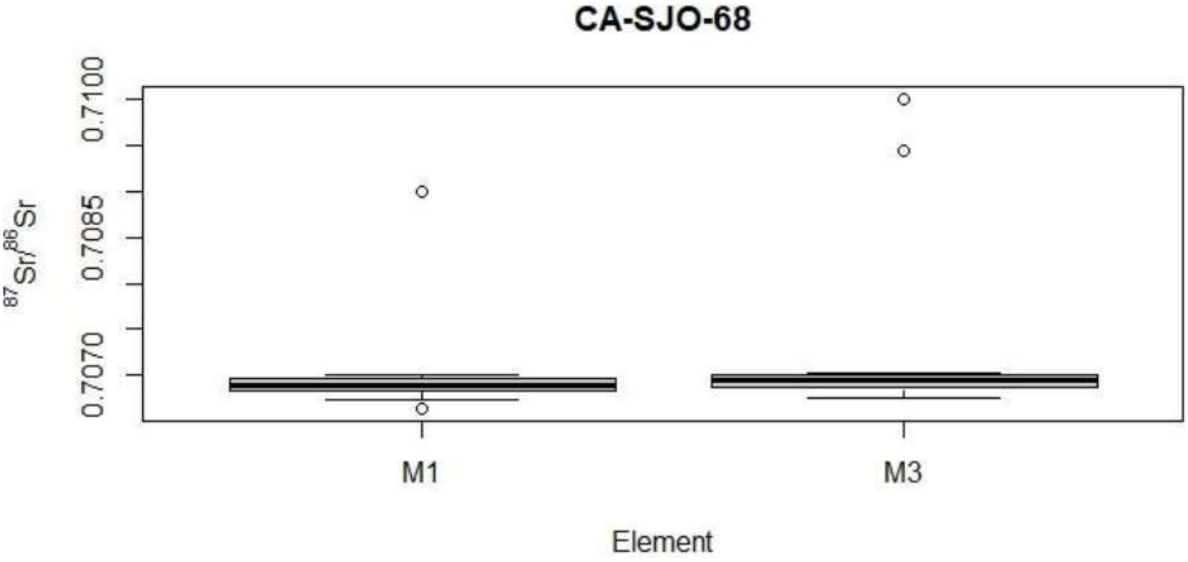

*Figure 6. 27 Boxplot comparing $^{87}Sr/^{86}Sr$ in first molar enamel (M1) and third molar enamel (M3) from CA-SJO-68*

*Table 6. 34 Levene's Test (One-Tailed) Results for Comparison of $^{87}Sr/^{86}Sr$ Values at CA-SJO-68*

| **Type** | ***df*** | **F** | | ***p* value** | |
|---|---|---|---|---|---|
| | | Median | Mean | Median | Mean |
| *var*(M1) vs. *var*(M3) | 1<br>36 | 1.25 | 5.17 | 0.27 | **0.03*** |
| *α = 0.05 | | | | | |

Parameters for $^{87}$Sr/$^{86}$Sr signatures of each environmental sampling location are set at two standard deviations around the mean and are graphically depicted in Figure 6.28. The CA-SJO-68 population's $^{87}Sr/^{86}Sr$ are consistent with signatures of both MA/CON-SED-1 and CON-SED-3 and are least consistent with METAVOL-4 (Table 6.9; Table 6.33; Figure 6.28). This indicates that those buried at the Blossom Mound likely did not spend their youth in environments with an underlying metavolcanic lithology formed during the Mesozoic (251.9–66.0 mya), such as the Sierra Nevada foothills east of the site. While CON-SED-3 is located approximately 36.9 km east of CA-SJO-68, samples were collected along the Mokelumne River, and $^{87}Sr/^{86}Sr$ of samples from this collection locale likely represent values from that water source. The Mokelumne River is the closest water source to the Blossom Mound, and likely, the population there relied heavily on this environment's resources.

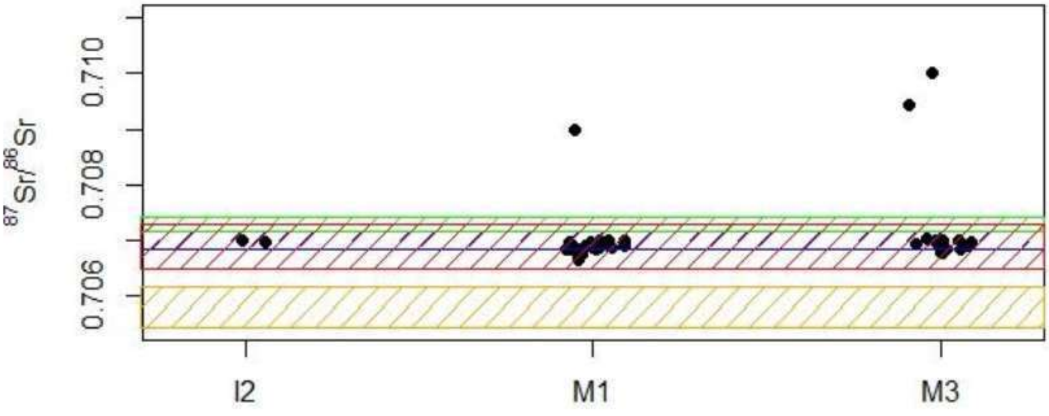

*Figure 6. 28 Stripchart showing $^{87}Sr/^{86}Sr$ of second incisor (I2), first molar (M1), and third molar (M3) enamel at CA-SJO-68. Shaded region represents two standard deviations around the mean of MA/CON-SED-1 (blue), MA/CON-SED-2 (green), CON-SED-3 (red), and METAVOL-4 (yellow).*

Interestingly, none of the individuals from CA-SJO-68 show $^{87}Sr/^{86}Sr$ of tooth enamel that falls within the MA/CON-SED-2 signature, although the population's mean values and range are consistent with those reported from this environmental sampling location. This may suggest that the CA-SJO-68 population spent their youth either in westerly foothills of the Sierra Nevada or originated further west from the site (e.g., the Montezuma Hills) in environments with underlying continental-sedimentary rocks (e.g., the lithology at CON-SED-3) that date to the Pliocene-Pleistocene (5.30–0.01 mya). Interestingly, the majority of the population's $^{87}Sr/^{86}Sr$ of tooth enamel also fall within the MA/CON-SED-1 parameters, which is located west of the Blossom Mound in the Big Break Regional Shoreline (Table 6.8; Table 6.9; Figure 6.28) and lends credence to the hypothesis that most buried at the site spent their youth west of CA-SJO-68.

One individual's first molar (12-7652.1) and two others' third molar values (12-7603(0) and 12-7575) are outliers and do not match any parameters of the environmental strontium sampling locations (Figure 6.28). These individuals and the $^{87}Sr/^{86}Sr$ signature of METAVOL-4 were removed from Figure 6.29 to more clearly display where the bulk of the tooth enamel values fall. From here, we can see two individuals' first molar $^{87}Sr/^{86}Sr$ (12-7569(0) and 12-7622.1 circled in light blue on Figure 6.29) that do not cluster as tightly with the others. Both 12-7569(0) and 12-7622.1 fall outside of two standard deviations (0.7067–0.7070) of the adjusted population first molar $^{87}Sr/^{86}Sr$ mean (outlier value of 12-7652.1 removed from the calculation; Table 6.33). The implications of these "unusual" strontium values are discussed in greater detail in the following section.

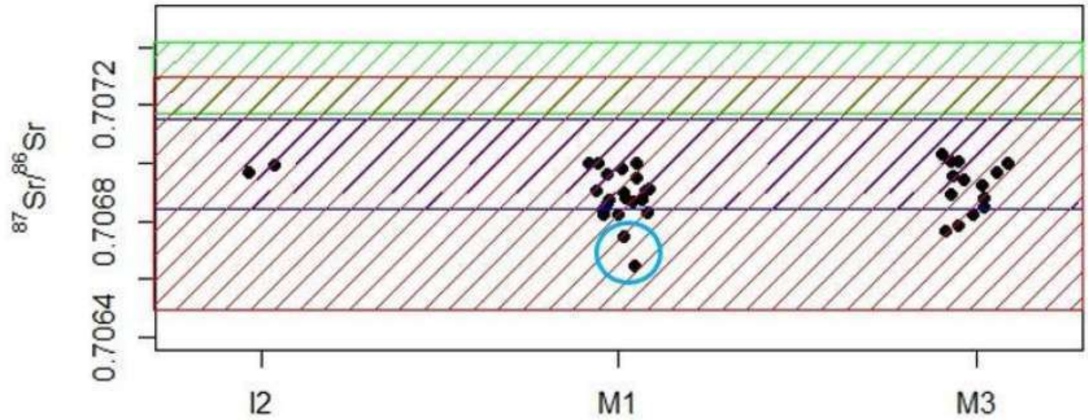

*Figure 6. 29 Stripchart showing $^{87}Sr/^{86}Sr$ of second incisor (I2), first molar (M1), and third molar (M3) enamel at CA-SJO-68 excluding values of 12-7652.1, 12-7603(0), and 12-7575(0). Shaded region represents two standard deviations around the mean of MA/CON-SED-1 (blue), MA/CON-SED-2 (green), and CON-SED-3 (red). Datapoints representing 12-7569(0) and 12-7622.1 are circled in light blue.*

Female $^{87}Sr/^{86}Sr$ of first and third molar enamel span from 0.70665 to 0.70700 (range = 0.00035; n = 11), and 0.70678 to 0.70945 (range = 0.00266; n = 5), respectively (Table 6.24; Table 6.33; Figure 6.30). The female mean $^{87}Sr/^{86}Sr$ are 0.70688 (SD = 0.00011) for first molars and 0.70742 (SD = 0.00114) for third molars. Male $^{87}Sr/^{86}Sr$ of first molar enamel range from 0.70682 to 0.70900 (range = 0.00218; n = 11) with a mean of 0.70708 (SD =0.00064) (Table 6.24; Table 6.33; Figure 6.30). The $^{87}Sr/^{86}Sr$ of third molar enamel for males vary from 0.70676 to 0.71000 for third molars (range = 0.00324, n = 11) and average 0.70720 (SD =0.00093).

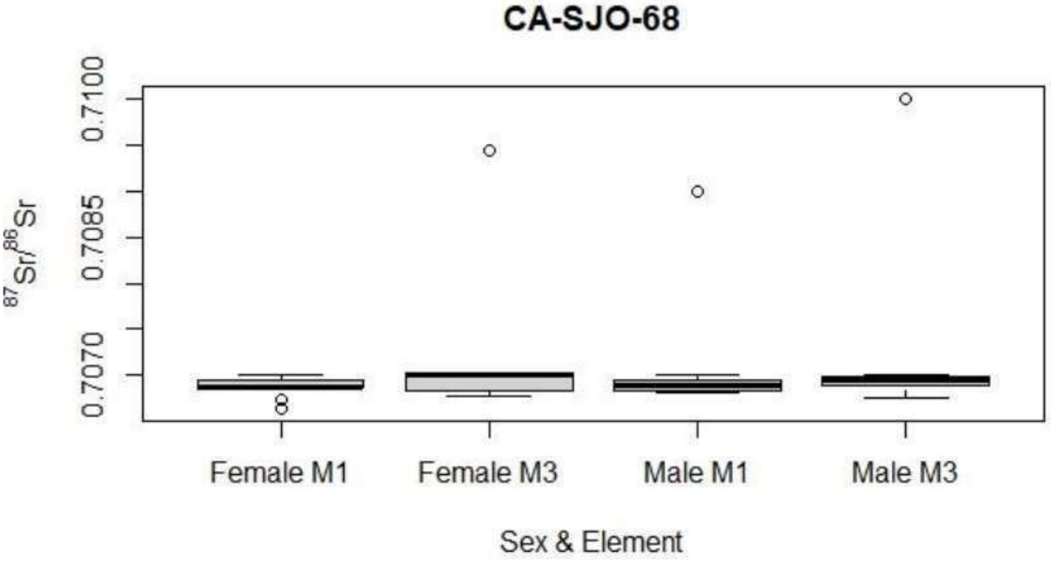

*Figure 6. 30 Boxplots comparing female versus male $^{87}Sr/^{86}Sr$ of first molar enamel (M1) and third molar enamel (M3) from CA-SJO-68*

Thus, overall, males show higher $^{87}Sr/^{86}Sr$ of first molars and greater inter-individual variation. On the other hand, females show higher $^{87}Sr/^{86}Sr$ of third molars while males have a greater range. These results are greatly affected by three individuals (12-7575(0), 12-7603(0), 12-7652.1) who appear to be outliers (Table 6.24; Figure 6.28). One female (12-7575(0)) shows $^{87}Sr/^{86}Sr$ of the third molar enamel that is greater than the female mean by 0.00203 (Table 6.24; Table 6.33). Paleodietary reconstruction using $\delta^{13}C$ and $\delta^{15}N$ of bone collagen shows that 12-7575(0) consumed fairly high-trophic-level foods for the CA-SJO-68 population and likely had as much as 22% marine contribution to her diet. Since mean $^{87}Sr/^{86}Sr$ of modern seawater is about 0.70918 (Mokadem et al. 2015), this female's enriched values of third molar enamel implies she engaged in forays to marine environments or consumed anadromous fish (e.g., salmon or sturgeon) as a teenager. The female mean of third molar enamel is 0.70690, and consistent with the mean of first molar enamel, when this individual is excluded from the calculations. Interestingly, 12-7575(0)'s $^{87}Sr/^{86}Sr$ of the first molar is in line with the rest of the female population.

One male (12-7603(0)) also shows unusual $^{87}Sr/^{86}Sr$ of the third molar that is greater than the male mean by 0.00280 (Table 6.24; Table 6.33). When this individual's value is removed from the calculation, the mean male $^{87}Sr/^{86}Sr$ of third molars is 0.70690 like the readjusted female mean. One male (12-7652.1) shows an unusual $^{87}Sr/^{86}Sr$ of the first molar that is 0.00192 greater than the male mean (Table 6.24; Table 6.33). While this male's values approach the mean $^{87}Sr/^{86}Sr$ of modern ocean water (0.70918; Mokadem et al. 2015), unlike 12-7575(0), isotopic reconstruction of the diet of 12-7652.1 shows the lowest likely contribution of marine resources (10%) and indicates reliance on low-trophic-level foods. When 12-7652.1's value is excluded from the calculation, the male mean becomes 0.70690. Thus, once these outliers are removed, the Blossom Mound population's $^{87}Sr/^{86}Sr$ values are tightly clustered. Even when the outliers mentioned above are included, the Mann-Whitney U test indicates that female and male $^{87}Sr/^{86}Sr$ are not statistically different at $\alpha = 0.05$ (Table 6.35).

*Table 6. 35 Mann-Whitney U Results for Comparison of Mean $^{87}Sr/^{86}Sr$ Values of Females versus Males at CA-SJO-68.*

| Type | *N* | *Z* | *p value**† |
|---|---|---|---|
| M1 Enamel $^{87}Sr/^{86}Sr$ | 22 | -0.67 | 0.50 |
| M3 Enamel $^{87}Sr/^{86}Sr$ | 16 | -0.82 | 0.41 |

* $\alpha = 0.05$
† alternative = "greater"

Only one of the three $^{87}Sr/^{86}Sr$ "outliers, 12-7652.1, consistently shows data suggesting that they lived in an area distinct from the rest of the Blossom Mound population using isotopic evidence (Table 6.36). As previously mentioned, this male shows $^{87}Sr/^{86}Sr$ of the first molar that is 0.00192 greater than the male mean (Table 6.24; Table 6.33). The $\delta^{34}S$ of first molar dentinal collagen from this individual also reflects a "nonlocal" signature; however, the $\delta^{18}O$ of first molar enamel is not markedly different from the rest of the population (Table 6.36; Figure 6.31; Figure 6.32). Interestingly, the $^{87}Sr/^{86}Sr$ of third molar enamel for 12-7652.1 is consistent with the rest of the Blossom Mound population (Table 6.24; Table 6.33), but $\delta^{34}S$ of third molar dentinal collagen falls outside of the "local" range (Table 6.24; Figure 6.31).

While it is challenging to ascertain a "local" signature using oxygen isotopes, $\delta^{18}O$ of third molar enamel for 12-7652.1 does fall on the upper tail of the CA-SJO-68 population distribution and lends some credence to the "nonlocal" status of third molar values (Table 6.24; Figure 6.32). Unlike 12-7652.1, the other two $^{87}Sr/^{86}Sr$ "outliers" (12-7575(0) and 12-7603(0)) do not have corroborating evidence using other isotopic indicators suggesting that they lived "nonlocally" as children or teenagers (Table 6.36; Figure 6.31; Figure 6.32). However, the $\delta^{18}O$ of third molar enamel for 12-7603(0) arguably falls within the lower tail of the Blossom Mound population.

*Table 6. 36 Examples of Paleomobility Patterns using Isotopic Evidence at CA-SJO-68*

| PAHMA # | Sex | M1 | | | M3 | | | Bone |
|---|---|---|---|---|---|---|---|---|
| | | $\delta^{34}S$ | $\delta^{18}O$ | $^{87}Sr/^{86}Sr$ | $\delta^{34}S$ | $\delta^{18}O$ | $^{87}Sr/^{86}Sr$ | $\delta^{34}S$ |
| 12-5833(0) | Male | L | — | — | L | (NL) | (L) | L |
| 12-6472(0) | Female | NL | (L) | (L) | — | — | — | L |
| 12-7568(0) | Male | NL | (L) | (L) | — | — | — | — |
| 12-7569(0) | Female | L | (L) | (NL) | L | (L) | (L) | L |
| 12-7575(0) | Female | L | (L) | (L) | L | (L) | NL | L |
| 12-7591(0) | Male | NL* | (L) * | (L) * | NL | (L) | (L) | — |
| 12-7603(0) | Male | L | (L) | (L) | L | (L?) | NL | L |
| 12-7622.1 | Female | L | (L) | (NL) | — | — | — | L |
| 12-7640.1 | Male | L | (NL) | (L) | NL | (NL) | (L) | L |
| 12-7646(0) | Male | L | (NL) | (L) | NL | (NL) | (L) | L |
| 12-7652.1 | Male | NL | (L) | NL | NL | (NL) | (L) | — |
| 12-8024(0) | Female | NL | (L) | (L) | — | — | — | L |
| 12-8025(0) | Female | (L) | (NL) | (L) | — | —- | — | L |

* incisor 2 sampled
( ) probable
— insufficient material for sampling

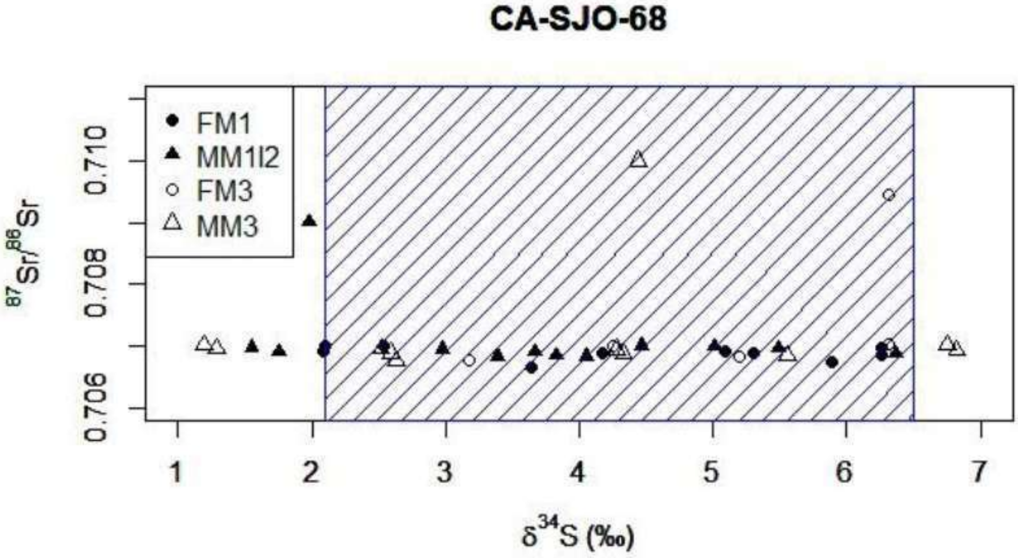

*Figure 6. 31 Biplot showing $^{87}$Sr/$^{86}$Sr and $\delta^{34}$S of female first molars (FM1), male first molars and second incisors (MM1I2), female third molars (FM3), and male third molars (MM3) at CA-SJO-68. Shaded region represents "local" $\delta^{34}$S range*

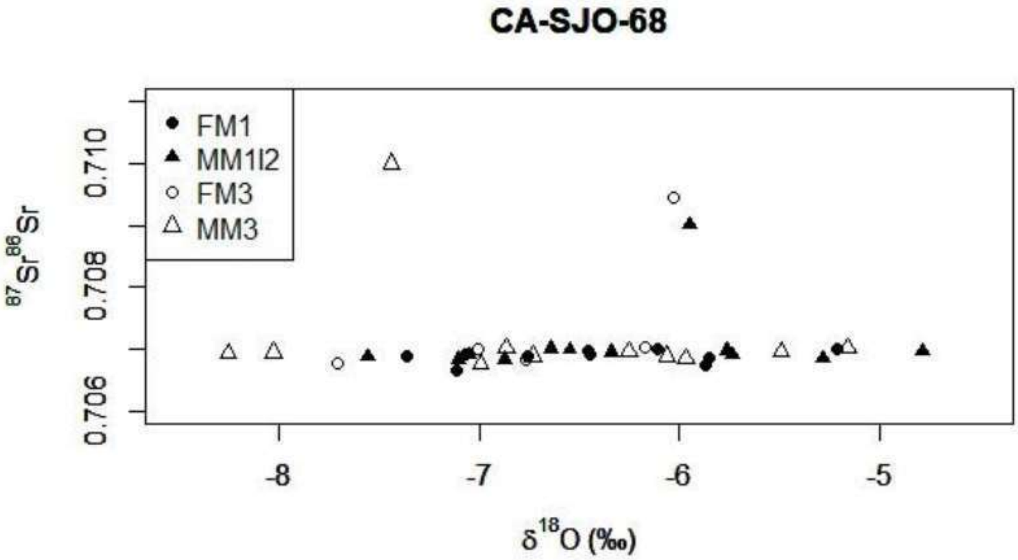

*Figure 6. 32 Biplot showing $^{87}$Sr/$^{86}$Sr and $\delta^{18}$O of female first molars (FM1), male first molars and second incisors (MM1I2), female third molars (FM3), and male third molars (MM3) at CA-SJO-68.*

Overall, $^{87}$Sr/$^{86}$Sr results corroborate both $\delta^{34}$S and $\delta^{18}$O findings and broadly suggest a sedentary arrangement with a few migrants for the CA-SJO-68 population. For instance, $^{87}$Sr/$^{86}$Sr of first molar enamel from 12-7652.1 supports previous isotopic evidence that indicates this male lived "nonlocally" during early childhood. In addition, $^{87}Sr/^{86}Sr$ data indicate that males have greater inter-individual variation, which is also congruent with $\delta^{34}S$ and $\delta^{18}O$ evidence. However, once $^{87}Sr/^{86}Sr$ "outliers" are removed from the calculations, female and male averages and variation are similar and suggest that the bulk of the CA-SJO-68 population lived in areas with comparable $^{87}Sr/^{86}Sr$ during their early childhood and teenage years. This result is consistent with a population that largely practices marriage-endogamy.

## Conclusion

This dissertation research examined the relationship between the sexual division of labor and postmarital residence for Early Period (c. 5000–2400 cal BP) populations in central California using isotopic evidence ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$) from two sites: CA-SAC-107 and CA-SJO-68. New radiocarbon dates at CA-SJO-68, presented in this chapter, are consistent with those reported in the literature ranging from 4497 ± 27 to 3132 ± 24 RCYBP. However, radiocarbon dating results at CA-SAC-107 revealed assays ranging from 3427±26 to 135±20 RCYBP and, therefore, necessitated the incorporation of diachronic assessments.

Paleodietary reconstruction using $\delta^{13}C$ and $\delta^{15}N$ of human bone collagen and $\delta^{13}C$ of bone apatite largely support expectations from archaeofaunal, paleobotanical, and artifactual evidence from central California. The CA-SAC-107 population's $\delta^{13}C$ and $\delta^{15}N$ values are consistent with consumers within $C_3$-terrestrial food webs, while comparison between female and male values indicates minimal differences in dietary behaviors. The temporal bias of sampled skeletal elements and small sample sizes constrained the evaluation of sex-biased mobility and postmarital residence at CA-SAC-107 using $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$. Generally, isotopic indicators of mobility at the Windmiller Mound are consistent with marriage endogamy and increasing sedentism over time.

Compared to CA-SAC-107, paleodietary reconstruction at CA-SJO-68 using $\delta^{13}$C and $\delta^{15}$N of human bone reveal a greater input of freshwater-riverine resources. Additionally, sex comparisons of $\delta^{13}$C and $\delta^{15}$N values show that males consumed higher-trophic-level resources than females. Analysis of paleomobility using $\delta^{34}$S, $\delta^{18}$O, and $^{87}$Sr/$^{86}$Sr at Blossom Mound demonstrates evidence for a few immigrants to the site and greater mobility for males, particularly during late adolescence. However, isotopic indicators of mobility at CA-SJO-68 are most consistent with a largely marriage-endogamous population with no strong preference for unilocal postmarital residence.

## CHAPTER VII. DISCUSSION AND CONCLUSION

This dissertation aimed to explore the association of the sexual division of labor with postmarital residence patterns for Early Period (*c.* 5000–2400 cal BP) populations from archaeological sites, CA-SAC-107 and CA-SJO-68. While the Windmiller Mound (CA-SAC-107) is a known multi-component site, the research design was set up to preferentially select samples from burials that likely date to the Early Period based on burial provenience and temporally diagnostic artifacts. New radiocarbon dates, reported in Chapter 6, reveal assays ranging from 3427±26 to 135±20 BP. These dates extend the period of occupation, or use of the mound as a burial ground, into the Historic Period. Therefore, diachronic assessment of isotopic evidence from CA-SAC-107 was incorporated into the study. New radiocarbon dates from CA-SJO-68 largely conform to those reported in the literature (Breschini et al. 1996; Cook and Heizer 1959; Heizer 1958; Ragir 1972), suggesting Early Period use of the site and revealing that the Blossom Mound was occupied as early as 4831–4976 cal BP, the currently oldest reported dates from the site.

This dissertation research tested three hypotheses at the Windmiller and Blossom Mounds:

1) Populations from CA-SAC-107 and CA-SJO-68 practiced exogamous marriage causing significant difference between isotopic mobility profiles in childhood/adolescence versus adulthood years.
2) If populations from CA-SAC-107 and CA-SJO-68 practiced unilocal postmarital residence (e.g., matrilocality or patrilocality), then there will be a significant difference between isotopic mobility profiles of males versus females.
3) If the relative economic importance of male versus female subsistence contributions influences postmarital residence practices, then dietary isotopic signatures consistent with "female labor" should associate with matrilocality while dietary isotopic signatures consistent with "male labor" should associate with patrilocality.

This study's hypotheses are derived from early anthropological and social theories, which suggest that the sexual division of labor is correlated with postmarital residence (Eggan 1950; Korotayev 2003a, 2003b; Lippert 1931; Linton 1936; Murdock 1949; Service 1962). They hypothesized that matridominant subsistence favors matrilocality while patridominant subsistence favors patrilocality. While cross-cultural tests on Indigenous North American groups conducted in the 1950s (Driver 1956; Driver and Massey 1957) seemingly support this assertion, other tests using worldwide samples did not find that the sexual division of labor and postmarital residence directly covary (Divale 1974, 1975, 1984; Ember and Ember 1971; Hiatt 1970; Korotayev 2003a, 2003b; White 1967). Research conducted by Korotayev (2003a; 2003b) indicates that the sexual division of labor and postmarital residence preference do not have a simple linear relationship, in particular, showing that both low (e.g., less than 20%) and high (e.g., greater than 70%) female input to subsistence is predictive of patrilocality. Additionally, while plant foods are traditionally associated with female labor, plant-resource-predictability shapes the value placed on gendered duties associated with the procurement, maintenance, and protection of resource patches. This project tested how the sexual division of labor co-varied with postmarital residence for two burial populations from CA-SAC-107 and CA-SJO-68 by using five isotopic systems (strontium, oxygen, sulfur, carbon, and nitrogen) to evaluate sex-biased mobility patterns and paleodiets.

## Summary and Discussion

To test Hypothesis 1, general mobility and hypothesized postmarital residence practices, based on individual-level mobility profiles of females and males, were evaluated using $\delta^{34}S$ of bone and dentinal collagen, $\delta^{18}O$ of bone apatite and tooth enamel, and $^{87}Sr/^{86}Sr$ of tooth enamel and modern plant and snail shells. When feasible, samples of bone, first molars (or other early-forming teeth), and third molars were selected from individuals from CA-SAC-107 and CA-SJO-68 to assess geolocation during adulthood, childhood, and late adolescence. Evaluating general paleomobility provides insights into whether the populations at CA-SAC-107 and CA-SJO-68 likely engaged in exogamous marriage.

There should be observable differences among the isotopic mobility profiles illustrative of childhood, adolescence, and adulthood.

$\delta^{34}$S results at CA-SAC-107 show greater variation in tooth values ((M1 = 3.9‰ ± 1.3, range = 3.1; EFT = 3.9 ‰ ± 1.3, range = 4.0; M3 = 4.6‰ ± 1.3, range = 3.1) than bone (6.1‰ ± 0.2; range = 0.6). However, the Levene's test for equality of variation indicates that only *var*(bone) and *var*(M1) are significantly different ($p = 0.01$). First molar (-5.3‰ ± 1.3, range = 3.3) and other early-forming teeth (-5.4‰ ± 0.6, range = 1.7) are more enriched in $^{18}$O than third molars (-6.5‰ ± 0.6, range = 1.1) and bone (-6.3‰ ± 0.7, range = 1.6), with first molar values showing the greatest variation, conforming to expectations for breastfeeding infants. Overall, the $\delta^{18}$O at CA-SAC-107 indicates that the population generally lived within the same east-west gradient in California. However, if the maternal signature drives the greater variation of $\delta^{18}$O of first molars, this may indicate that their mothers originated from a wider range of environs. The population's $^{87}$Sr/$^{86}$Sr values are comparable across teeth; however, sample sizes from each tooth category are too small to run meaningful statistical tests. Additionally, the CA-SAC-107 values are consistent with modern samples from the Big Break Regional Shoreline (MA/CON-SED-1; 0.70696 ± 8.0 X 10-5) and the Mokelumne River (CON-SED-3; 0.70695 ± 20.0 X $10^{-5}$). Overall, reconstruction of general paleomobility using isotopic evidence at CA-SAC-107 suggests limited mobility and no sex differences. This is consistent with sedentary populations that practiced marriage endogamy. However, conclusions drawn from these interpretations should be tempered given the intersection of confounding variables, including small sample sizes and the temporal bias of sampled elements.

Some diachronic patterns emerge when assessing isotopic tracers of human geolocation at CA-SAC-107. For instance, Early Period (5.3‰ ± 1.4, range = 4.4) $\delta^{34}$S values are more variable than Late Period (3.9 ‰ ± 1.5; range = 2.9) and Historic (3.7 ‰ ± 1.1; range = 3.4) samples. This suggests increasing sedentism over time. Statistical comparison of each period's mean $\delta^{34}$S values using the Mann-Whitney test demonstrates a significant difference ($p = 0.03$) between Early and Historic periods' mean values at the 0.05 level. Therefore, the CA-SAC-107 population foraged in environments during the Early Period with distinct sources of available sulfur compared to the Historic Period. However, this difference may be shaped by the dissimilarity of childhood/adolescent versus adult mobility since none of the Historic Period samples include bone collagen.

The mean $\delta^{18}O$ of the Historic Period (-5.0‰ ± 1.4) is more elevated in $^{18}O$ than the Early (-6.0‰ ± 0.7) and the Late (-6.6‰ ± 0.3) Periods. While a Mann-Whitney test indicates that mean $\delta^{18}O$ is not significantly different between the Early and Historic periods, one male (12-7787(0)) dating to the Historic Period has a third molar enamel $\delta^{18}O$ value (-7.2‰) noticeably lower than values from contemporaneous burials. Once this outlier is removed from the mean $\delta^{18}O$ calculation for the Historic Period, it reveals even more significantly higher values relative to older periods.

Since $\delta^{18}O$ becomes progressively more negative the further inland in California (Kendall and Copeland 2001), this pattern may indicate that the earlier Windmiller Mound occupants spent more time in environments further east than those who were buried at the site after about 150 years ago. It is possible that during the Historic Period individuals were living in different areas than their ancestors but were returned to the Windmiller Mound only for burial. Alternatively, diachronic $\delta^{18}O$ patterns may be related to differences in settlement-subsistence practice. For example, if Early Period individuals moved to higher elevations east of CA-SAC-107 during the summer months, this would result in lower average $\delta^{18}O$ compared to the Historic Period. Finally, changes in precipitation over time in central California with a more arid climate during the Historic Period could also explain the higher $\delta^{18}O$ values.

While $\delta^{34}S$ and $\delta^{18}O$ reveal interesting diachronic patterns, most samples analyzed for $^{87}Sr/^{86}Sr$ date to the Historic Period and made meaningful diachronic statistical comparisons not possible. Overall, isotopic tracers of human geolocation at the Windmiller Mound are consistent with marriage endogamy with increasing sedentism over time. The above findings are not well suited to assess sex-biased mobility necessary to test Hypothesis 2.

At CA-SJO-68, $\delta^{34}S$ (M1 = 4.1‰ ± 1.5, range = 4.6; M3 = 4.3 ‰ ± 1.8, range = 5.6) and $\delta^{18}O$ (M1 = -6.4‰ ± 0.8, range = 2.8; M3 = -6.7‰ ± 0.9, range = 3.1) of teeth show greater variation than bone values ($\delta^{34}S$ = 4.3‰ ± 1.1, range = 4.1; $\delta^{18}O$ = -7.9‰ ± 0.6, range = 2.3). Particularly, the Levene's test for equality of variance indicates significant difference between bone and third molar $\delta^{34}S$ ($p = 0.03$) and $\delta^{18}O$ ($p = 0.05$). This suggests that the CA-SJO-68 population foraged and drank water from moderately more varied environments with greater heterogeneity in available sulfur and oxygen as children and adolescents than as adults. This finding is consistent with exogamous marriage where some individuals lived elsewhere in their youth but then moved within the locality of CA-SJO-68 as adults after marriage. Results from CA-SJO-68 are better suited to test Hypothesis 2 which predicts a significant difference between isotopic mobility profiles of males versus females for populations practicing unilocal postmarital residence.

Sex comparisons of $\delta^{34}S$ and $\delta^{18}O$ of all sampled elements illustrate that males are more variable than females at the Blossom Mound. This difference in variation is most pronounced for third molar values. $^{87}Sr/^{86}Sr$ of first and third molar enamel also reflect this pattern; however, the difference between females and males is not as striking. While more variable tooth values of males suggest they had higher mobility than females, and thus, may indicate male-dispersal, a pattern consistent with matrilocality, the degree of third molar variation is particularly interesting. At a nearby Early Period site, CA-SJO-112 (Harold et al., 2016), third molar $^{87}Sr/^{86}Sr$ values showed that males lived 'nonlocally' as teenagers. At this site, 60% of males reveal a local ⇢ nonlocal ⇢ local mobility profile. Harold and colleagues (2016) argued that this pattern signifies males leaving their natal homes to perform bride service in the villages of their future wives and then returning afterwards. While the greater variation of third molar isotope values for males at CA-SJO-68 could be interpreted similarly, evidence from Harold et al. (2016) indicates that the CA-SJO-112 population likely practiced patrilocality, which does not seem to be the case in this study. Therefore, greater variation of third molar isotope values for males at CA-SJO-68 may be tied to other social behaviors in which males were expected to travel as teenagers.

Overall, isotopic indicators of human geolocation and mobility at CA-SJO-68 suggest that the population foraged in environments with a greater range of available sulfur, oxygen, and strontium as children and teenagers than as adults. Therefore, at least some individuals originated from other locales in their youth and migrated to the proximate area of the site later in life. While superficially, these results are consistent with some degree of marriage exogamy and a preference for male-dispersal, this assertion should be interpreted cautiously. For instance, $\delta^{34}S$ of first molars and other early forming teeth indicate that about 17% of females and 21% of males lived ‘nonlocally’ as children, while $\delta^{34}S$ of third molars show that 0% of females and about 33% of males lived 'nonlocally' as teenagers or early adults. This seemingly slight bias of 'nonlocal' males differs from preliminary results for this site (Ralston et al. 2020) which suggested a slight preference for patrilocality. In both studies, statistically significant differences between the proportion of ‘nonlocal’ males *versus* females could not be demonstrated at the 0.05 level using the Fisher's exact test. As well, comparisons of female and male $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ using the Mann-Whitney test reveal that isotopic indicators of human geolocation are not significantly different between the sexes. Thus, isotopic indicators of mobility at CA-SJO-68 are consistent with a sedentary population primarily practicing village (or within the immediate area) marriage-endogamy, with a few migrants.

The preference for endogamy apparent at CA-SJO-68 using $\delta^{34}S$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ isotopic evidence is consistent with other studies conducted on Early Period populations in central California (Burns et al. 2012; Jorgenson et al. 2012). While Jorgenson's (2012) study at CA-CCO-548 using $^{87}Sr/^{86}Sr$ of tooth enamel and bone apatite reveals that the population was largely endogamous, the data also suggest that in cases of exogamy, there was a shift in the preference of which sex disperses over time. In particular, matrilocality seems to have been favored between about 3340–3900 cal BP with 74% of immigrants being male. Between about 2900–3300 cal BP, approximately 54% of males and 41% of females exhibit 'nonlocal' $^{87}$Sr/$^{86}$Sr values, suggesting a shift towards ambilocality over time at CA-CCO-548.

To test Hypothesis 3, $\delta^{13}$C and $\delta^{15}$N of bone collagen and $\delta^{13}$C of bone apatite were analyzed to reconstruct diets at the Windmiller and Blossom Mounds. Economically significant food resources should dominate the diet and, therefore, drive the population's dietary isotopic signatures. Since the ethnographic record for California indicates that the gathering and processing of plants foods were associated with female labor (Jackson 1991; Wallace 1978; Willoughby 1963), dietary isotopic signatures characterized by low-trophic-level, terrestrial resources were expected if female contributions to the subsistence-economy were important. By contrast, if male labor was significant to the subsistence-economy, dietary isotopic signatures should suggest dependence on high-trophic-level terrestrial, freshwater, and/or marine resources since male subsistence practices were associated with hunting and fishing in California (Jackson 1991; Wallace 1978; Willoughby 1963).

Unfortunately, due to sampling limitations, only five individuals were sampled for bone from CA-SAC-107. Radiocarbon dating reveals that these samples date to the Early Period and to the Early/Middle Transition, and therefore, $\delta^{13}$C and $\delta^{15}$N analysis of bone will reflect the diet during that time. Mean $\delta^{13}C_{col}$ (-19.7‰), $\delta^{13}C_{ap}$ (-14.2‰), and $\delta^{15}$N (9.0‰) at CA-SAC-107 are consistent with lower-trophic-level, terrestrial resources and freshwater fish. Sex comparisons suggest that females and males were largely consuming the same kinds of food; however, the small sample size makes meaningful assessment challenging.

Mean $\delta^{13}C_{col}$ (-19.5 ‰) and $\delta^{13}C_{ap}$ (-13.4 ‰) at CA-SJO-68 are comparable to CA-SAC-107 and indicate that the population relied mainly on $C_3$ and freshwater sources of dietary protein, carbohydrates, and fats. Mean $\delta^{15}$N (11.2‰), when considered with $\delta^{13}$C values, suggests a freshwater-riverine-based diet at this site. Males (11.9‰) at the Blossom Mound show higher $\delta^{15}$N than females

(10.6‰), a pattern consistent with other sites in central California (Bartelink 2009; Bartelink et al. 2020; Beasley et al. 2013; Eerkens and Bartelink 2013; Eerkens et al., 2020; Ralston et al. 2016). This suggests sex differences in dietary behaviors, particularly with males having, on average, greater access to higher-trophic-level resources. As well, a marine-carbon-mixing-model predicts that males had greater access to marine resources than females, although the overall expected percent marine contribution is low (about 17%). Studies of modern hunter-gatherer populations suggest that differences in female and male food consumption patterns correlate to the sexual division of labor, with men having more straight-forward access to hunted game and, as a result, tend to consume meat in greater amounts (Hawkes et al. 2001; Walker and Hewlett 1990). If sex differences in diet correlate to females and males engaging in distinct tasks, then sex differences in $\delta^{15}N$ and % marine contributions indicate more gendered-labor at CA-SJO-68. Additionally, males show greater variation in dietary isotope values, particularly $\delta^{15}N$, which indicates differential access to a broader range of protein sources.

At CA-SJO-68, one male (12-7652.1), approximately 24 years old at death, shows unusual results for all isotopic systems used in this study. Paleodietary reconstruction of this individual reveals that he consumed lower-trophic level resources that are relatively depleted in $^{13}C$ compared to the rest of the CA-SJO-68 population. Additionally, 12-7652.1 has the lowest $\delta^{15}N$ value among males. $\delta^{34}S$ values of first and third molars fall outside the 'local' signature at CA-SJO-68. The $^{87}Sr/^{86}Sr$ value of first molar enamel from 12-7652.1 is distinctly different from the CA-SJO-68 population. While the $^{87}Sr/^{86}Sr$ value of third molar enamel from 12-7652.1 is consistent with the rest of the population, $\delta^{18}O$ is relatively higher. Isotopic indicators of human geolocation reveal that this individual was a recent immigrant to the site and engaged in dietary behaviors that differ from other males at CA-SJO-68. Despite this, 12-7652.1 was buried in a culturally consistent fashion with others at the Blossom Mound. Burial records indicate that he was interred dorsally-extended with his head oriented towards the southwest. Five *Haliotis* discs, each with two central perforations, were recovered with the body; two were placed on the head and four in the vicinity of the neck.

## Conclusion

Paleodietary reconstructions using isotopic evidence at CA-SAC-107 and CA-SJO-68 largely conform with expectations based on archaeological indicators in central California. $\delta^{13}C$ and $\delta^{15}N$ at both sites suggest reliance on $C_3$ terrestrial resources and freshwater fish. This suggests that $C_3$ plant foods, such as acorns and small seeds, were significant at CA-SAC-107 and CA-SJO-68 and is supported by paleobotanical and artifactual evidence showing acorn remains and mortar and pestle technology in marshland and riparian zones of the northern San Joaquin and southern Sacramento Valleys (Moratto 1984; Rosenthal et al. 2007; Wohlegumuth 1996).

In the case of CA-SAC-107, isotopic evidence for plant foods, terrestrial game, and likely some freshwater fish do not provide a clear indication for matridominant or patridominant subsistence at the Windmiller Mound. However, since plant foods, such as acorn, have predictable returns and are amenable to storage, they may be more economically important at CA-SAC-107. Since the labor tied to plant foods in California is traditionally female work (Jackson 1991; Wallace 1978; Willoughby 1963), and if the sexual division of labor predicts postmarital residence preferences, then matrilocality is predicted for the CA-SAC-107 population. As discussed in Chapter 3, Murdock (1949: 203-213) describes the skills associated with traditionally female labor as locally restricted but transferable. Put another way, skills associated with women's work tend to be confined within the community or village and within the proximate area. However, a women's specialized skills are easily transported to another village location (e.g., one could apply the same knowledge and skills required to process acorns in one village versus another). Dietary isotope evidence at CA-SAC-107 also suggests contributions of terrestrial game and freshwater fish, acquisition of which is traditionally associated with male labor. Murdock (1949: 213) argues that, unlike female labor, male subsistence activities typically require regionally specialized knowledge, for example, knowing the location of important fishing spots and, therefore, are not as readily transferable to new village locations. Thus, incentives for matrilocality at CA-SAC-107 are lessened, even if female subsistence contributions represent the bulk of the diet since those necessary skills can be contributed by any female regardless of her natal origins. Balancing the need for skill sets required of women in a village to provide stable resources to the community and specialized, regional knowledge provided by males does not drive the development of a strong unilocal residence preference. However, residence patterns cannot be confidently established due to confounding variables present in this study of CA-SAC-107.

Elevated $\delta^{15}$N values at CA-SJO-68 indicates greater reliance on freshwater resources than at CA-SAC-107. Archaeological evidence from the Early Period in central California reveals fishing technology, including gorge hooks, composite bone hooks, spears, and a strong representation of fish remains (Moratto 1984; Rosenthal et al. 2007). As Jorgensen (1980: 153) argues, resources that are more geographically constrained and provide predictable returns are typically preferred for ethnographic groups of California. A subsistence-economy focused on $C_3$ plant resources and fish during the Early Period is consistent with this argument. The ethnographic record in California suggests that fishing is predominantly a male-associated activity, and fishing stations were often owned by families and were managed/exploited by tasks-groups of men related patrilineally (Jackson 1991; Jorgensen 1980; Wallace 1978; Willoughby 1963).

In addition to showing higher average $\delta^{15}$N values than the CA-SAC-107 population, sex differences are apparent at CA-SJO-68, with males showing significantly higher $\delta^{15}$N values. This suggests that males, on average, were consuming higher trophic-level resources compared to females at the Blossom Mound. Differences in male and female dietary patterns are consistent with expectations for gendered labor. Males as 'hunters' and 'fishermen' have more regular access to higher-trophic level resources, while females, as 'gatherers,' have greater access to low-trophic plant foods. While engaged in gendered-subsistence tasks, females would likely consume more plant resources while males would consume more meat and fish. Previous bioarchaeological studies in California also suggest different dietary behaviors between females and males, with females showing a higher incidence of dental caries (Bartelink 2006; Kolpan 2009; Kolpan and Bartelink 2019; Schulz 1981, Walker and Erlandson 1986).

A study conducted by Kolpan and Bartelink (2019) investigated how dental pathologies for four Windmiller populations (CA-SAC-107, CA-SJO-56, CA-SJO-68, and CA-SJO-142), including individuals from both the Windmiller and Blossom Mounds, elucidates subsistence patterns. Chi-square results for male versus female carious teeth reveal statistically significant differences (Observed χ2 =10.253, p=0.001; Corrected χ 2 =47.125, p<.001) and demonstrate that females have higher incidences of carious lesions than males (Kolpan 2009: 95; Kolpan and Bartelink 2019). Kolpan and Bartelink (2009) suggest that this is the result of women's role as gatherers and their, on average, higher consumption of plant foods. Sugary plant foods (e.g., berries) are cariogenic and, when combined with 'sticky' starches, such as seed and acorn mush, foster the development of dental caries.

If ethnographic patterns (patrilineally managed fishing stations) hold for the Early Period and these male-associated subsistence tasks were highly valued, then a preference for patrilocality is expected at CA-SJO-68. Isotopic evidence used to reconstruct paleomobility and interpret postmarital residence does not support this hypothesis. Instead, the results do not show a clear indicator for unilocal residence practices with, perhaps, a slight preference for matrilocality. However, it is important to note that in this case, evidence of greater mobility for males during their childhood, and in particular, during the teen and early adult years, may be capturing other social behaviors in which males are expected to engage in forays away from their homes.

While matridominant and patridominant diet and subsistence are hypothesized drivers of societal preferences for postmarital residence practices, ethnographic studies also reveal a complex interaction among variables, including the sexual division of labor, territoriality, and warfare. For instance, female and male labor and diet contributions may be valued equitably at CA-SJO-68, and other pressures, such as a need for resource safeguarding, may be absent. Thus, it is possible that the Blossom Mound population had greater flexibility for postmarital residence rules.

Taken together, isotopic evidence from CA-SJO-68 and other Early Period sites (e.g., CA-CCO-548 and CA-SJO-112), indicate a diversity of postmarital residence practices in central California. Lower population density during the Early Period may relax societal rules for where individuals live after marriage and thus enabled this diversity. Bioarchaeological research conducted by Bartelink (2006), which includes individuals from the Blossom Mound, indicates a decline in health status through time for populations from the Sacramento Valley as evidenced by a significant increase in tibial periosteal reactions, porotic hyperostosis, and enamel hypoplasias. These results conform to predictions of resource intensification models that suggest increasing sedentism and population densities and declining dietary quality and health status over time Increasing population densities in California likely resulted in resource competition and shaped the importance of resource safeguarding over time. As Bettinger (2015) argues, this likely would increase the value of resource defense, a predominantly male-associated endeavor, driving societies to favor patrilocal residence, the most reported pattern for ethnographic groups in California. Further study of site-specific data from different periods using a multi-isotopic research design to elucidate human mobility and sex-biased dispersal patterns are needed to evaluate Bettinger's (2015) hypothesized evolution of social organization in central California. For instance, more directly radiocarbon dated samples from CA-SAC-107 and associated isotopic analyses would clarify the diachronic assessments presented here. Incorporating multiple lines of isotopic evidence enhances the interpretive power of these analyses for understanding human mobility and the food webs they exploit, particularly when compared to studies that rely on fewer isotopic systems. When applied to investigation of regional and diachronic trends, such as subsistence, demography, and skeletal trauma, future research that adopts such an approach will clarify sociocultural change in central California.

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