PALEODIET RECONSTRUCTION AT CA-CCO-151 (EL SOBRANTE MOUND) THROUGH STABLE ISOTOPIC ANALYSIS OF FIRST AND THIRD MOLARS

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This study examines stable isotope data in dental remains of eight individuals from CA-CCO-151 in order to reconstruct dietary patterns of individuals during various life stages. Initial excavations at the site were conducted by UC Berkeley Fields Schools in the 1950s, but the collection has remained largely unanalyzed. We report new radiocarbon dates confirming a Middle Period occupation at the site. We also report new carbon and nitrogen isotope ratios in layers of dentin in permanent first and third molars in human teeth as insight into changes in diet, and by extension place of residence, during childhood to early adult years. Results show that marine foods were an important component of the diet of many individuals throughout the first and second decades of life. Isotopic data also indicate relatively late ages of weaning in this population. We interpret evidence of dietary shifts during adolescent years as shifts in residence, likely linked to bride service and post-marital residence patterns.

Site CA-CCO-151 (the El Sobrante Mound, sometimes also referred to as the Philippi Mound) was a residential site in the modern-day city of El Sobrante, California. The site was excavated by University of California, Berkeley field schools in the 1950s under the direction of Robert Heizer. The site was leveled in the late 1950s as part of a housing development. At the time of excavation, the mound measured approximately 115 by 40 meters and contained a range of archaeological domestic and mortuary materials, including house floors, hearth features, midden, common tools, and a number of human interments. The mound was situated next to San Pablo Creek in Contra Costa County, about 4–5 kilometers inland from San Francisco Bay (Figure 1).

Since the excavations, minimal analysis on the artifacts and human remains has been conducted. Of relevance to the current study, four *Olivella* beads from CCO-151 were recently submitted for AMS dating as part of a study that sought to update the regional bead chronology (Groza et al., 2011). The shell beads from burials 27, 28, 41, and 60 were submitted for ^{14}C dating, producing dates between 2035 ± 30 and 2205 ± 30 cal BP, confirming chronological indications that the site was occupied during the Middle Period. Of note, one of these individuals, burial 28, was also included in this study with a date on the bead measuring 2160 ± 30 cal BP (Groza et al. 2011).

This study focuses on childhood through early adult dietary patterns of individuals interred at the site through a stable isotope approach using the first and third molars. Because dental tissues are synthesized from the foods humans eat and digest, and are not subsequently remodeled after formation, they contain traces of the diet of an individual during the time the tooth was growing. We use first molars to approximate dietary change during the first decade of life and third molars to approximate diet during the second decade of life. The permanent first molar begins to develop in utero and is completely formed at approximately 9.5 years of age. By analyzing the first molars, we gain insight into the changing dietary patterns within this age range. Analysis of permanent third molars provides dietary information from approximately 8.5 to 21.5 years of age, corresponding to its developmental period.

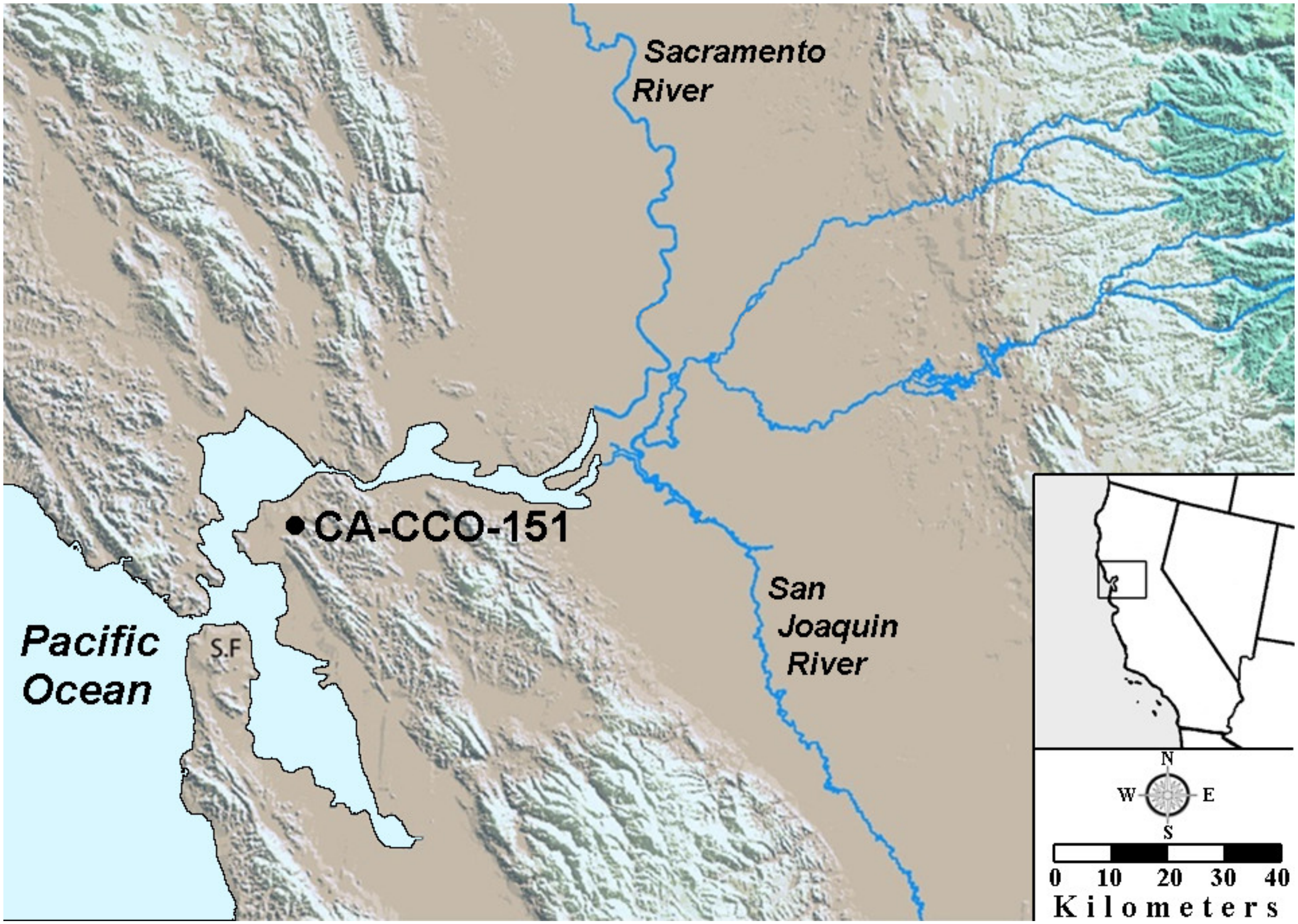

Figure 1. Map of San Francisco Bay Area, showing the Location of CA-CCO-151.

We employ a serial sampling technique following methods established by Eerkens and colleagues (2011) to reveal diachronic changes in diet at approximately an annual level (i.e., dietary changes *within* the lifetimes of individuals). In this study, we are interested in three issues: estimating the age of weaning, estimating the role of marine foods in the diet, and estimating dietary variation during the second decade of life as individuals were transitioning from childhood into adult years (and may have been practicing pre- or post-marital residence shifts). The study focuses on the diets of eight individuals: four individuals using the first molar, three individuals using the third molar, and one individual using both.

BACKGROUND

Excavations by the UC Berkeley Archaeology Field School in the 1950s yielded a wide range of features, ecofacts, and artifacts relating to subsistence strategies and dietary patterns of inhabitants of CCO-151. None of these seem to have been studied in detail since excavation, but unpublished field notes and photographs on file at the Phoebe A. Hearst Anthropology Museum (PAHMA) provide some information of relevance to the current study. At least 80 domestic features were recorded during excavations, including what were interpreted as the remains of house floors, storage pits, hearths, and pit-hearth cooking features. As examples, Features 6 and 7 were located next to one another and comprise concentrations of cooking stones approximately 30 and 40 centimeters in diameter that represent evidence for food processing.

Various faunal and shell remains were also recovered in the initial excavations of the site. For example, Feature 23 is a shell and ash concentration that includes a number of sturgeon “scales” (presumably scutes) and antler, while Feature 66 (a concentration of rocks and charcoal) includes a high density of fish bones, broken mussel shell, and small white barnacles. Sea mammal and bird bone were found in association with several of the burials. While it is difficult to gauge the relative density of faunal bones and shellfish from the field notes, and hence their relative importance in the diets of individuals, large mammal bones, shellfish, and fish bones are often mentioned and described in the field notes.

Artifacts recovered during excavations provide additional insight into subsistence practices, especially plants. A number of mortars and pestles were discovered with burials and as part of domestic features. For example, Feature 20 contained fragments of a large stone mortar and one stone pestle, Feature X1 comprises a group of mortar and pestle fragments, and Feature 37 includes approximately 20 boiling stones and a hammerstone. As mortars and pestles are typically associated with the processing of acorn and other nuts (Basgall 1987), these items attest to the importance of plant foods in the diet.

In addition, excavations at the site revealed at least 77 individuals buried in 63 burial features. The interred were buried in both flexed and extended positions and were found to a depth of approximately 2 meters below the ground surface within the mound. Burials were not concentrated in a particular part of the site but appear to be intermixed with habitation debris. The analyses below are focused on eight of these individuals.

In short, the excavations at CCO-151 provided evidence of a habitation site with burials, all in the same location, as is typical of villages in Central California. From field notes, it is clear that ungulates, sea mammal, shellfish, birds, and fish were an important part of diet of the mound inhabitants. However, not much research has been conducted on the artifacts or burials since the site was excavated. By using stable isotopic data, we provide new information on the types of foods in the diet, as well as dietary variation across several years. We also provide new temporal information at the site in the form of AMS dates on bone collagen.

HUMAN DIETARY LIFE HISTORY

Weaning practices among humans has been an important area of research in human evolutionary studies, specifically focusing on reproductive and investment decisions (e.g., Lee 1996; Kennedy 2005; Humphrey 2010; Wright et al. 1998). Weaning is defined as a process that begins with the introduction of solid food and lasts until breastfeeding is complete (McDade 2000). Breastfeeding is beneficial to the infant, but costly for mothers, and at a certain age the mother can no longer support the nutritional needs of a growing child. The transition from breastfeeding to the consumption of solid food is important for understanding the costs and benefits associated with weaning.

Breast milk contains vital nutrients to support an infant's growth and development. The calories and protein present in breastmilk are essential for the infant's developing brain (Kennedy 2005). Furthermore, breastmilk is a pathogen-free food that provides the infant with antibodies that help develop its immune system to defend against diseases (McDade 2000). In traditional natural-fertility societies, humans typically have an average age of weaning between two and four years (Kennedy 2005). After approximately three years of age, a growing child needs more protein than breastmilk can provide, and the child must supplement its diet with solid food to support nutritional needs.

Of relevance to this study the weaning process can be observed initially as a drop in trophic level. This drop can be observed through the analysis of nitrogen isotope ratios ($^{15}N/^{14}N$, expressed as $\delta^{15}N$ in isotopic studies). During food digestion, animals preferentially excrete the lighter isotope of nitrogen as urea (CH_4N_2O) and retain the heavier isotope for tissue synthesis (Hedges and Reynard 2007). As a result, ^{15}N becomes concentrated in animal tissues up the food chain. Breastmilk is a food resource that is synthesized by a mother, and as such, is one trophic level higher than the foods the mother was consuming. The transition from breastmilk to solid food is recorded in teeth as a drop in $\delta^{15}N$ (Fogel et al. 1989; Fuller et al. 2003; Eerkens et al. 2011). In cases where a child is gradually weaned, $\delta^{15}N$ will drop slowly, while in cases where a child is abruptly weaned, $\delta^{15}N$ will drop quickly.

Nitrogen and carbon isotope ratios can also provide insight into the post-weaning diets of individuals. Post-weaning diets can include a wide range of foods. For example, some individuals may be provisioned by adults, consuming foods similar to what adults eat, while other individuals may engage in independent foraging, which may be unique from the adult diet (Greenwald et al. 2016; Kaplan el al. 2000). Initially, a child experiences slow physical growth until a growth spurt occurs in adolescence. The rate of juvenile growth and development varies among different hunter-gatherer populations and may require differing levels of parental provisioning versus independent foraging (Walker et al. 2006).

This study examines the age of weaning and subsequent dietary variation in early childhood post-weaning years, into early adulthood years. First and third molars were chosen because they provide the longest temporal record with the least impact on skeletal samples. Remains are designated as "culturally unidentifiable" under NAGPRA.

STABLE ISOTOPES

Stable isotope ratios of carbon and nitrogen are useful for distinguishing differences in diet. The ratio of $^{13}C/^{12}C$ (written as $\delta^{13}C$ relative to an international standard) can be different among plant species, depending on how they absorb atmospheric carbon into their tissues through photosynthesis. Plants follow one of three main photosynthetic pathways: C_3, C_4, and Crassulean acid metabolism (CAM; Farquhar et al. 1989). These pathways result in very different carbon isotope signatures, especially between C_3 versus C_4 plants (DeNiro 1987). Marine organisms incorporate carbon from ocean water, which has higher $\delta^{13}C$ values that largely overlap with C_4 plants. Since C_4 plants were not important in the diets of Native Californians prior to contact, carbon isotope ratios in this region are used to distinguish between terrestrial and marine food resources. For CCO-151, any marine-derived carbon would most likely have come from the San Francisco Bay estuary. Furthermore, because different villages in the region likely had consistent access to marine resources, one possible interpretation of changes in $\delta^{13}C$ is a change in village location, or residence.

Nitrogen isotope ratios used in conjunction with carbon isotope ratios can provide greater insight into dietary variations. As discussed above, $\delta^{15}N$ records information about the trophic level of foods consumed, with trophic levels separated by approximately 2–6‰ differences (O'Connell et al., 2012). These levels can distinguish between diets that are focused on plants, herbivores, and carnivores. In short, differences in $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios can be used to identify differences in dietary patterns (DeNiro and Epstein 1981; DeNiro 1987; DeNiro and Schoeninger 1983).

METHODS

We cut each tooth in half and removed enamel and cementum from one half using a Foredom drill with a stainless-steel bit. Exposed dentin, such as on the occlusal surface of worn teeth, was also lightly drilled to remove potential surface contaminants. The tooth was then sonicated in deionized water (DI), dried, and placed in 0.5 M HCl at 1 °C for demineralization. HCl was replaced every 1–2 days until the tooth no longer visibly reacted with the HCl solution and was spongy in texture (typically 5–15 days). Following demineralization, the tooth was rinsed and sliced with a scalpel into thin parallel sections approximately 1 millimeter thick, perpendicular to the central axis of the root. We were able to generate between 10 and 16 serial sections per tooth, depending on the degree of tooth wear and the size of the tooth. For mass spectrometry analysis, which requires 1 milligram of collagen per analyte, we occasionally had to combine collagen from adjacent sections to meet the minimum sample size requirement. In cases where this was necessary, there is a discrepancy between the number of sections the tooth was initially divided into and the number of isotopic samples we submitted. Figure 2 shows schematic of a hypothetical tooth with internal growth lines (in black) and 10 section cuts (in blue; sections labeled A through J).

The demineralized sections were then placed in separate glass vials, labeled, and treated with 0.125 M NaOH for 24 hours to remove humic contaminants. Samples were then rinsed with DI, immersed in pH3 water, and placed in an oven at 80 °C for 24 h to solubilize the collagen. Samples were centrifuged, with the liquid fraction removed and freeze-dried. Collagen $\delta^{13}C$ and $\delta^{15}N$ was measured by continuous-flow mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer) at the Stable Isotope Facility at UC Davis. Long-term analysis of standards shows that sample precision is approximately 0.2‰ for $\delta^{13}C$ and $\delta^{15}N$.

SAMPLES

The teeth used in this study were recovered during excavations by the UC Berkeley Field School during the 1950s and have been housed at the Phoebe A. Hearst Museum of Anthropology (PAHMA) since then. This study focuses on four first and five third molars, totaling nine teeth from eight different individuals (Table 1). Burial 26 consists of the only combination of first and third molar, whereas each of the other seven individuals had either one or the other tooth sampled. Age and sex were determined by the authors through examination of skeletal features, especially the pelvis and cranium. The entire sample consists of a total of six adult males and two adult females. Bone collagen from each individual was also submitted for AMS radiocarbon dating, providing an estimate of archaeological age.

Unpublished data from bone collagen show a marked transition in $\delta^{13}C$ at the site, with individuals pre-dating 1550 RCYBP generally elevated in $\delta^{13}C$ while those post-dating 1550 RCYBP (until 1100 RCYBP) show lower $\delta^{13}C$ values (data in possession of EJB and JWE). We use 10th and 90th percentiles to define a "local" range in $\delta^{13}C$ for individuals inhabiting the site. For burials older than 1550 RCYBP, this range is -17.0‰ to -15.2‰. For burials dating between 1100 and 1550 RCYBP this range is -18.5‰ to -16.3‰. We use these ranges to estimate whether an individual was living locally or non-locally while their third molars were growing.

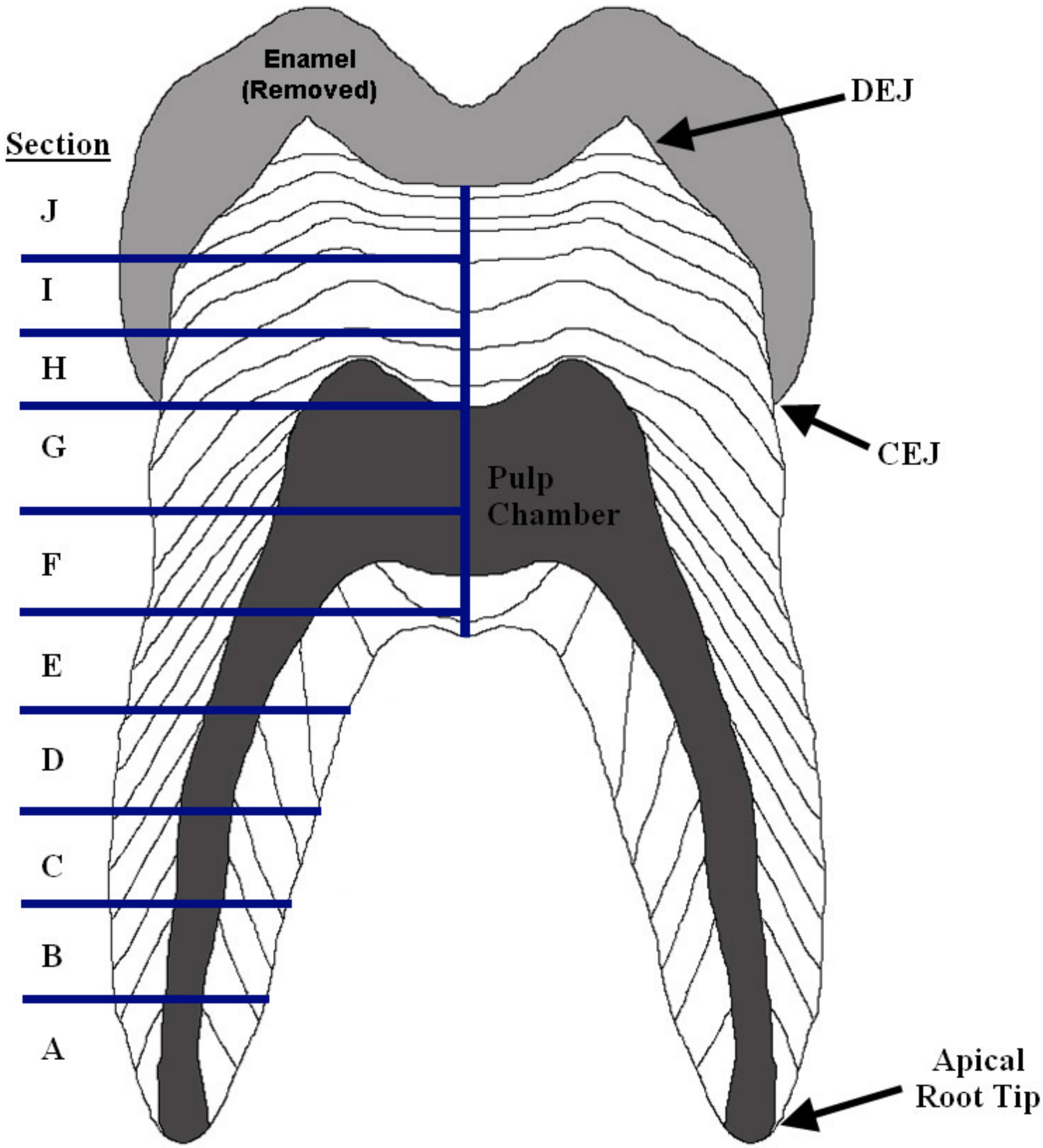

Figure 2. Schematic of Sectioned Tooth according to Sampling used in this Study.

Table 1. Samples Used in this Study with Additional Demographic and Radiocarbon Information.

PAHMA ID	Field Burial #	Age at Death (years)	Sex	Burial Position	^{14}C Date (Uncal. BP)	Tooth	#Sec-tions	# Isotopic Samples Submitted
12-8190	7	40+	Female	Semi-Extended	1480 ± 35	LLM3	15	13
12-8193	10	20–24	Male	Ven. Extended	1310 ± 35	LLM1	12	12
12-8533	20	30–34	Male	Semi-Extended	1710 ± 35	LRM1	11	11
12-8534	26	30–45	Male	Ven. Extended	1110 ± 40	LLM3	15	10
						LLM1	10	10
12-8535	28	20–24	Male	Loose Flex	1730 ± 30	LRM3	12	12
12-9746	44	30–34	Female	Loose Flex	1210 ± 30	LLM3	15	6
12-9749	51	20–29	Male	Semi-Extended	1600 ± 30	LLM1	10	10
12-9844	59	25–29	Male	Flexed	1840 ± 30	LRM3	16	16

Notes: Ven. – Ventral

RESULTS

Table 2 provides results from the stable isotope analyses. The state of preservation for each tooth section was evaluated by examining the atomic C/N ratio. All the dentinal collagen samples fell within the acceptable range of 2.9 to 3.6 (DeNiro 1985). However, low collagen yield for some sections made it necessary to combine adjacent tooth section to meet the minimum requirement of 1 milligram of collagen per submitted sample. In particular, some sections from Burials 7, 26, and 44 had to be merged (Table 2).

Three out of four first molars show marked decreases in δ^{15}N values consistent with a drop in trophic level, and hence, what we interpret as a weaning signature (Figure 3). For Burials 26 and 51, this decrease occurs gradually over a number of years, beginning before age 2 and completing between ages 3 and 5 years. Burial 10 has fewer serial samples from within the crown, limiting our resolution on diet during the first three years, but seems to have been weaned at or before 3 years of age. Finally, Burial 20 also has few serial samples from higher in the crown corresponding to ages before 2 years, but the earliest-growing section already has low δ^{15}N. Based on this pattern, he seems to have been weaned at or before 2–3 years of age.

Results from the first molars are summarized in Table 3, showing age of weaning estimates and isotopic values at different stages in early childhood. Overall, δ^{15}N values follow a similar trajectory for the four individuals, wherein δ^{15}N values decrease from a pre-weaning high to a low point between ages 3 and 5 years of age. δ^{15}N values remain steady for several years thereafter but increase again for three of the four individuals after age 6–7 years of age. By contrast, δ^{13}C values vary only minimally throughout this period, suggesting a fairly low and consistent amount of marine food in the early childhood diet, and by extension, a consistent place of residence. A slight exception is Burial 20, who shows an increase in δ^{13}C between ages 8 and 9 years of age that may indicate a shift in residence to a village closer to San Francisco Bay.

Figure 5 shows δ^{13}C for the three individuals dating after 1550 RCYBP. As shown, Burials 26 (male) and 7 (female) fall entirely within the local range and show very little variation. This suggests both were living locally at CCO-151 throughout their adolescent years. By contrast, Burial 44, a female, falls completely outside the local isotopic range for the site, suggesting she only moved to the site after age 20 years. Her adolescent diet indicates access to significant amounts of marine food, suggesting she lived closer to San Francisco Bay.

Table 2. Stable Isotope Results.

BURIAL #	TOOTH	SECTION	MEDIAN AGE	TOTAL C	TOTAL N	C/N RATIO	Δ^{13}C	Δ^{15}N
51	M1	A	9.0	396.9	143.2	3.2	-19.3	9.0
		B	8.2	354.7	128.8	3.2	-19.0	9.1
		C	7.7	406.0	147.6	3.2	-18.4	9.2
		D	7.2	336.3	122.1	3.2	-18.7	8.9
		E	6.5	371.2	134.3	3.2	-18.7	9.3
		F	5.7	312.4	113.3	3.2	-18.8	9.5
		G	5.0	398.7	144.3	3.2	-18.7	8.7
		H	4.0	393.2	142.1	3.2	-18.7	10.2
		I	3.0	374.9	135.4	3.2	-18.3	11.3
		J	1.9	453.7	165.4	3.2	-18.2	12.5
59	M3	A	20.9	290.3	104.8	3.2	-15.8	15.8
		B	20.1	270.1	98.0	3.2	-16.3	14.5
		C	19.5	290.3	105.6	3.2	-16.4	14.9
		D	18.9	319.8	115.5	3.2	-15.8	15.7
		E	18.3	380.4	138.7	3.2	-15.5	16.1
		F	17.8	312.4	113.3	3.2	-15.4	15.8
		G	17.2	391.4	142.1	3.2	-15.0	16.6
		H	16.6	327.1	117.7	3.2	-14.4	17.1
		I	16.1	382.2	138.7	3.2	-14.2	17.1
		J	15.5	461.0	167.6	3.2	-14.2	17.1
		K	14.9	308.7	112.2	3.2	-14.0	17.3
		L	14.3	420.7	152.1	3.2	-14.0	17.4
		M	13.8	376.7	136.5	3.2	-14.5	16.3
		N	13.2	417.0	152.1	3.2	-15.8	14.9
		O	12.6	462.8	168.7	3.2	-16.0	14.1
		P	11.8	479.3	174.3	3.2	-14.9	15.2
26	M1	A	8.9	420.7	152.1	3.2	-18.1	10.3
		B	8.1	446.4	162.0	3.2	-18.5	9.5
		C	7.6	325.3	117.7	3.2	-18.6	9.1
		D	6.7	341.8	123.2	3.2	-18.8	8.8
		E	5.6	369.4	133.2	3.2	-19.0	8.4
		F	4.5	418.9	150.9	3.2	-18.8	8.5
		G	3.4	411.5	147.6	3.3	-18.2	9.7
		H	2.3	345.5	125.4	3.2	-18.0	11.0

Table 2. Stable Isotope Results continued.

Burial #	Tooth	Section	Median Age	Total C	Total N	C/N Ratio	$\Delta^{13}C$	$\Delta^{15}N$
26	M1	I	1.2	292.2	105.7	3.2	-17.7	11.6
		J	0.1	440.9	158.7	3.2	-17.6	12.5
20	M1	A	8.9	342.3	121.6	3.3	-17.4	12.1
		B	8.1	329.4	117.3	3.3	-17.3	12.2
		C	7.5	347.9	123.9	3.3	-18.2	10.9
		D	6.9	392.6	140.0	3.3	-18.3	10.7
		E	6.4	330.4	118.4	3.3	-18.2	10.6
		F	5.8	405.9	146.2	3.2	-18.2	10.6
		G	5.2	443.1	159.1	3.2	-18.0	10.8
		H	4.7	321.9	116.0	3.2	-17.8	11.1
		I	4.1	328.7	118.2	3.2	-18.0	10.8
		J	3.2	419.4	149.6	3.3	-18.6	10.5
		K	2.1	403.7	145.5	3.2	-18.5	10.8
10	M1	A	9.0	394.1	140.6	3.3	-18.6	9.4
		B	8.2	382.3	136.1	3.3	-18.6	9.5
		C	7.6	469.6	168.4	3.3	-18.5	9.4
		D	7.1	369.6	132.2	3.3	-18.6	8.8
		E	6.6	395.0	142.3	3.2	-18.7	8.5
		F	6.0	462.1	164.9	3.3	-18.4	8.8
		G	5.5	384.8	138.8	3.2	-18.5	8.6
		H	4.9	432.0	154.4	3.3	-18.0	9.5
		I	4.4	359.1	128.5	3.3	-18.2	9.4
		J	3.9	488.4	173.6	3.3	-18.4	9.6
		K	3.1	454.5	162.4	3.3	-18.6	9.4
		L	2.0	370.8	133.4	3.2	-18.5	10.9
28	M3	A	21.0	259.5	93.6	3.2	-15.4	15.9
		B	20.2	364.5	131.3	3.2	-15.5	15.1
		C	19.6	372.9	134.5	3.2	-16.1	14.0
		D	19.1	395.1	143.6	3.2	-17.2	12.9
		E	18.6	366.4	132.2	3.2	-16.8	13.4
		F	18.1	413.8	148.2	3.3	-16.0	14.6
		G	17.5	448.6	160.7	3.3	-15.7	14.9
		H	17.0	324.0	116.8	3.2	-15.4	14.8
		I	16.2	431.3	155.3	3.2	-16.1	13.9

Table 2. Stable Isotope Results continued.

Burial #	Tooth	Section	Median Age	Total C	Total N	C/N Ratio	Δ13C	Δ15N
28	M3	J	15.1	430.0	154.5	3.2	-16.7	12.7
		K	14.1	361.9	130.0	3.2	-17.5	11.8
		L	13.0	429.1	154.0	3.3	-17.2	11.9
26	M3	A	20.7	272.7	95.3	3.3	-17.9	11.0
		BC	19.1	286.2	99.7	3.3	-18.0	10.5
		DE	17.5	382.9	135.6	3.3	-18.5	9.6
		FG	15.8	445.7	157.2	3.3	-18.6	9.9
		HI	14.2	298.5	105.3	3.3	-18.5	9.8
		JK	12.6	266.7	94.8	3.3	-18.4	10.3
		L	11.4	303.0	107.9	3.3	-17.8	11.2
		M	10.6	322.7	114.4	3.3	-17.8	11.3
		N	9.8	264.4	94.0	3.3	-18.1	10.0
		O	8.9	465.1	164.8	3.3	-18.5	8.6
44	M3	ABC	19.9	144.6	48.4	3.5	-14.7	15.4
		DEF	17.0	148.0	50.7	3.4	-14.8	14.9
		GH	15.4	133.5	46.4	3.4	-14.7	14.5
		IJK	13.4	184.5	61.5	3.5	-12.8	16.3
		LM	11.8	92.3	32.1	3.4	-13.2	16.8
		NO	10.2	112.4	39.7	3.3	-13.2	16.3
7	M3	AB	20.3	319.9	114.3	3.3	-17.7	12.3
		C	18.7	463.6	167.1	3.2	-18.1	10.4
		D	17.9	304.8	112.7	3.2	-18.0	10.8
		E	17.0	351.3	125.8	3.3	-18.4	9.9
		FG	15.8	237.9	85.9	3.2	-18.2	9.5
		H	14.6	393.9	141.2	3.3	-18.1	9.6
		I	13.8	400.4	144.2	3.2	-18.0	9.9
		J	13.0	465.8	166.7	3.3	-17.8	10.8
		K	12.2	479.0	173.7	3.2	-17.8	10.5
		L	11.4	381.9	138.1	3.2	-17.9	10.5
		M	10.6	454.7	164.4	3.2	-18.1	10.2
		N	9.8	380.5	135.4	3.3	-18.2	10.0
		O	8.9	390.3	141.4	3.2	-18.3	10.0

Multiple letters in the section column indicate cases where collagen yield was low and adjacent sections had to be combined.

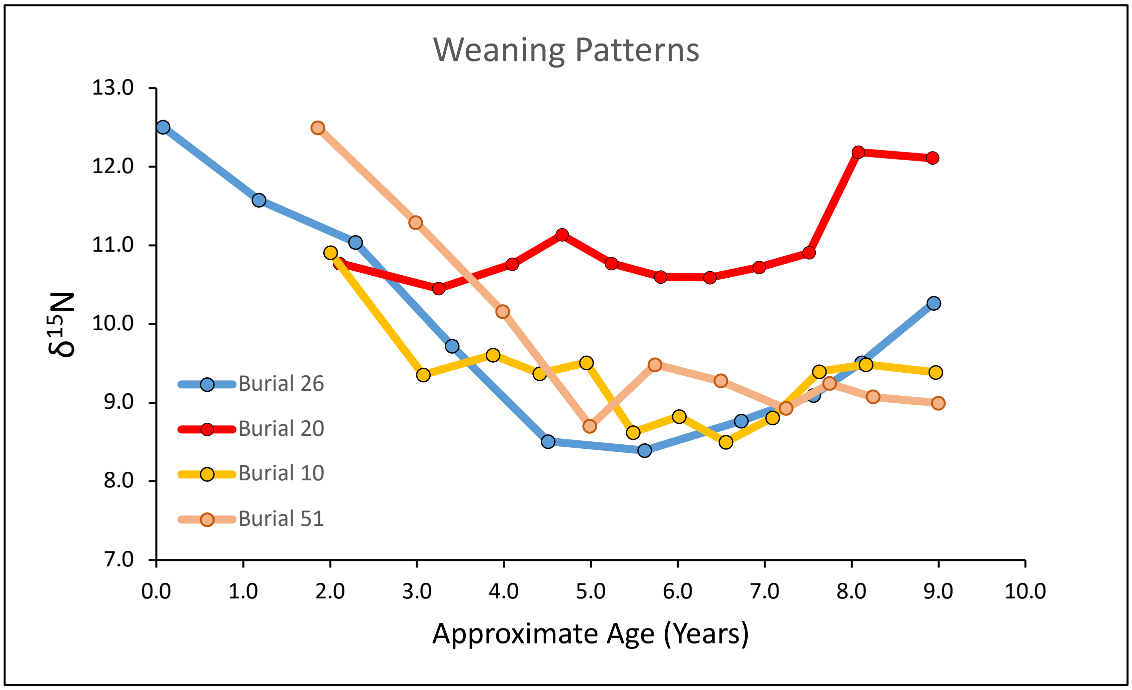

Figure 3. $\delta^{15}N$ Values in Serial Samples of Four Individuals from CA-CCO-151 showing Weaning and Early Childhood Diets.

Table 3. Age of Weaning Estimates and Early Childhood Isotopic Values.

Burial #	Age of Weaning	Pre-wean High		Weaning Food		Age 5–7		Age 8–9	
		$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$	$\delta^{13}C$	$\delta^{15}N$
10	2.0–3.1 yrs	-18.5	10.9	-18.6	9.4	-18.6	8.7	-18.6	9.4
20	<3.2 yrs	-	-	-18.6	10.5	-18.2	10.7	-17.4	12.1
26	3.4–4.5 yrs	-17.6	12.5	-18.8	8.5	-18.9	8.6	-18.3	9.9
51	4.0–5.0 yrs	-18.2	12.5	-18.7	8.7	-18.7	9.2	-18.9	9.1
Avg.	3.1–4.0 yrs	-18.1	12.0	-18.7	9.3	-18.6	9.3	-18.3	10.1

DISCUSSION

The results of the first molars illustrate variation in the age of weaning among the four individuals. Although the number of serial sections that pre-date 2 years of age is limited, we were still able to estimate the age of weaning for Burials 10, 20, and 51. Based on the results of the four individuals, the average age of weaning is between approximately 3.1 and 4 years. This is similar to ages of weaning reconstructed among individuals at an Early Period site (3000–4000 BP) CCO-548, but somewhat later than observed in sites dating to the Middle/Late Transition and Late Periods (after 1000 BP; Greenwald 2017).

Furthermore, the isotopic data show variation in the post-weaning diets of the four individuals. In particular, the $\delta^{15}N$ of Burial 51 shows a stable post-weaning diet, consistent with what Greenwald and colleagues classify as an "assisted foraging" signature, where parents are provisioning children (Greenwald et al. 2016). Such assisted foraging indicates significant parental investment after weaning. On the other hand, Burials 20 and 26 show more variable post-weaning diets. Both of these individuals display a short period of stability after weaning, with post-weaning diets initially focused on lower trophic-level foods,

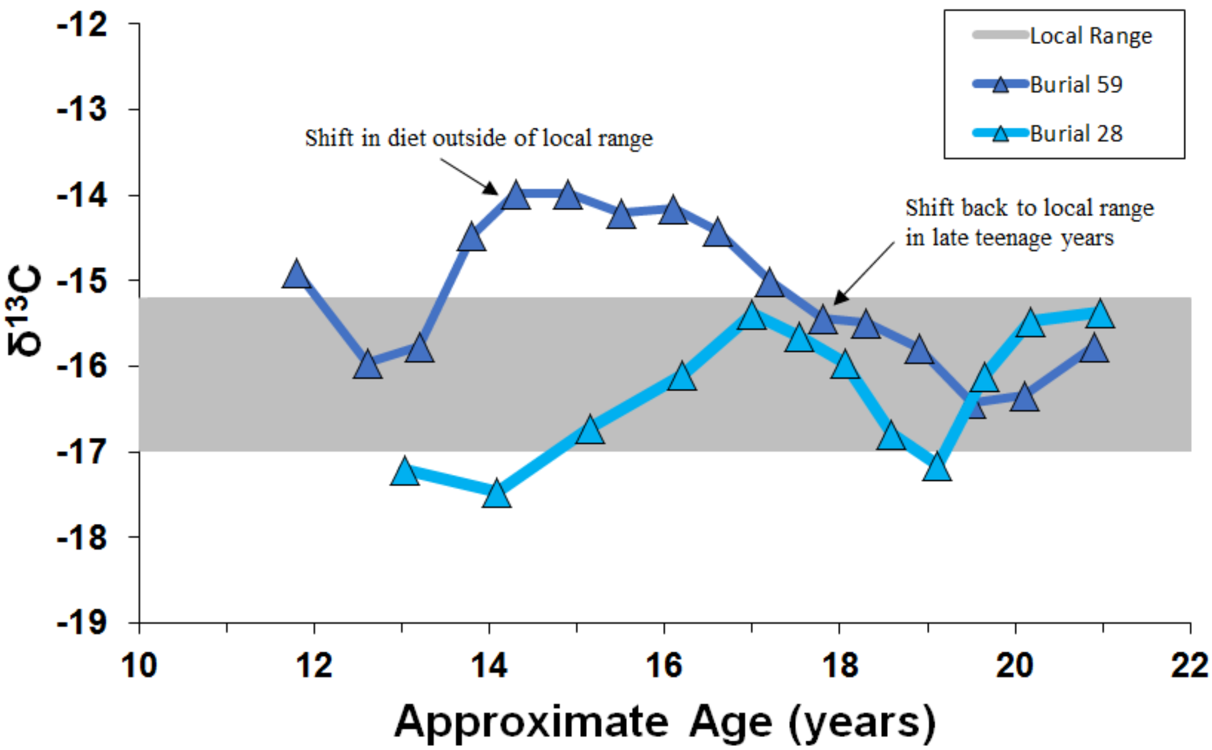

Figure 4. Serial $\delta^{13}C$ Values for Third Molars of Burials 28 and 59, showing Shifting Patterns of Local and Non-local Values.

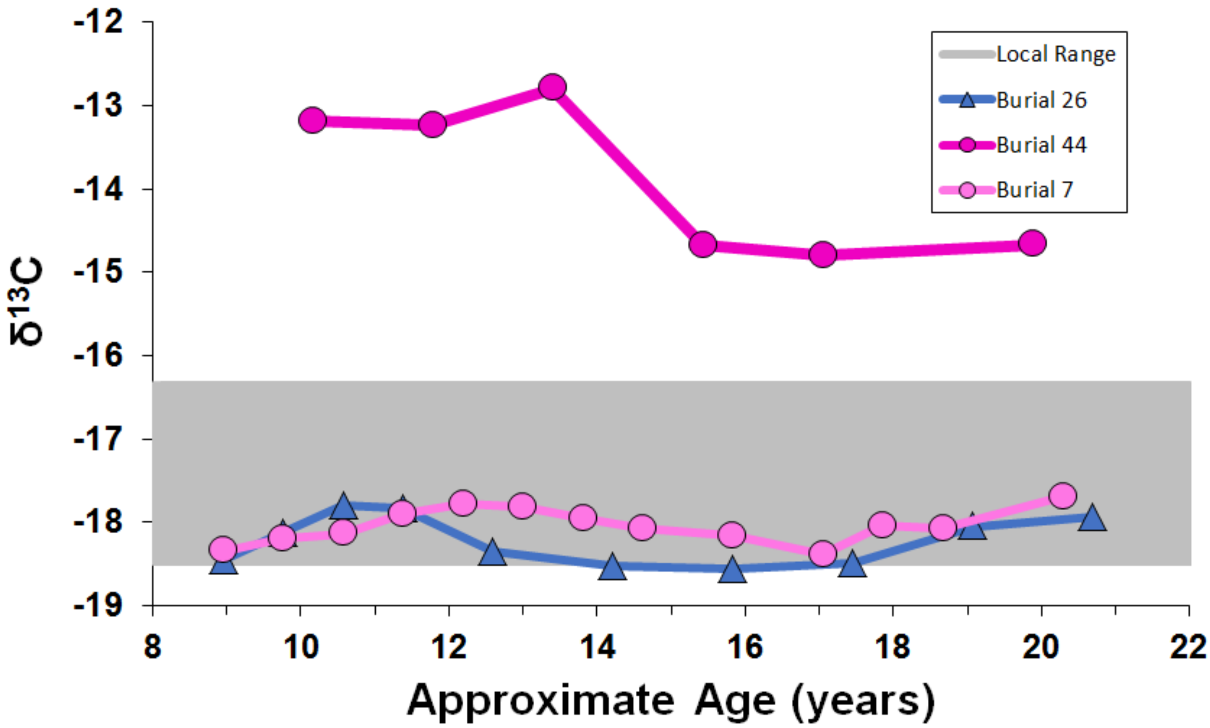

Figure 5. $\delta^{13}C$ Values in Third Molars for the Three Individuals Dating after 1550 RCYB.

followed by a notable increase in $\delta^{15}N$ values around age 7–9 years, suggesting an introduction of foods higher in trophic level. Such a pattern could result from "independent foraging" efforts during later childhood years for these young boys. For example, Burial 20 (male) illustrates a stable diet after being weaned, until about 7.5 years of age when there is a dietary shift and $\delta^{15}N$ increases. This might result from developing hunting skills of this male and an increase in the consumption of meat as a result. Burial 20 also shows a post-weaning diet higher in overall $\delta^{15}N$ values compared to the other three individuals sampled. Finally, Burial 10 shows an intermediate post-weaning diet, with a mostly stable pattern, but a slight increase around age 7.5 years.

Based on the data of the third molars there is also dietary variation in adolescent diets. Burials 26 and 7 illustrate a diet that is lower in $\delta^{15}N$ trophic levels compared to the other burials, while burials 28 and 59 show a diet composed of marine food high in trophic level. Similarly, Burial 44 shows a diet composed of high quantities of marine food. This suggests that these individuals had consistent access to marine resources, presumably through direct foraging at a location near the Bay.

One interpretation of marked shifts in $\delta^{13}C$ values in third molars is as a shift in residence and a different degree of access to marine foods at different villages. Such shifts in $\delta^{13}C$ could be due to extended stays in locations or villages that are closer to San Francisco Bay (higher $\delta^{13}C$) or farther in the interior (lower $\delta^{13}C$). Alternatively, could be due to changes in access to marine foods while living in the same village.

Two individuals, Burials 7 and 26, showed third molar sequences that are entirely within the local range for CCO-151. This would be consistent with the interpretation that they were living at the site throughout their adolescent years and had consistent access to San Francisco Bay resources. However, one individual, Burial 44, showed a pattern that was entirely outside and above the local CCO-151 range. It is possible she lived all her adolescent years in a location closer to San Francisco Bay.

The final two individuals, Burials 28 and 59, show an interesting shift from local to non-local values throughout their second decade of life. Assuming these shifts represent changes in residence, Burial 59 lived closer to San Francisco Bay around age 11.5 years, moved to CCO-151 around age 12–13 years, returning to the Bay around age 14 to 17 years, and then moved back to CCO-151 around age 17 years, where he stayed through age 21 years. Burial 28 shows a similar pattern, staring out at a location farther in the interior around age 14 years, moving to CCO-151 around age 15–18 years, moving back out again briefly around age 19 again to the interior, and then settling back at CCO-151 around age 20–22 years. The pattern for these two individuals is as expected for males preforming "bride service" within a patrilocal most-marital residence pattern. Here, males move to the village of their to-be bride, perform labor for their to-be-spouse's family, and eventually return to their home village with their spouse after completing this work. In that respect, the pattern of Burial 44, a woman, is also as expected under such a social system, as she seems to have lived close to San Francisco Bay throughout her teenage years, but eventually moved to the CCO-151 sometime after age 20 years and was ultimately buried there after death. It is possible that she moved to the site only after her husband performed bride service and brought her to his natal village.

Other interpretations for the shifting $\delta^{13}C$ values, beyond residential shifts, are also possible. Thus, changes in relations between villages, and changes in the intensity of exchange between bayshore and more inland locations, could also account for the shifting $\delta^{13}C$ values in the third molars. Thus, the amount of foods from the bay may have shifted in concert with estuarine productivity and/or stronger trade relations during small 3–5-year windows. This could have affected the ability of more inland people to access bay foods, such as shellfish, sea mammal, and fish. Future analyses using other isotopic tracers that are more strongly tied to underlying geology (e.g., sulfur, strontium) could be used to test the hypothesis of a bride service and patrilocal post-marital residence system.

CONCLUSIONS

As expected of early growing teeth, $\delta^{15}N$ values in first molars of three individuals showed a distinct drop in trophic level. This drop in trophic level is consistent with a child being weaned from breastmilk and introduced to solid foods. Two individuals, Burials 26 and 51, illustrate a gradual transition to solid food and ages of weaning between ages three and five years. Burials 20 and 10 had fewer serial sections from before two years old, which impacted the analysis of a weaning signature. However, both individuals were weaned at or before three years of age. In sum, our analysis of first molars show significant variation in ages of weaning, reflective of variations in parental investment in children, consistent with previous studies in Central California (Eerkens and Bartelink 2013; Eerkens et al. 2017; Greenwald et al. 2016).

We also analyzed variation in post-weaning diets of the four individuals suggesting differences in foraging patterns. The $\delta^{15}N$ values in Burial 51 indicated as a stable post-weaning diet, consistent with "assisted foraging" for this individual (Greenwald et al. 2016). By contrast, two individuals (Burials 20 and 26) are more consistent with an "independent foraging" pattern. Burial 20 also indicates a dietary shift during the late stages of childhood.

Analysis of the third molars provides detailed dietary reconstructions of the adolescent and early adulthood years of five individuals. The $\delta^{15}N$ values of Burials 26, 7, 28, 59, and 44 shows that marine food was a significant, but not an exclusive, portion of their diet, likely due to the proximity of San Francisco Bay. The $\delta^{13}C$ values of the dental remains were analyzed in conjunction with the bone collagen to illustrate potential shifts in mobility. Based on the "local range" established by the bone collagen, Burials 7 and 26 show values throughout these years corresponding to this range. However, Burial 44 illustrates values completely outside of the local range, suggesting that this individual was not local and possibly migrated into the site during adulthood. Burials 28 and 59 also show some patterns outside of the "local range" varying during different ages. This fluctuating pattern is expected of males performing "bride service" and then returning to their natal village some years after marriage, consistent with a patrilocal pattern. Based on our analysis there is evidence of increased mobility during the adolescent and early adulthood years by both males and females.

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