LANDSCAPE MOBILITY OF THE PRECONTACT OHLONE: AN ISOTOPIC INVESTIGATION OF DIETARY RECONSTRUCTION, LANDSCAPE MOBILITY, AND MARRIAGE PATTERNS

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ABSTRACT:

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By Kelli Sullivan

Marriage and post-marital residence patterns shape and define various aspects of a population's culture. This study aims to understand the complex relationships of precontact individuals from one earthen-mound burial site, Ryan Mound (CA-ALA-329), by examining human stable isotopes to elucidate mobility patterns through time. Carbon and nitrogen stable isotopes from serial-sections of human third molars from the Ryan Mound suggest that mobility increased for males around the ages of sexual maturity for the Middle Period and Phase I of the Late Period, while females tended to be more stable in their residence, consistent with a matrilocal society. Both males and females showed greater mobility on the landscape during Phase II of the Late Period. This information informs on diet and human interactions with the environments of the southern San Francisco Bay, along with marriage and residence patterns of the population buried at Ryan Mound.

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CHAPTER 1: INTRODUCTION

1.1 Problem Statement

Without historical documents on the topic and with limited oral histories, marriage patterns in California prior to European contact are difficult to study. Yet, marriage patterns can elucidate vital cultural strategies of kin network construction and maintenance, subsistence access, and mobility of individuals (Bettinger 1991; Binford 1980; Ember 2014; Fox 1967; Harrington 1942; Hill 1970; Jackson 1991; Jones and Klar 2007; Kroeber 1925; Kroeber 1939; Levy 1978; Margolin 1978; Milliken et al. 2007; Moratto 2004; Stockard 2002). Stable isotope analysis of carbon and nitrogen isotopes in human skeletal remains provides researchers one means of inference about precontact lives, residence, and mobility (DeNiro and Schoeninger 1983; DeNiro 1987; Eerkens et al. 2014; Eerkens and Bartelink 2013; Eerkens, Berget and Bartelink 2011; Eerkens, Sullivan and Greenwald 2016; Eerkens, Mackie and Bartelink 2013). The Ohlone are the Native American group who, in precontact periods, resided in the region stretching from the San Francisco Bay Area to the Monterey Bay Area, occupying a vast cross-section of the central California coastline (Harrington 1942). Detailed information about their history is limited by the few 19th- and 20th-century ethnographic reports, which were incomplete due to Spanish missionary and colonial efforts to dismantle their culture beginning in 1769 when long-term occupation of the region was initiated (Jones et al. 2007). Observations of the Ohlone were recorded by the earliest Spanish explorers and missionaries; however, they remain incomplete and biased (Jones et al. 2007). Attempts at a more systematic approach to recording Ohlone culture were made by Harrington some 150 years later. However, Ohlone communities had suffered immense population decline and loss of much information by then due to genocide and the spread of introduced diseases (Jones et al. 2007; Milliken et al. 2007). The small number of informants and limited scope of investigations by Harrington surely represent just a limited range of the diversity of pre-contact Ohlone culture, especially information regarding ancestral mobility, residence, and marriage patterns. In that regard, scientific approaches that can help reconstruct ancient mobility practices could shed new light on marriage and residence patterns, trade routes, and contact patterns from various groups in the area, and how those changed over hundreds or thousands of years.

This stable isotope analysis examines carbon and nitrogen in human remains. These elements are essential in the construction of osseous materials and are routed to bone and teeth through the consumption of food resources over an individual's lifetime (Eerkens et al. 2013). In Central California, carbon isotopes provide information regarding the amount of marine food in an individual's diet, while nitrogen informs on the trophic level of consumed foods (DeNiro and Schoeninger 1983; DeNiro 1987; Eerkens, Mackie and Bartelink 2013). While stable isotope signatures inform on diet, the extreme ecological diversity of Ohlone territory allows researchers to simultaneously gain information on where an individual resided while those osseous tissues were forming (DeNiro and Schoeninger 1983; DeNiro 1987). Other archaeological methods, such as analysis of faunal or paleobotanical remains, rarely give information about human behavior at the individual level with regards to dietary reconstruction, and generally only speak to a population, or at best, a subset of the population. This is because it is rare to identify items in the archaeological record that were used specifically by one person.

Ethnographic records can at times give accounts of specific individuals but can also be biased by informants and ethnographers. With the exception of ethnographic records, no other methodology typically provides data on where specific individuals resided during certain times in their life. Stable isotope analysis is extremely useful when examining landscape mobility, relationships between polities, and marriage patterns because researchers can examine mobility at the level of specific individuals, rather than the entire population (Eerkens, Sullivan and Greenwald 2016).

This project addresses a gap in the knowledge about Ohlone lifeways by answering the research question: what were the precontact mobility patterns in the Bay Area and how did those change (or not) over time? This will be examined through burials from the archaeological site CA-ALA-329 (Ryan Mound), which is one of the largest precontact cemetery earthen-mound sites excavated in the United States (Leventhal 1993). Through stable isotope analysis of carbon and nitrogen isotopes, marriage patterns of past Ohlone people can be investigated (Eerkens and Bartelink 2013). Stable isotope analysis can provide information about where individuals resided during periods of their lives through studies of consumed foods. Past uses of stable isotope analysis have proven effective in answering questions about individuals where there is not enough other archaeological evidence present to interpret specific characteristics (Eerkens et al. 2015).

The archaeological site of Ryan Mound was excavated by a team from San José State University during 1962-1968. The earthen-mound contains three distinct strata, all of which contain burials and cultural remains (Leventhal 1993). These distinct strata relate to specific time periods, with the deepest being the oldest and those closer to the surface being more recent. Analysis of burials from these strata allowed for addressing questions of mobility and subsistence strategies over time, including the vital years prior to Spanish colonization.

Figure 1: Map of the San Francisco Bay Area with CA-ALA-329.

1.2 Significance of Study

Understanding diet, an important aspect of a population's culture, allows researchers and native communities the opportunity to gain further insight into past lifeways. First, the methodology allows researchers to obtain a more complete picture of precontact lifestyles. Because of minimal ethnographic information about marriage and residence patterns of Ohlone groups, this study can begin to reconstruct what those patterns may have looked like (Moratto 2004). Eventually, these patterns can inform on larger scale relationships from various populations and how they may have interacted. This information contributes to our understanding of prehistory in the San Francisco Bay Area.

In addition to the valuable knowledge it will provide for researchers, the information will allow descendants to know more about the cultural practices of their ancestors. The San José State University's Applied Anthropology M.A. program is designed to train professionals with methods to make a difference and contribute to communities. The Muwekma Ohlone are interested in knowing more about their past and this information can provide many answers to questions they may have. The request of the Muwekma Ohlone is as long as the burials are out of the ground from where they were originally laid to rest, they want as much information to be obtained as possible. Understanding how their ancestors moved through the landscape that they still inhabit today, can provide them with connections to that homeland and insights into their traditional culture.

1.3 Research Context

This study aims to reconstruct how the people of CA-ALA-329 resided in the Bay Area landscape during later youth and young adulthood (8.5-21.5 years of age). This age range represents the typical growth period of human third molars, and also includes the age when individuals would be reaching sexual maturity, and thus marriage. Examination of this age range would provide insight of the dietary practices, and therefore landscape habitation of an individual before and after sexual maturity. This study examines twenty individuals, ten males and ten females, from three distinct time periods at Ryan Mound. Examination and comparison of isotopic signatures will provide insight regarding whose diets remained stable throughout sexual maturity, and whose did not. Because of the varied ecology in the region, a stable diet would indicate there was little movement throughout the ages of 8.5-21.5 years old and that an individual likely did not make major residential moves during sexual maturity and marriage. In contrast, a shift in diet may indicate that a move was made.

1.4 Aims of Thesis

This study aims to explore the marriage and residence patterns of the individuals interred at Ryan Mound through carbon and nitrogen stable isotopic applications. There is a gap in research and recorded information on the marriage patterns of the precontact communities of the San Francisco Bay Area. Based on previous studies and predictions from anthropological theory, it is hypothesized that the precontact native populations of the San Francisco Bay Area practiced matrilocality (Eerkens et al. 2014). The small population size of most villages made it likely that marriage partners would often have to come from exogamous locations, or outside the village (Jones and Klar 2007; Moratto 2004). Ohlone were reliant on acorn subsistence, and artifacts present and related to processing of acorns abound at CA-ALA-329 (Leventhal 1993). Females often owned and operated these groves and granaries, as seen in many Native California communities (Raab and Jones 2004). Mothers and grandmothers would likely pass on these territories and skill sets to their daughters. Cross-cultural studies show that most matrilineal societies are based on plant-dominant sustenance adaptations (Stockard 2002). This thesis aims to utilize stable isotopic applications of nitrogen and carbon isotopes found in the osseous tissue of individuals interred at Ryan Mound to gain further insight into mobility and marriage patterns.

CHAPTER 2: SURVEY OF RELEVANT LITERATURE

2.1 Introduction

Like many areas of California, the Ohlone region houses a complex ecosystem with a variety of landforms allowing for many micro-environments to be present within a territory. Ethnographic records and archaeological deposits relating to the native populations who resided on the landscape reveal characteristics about the culture, which was continuous throughout time (Moratto 2004). Although ethnographic reports and the archaeological record provide some insight into the past lifeways of the Ohlone, various elements have limited information available, such as marriage and residence patterns. Certain methodologies, such as stable isotopic analysis of human remains can provide further insight into past lifeways.

2.2 The Ohlone

The California hunter-gatherer group, the Ohlone, is a linguistic group formerly referred to as the Costanoan (Levy 1978; Margolin 1978). Costanoan is a Spanish term ascribed to the native people of the area. The name comes from the Spanish word *Costaño,* meaning native peoples of the coast (Ortiz 2015). Costanoan belongs to the Penutian language family, which includes four other language groups: Wintun, Maidu, Miwok, and Yokuts (Kroeber 1925). The Ohlone language is comprised of eight different branches that are mutually unintelligible (Levy 1978). The eight branches are spoken in different geographic areas of the Ohlone territory. The following are the divisions that were spoken in the Ohlone territory at the time of ethnohistoric recording, from north to south: Karkin, Chochenyo, Ramaytush, Tamyen, Awaswas, Mutsun, Rumsen, and

Chalon (Margolin 1978). The Ohlone's historic territory spans through portions of the San Francisco Bay region south to the Monterey Bay area (Figure 2). The eastern boundary is the western margin of the central valley of California, while the western boundary is the Pacific Ocean (Harrington 1942; Levy 1978; Margolin 1978).

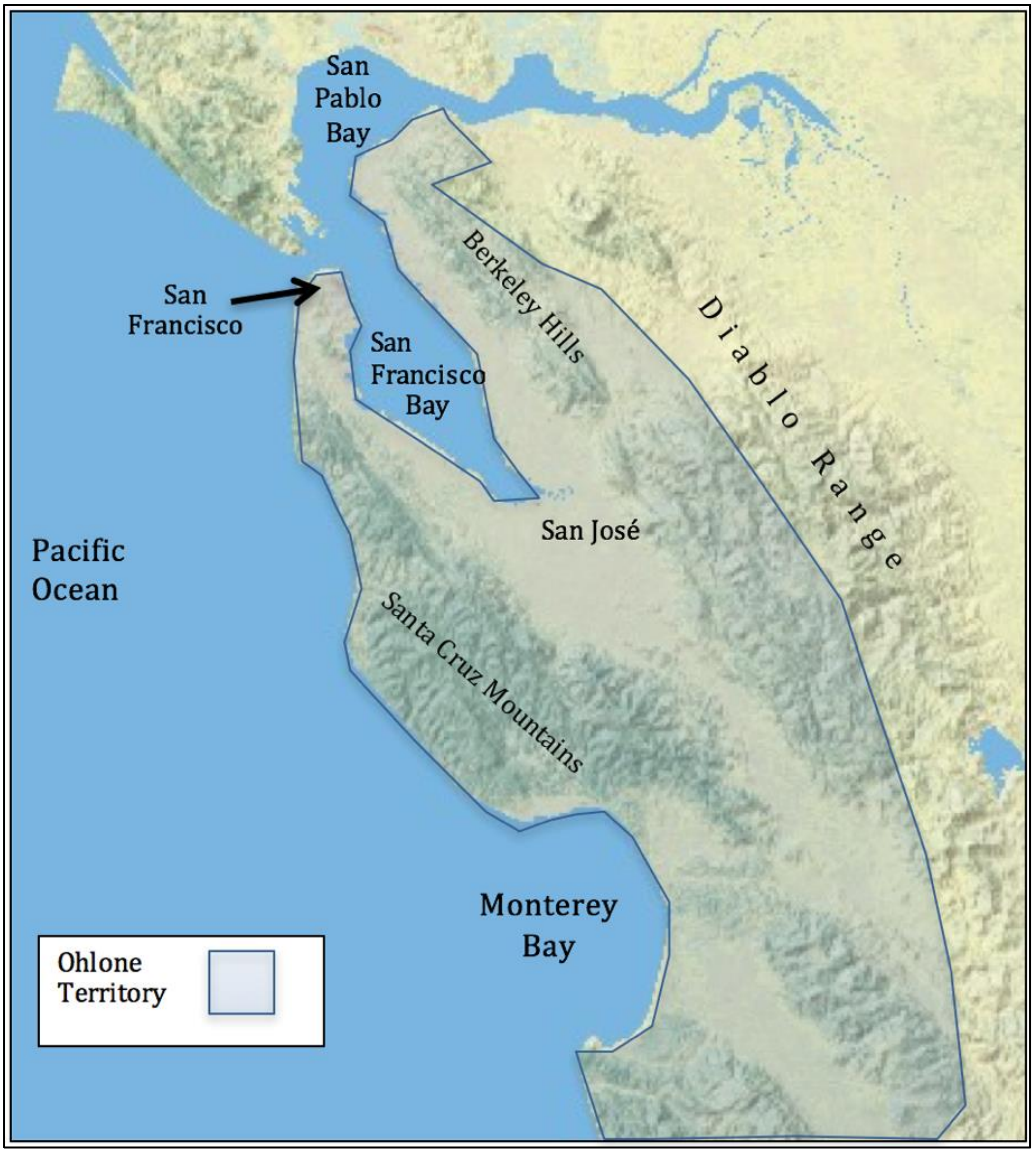

Figure 2: Ohlone Territory (adapted from Margolin, 1978).

2.3 The Environment

The San Francisco Bay area is comprised of various bayshore areas, valleys, and hills that extend out approximately 50 km from the largest estuarine system in California (Moratto 2004). This region is located in a late Pliocene channel that flooded repeatedly during interglacial periods, creating valleys including the southern Santa Clara and San Benito valleys, the northern Petaluma, Sonoma, and Napa valleys, which are bounded by the western coastal mountain ranges, and the eastern Berkeley and Diablo ranges. The last filling of the San Francisco Bay was during the past 10,000 years. At 15,000 years before present (B.P.), the coastal shoreline was more than 25 kilometers west of the present ocean beaches and what is today San Francisco Bay was a large river valley (Moratto 2004). As glaciers have melted, sea levels have risen, thus changing the landscape and submerging the prior coast line and valley.

The Ohlone territory is defined by a series of ranges and valleys that run north to south, as seen in Figure 2 (Harrington 1942; Levy 1978; Margolin 1978). To the far west of their territory, at the Pacific Ocean, the Santa Cruz Mountains rise up abruptly and then lose elevation, moving eastward and turn into the Santa Clara Valley (Schoenherr 1992). The Santa Clara Valley runs east into the Diablo Range, which marks the eastern boundary. In the more northern areas of the territory, the valley is replaced by the San Francisco Bay, which also creates the northern boundary. The northeast portions the Berkeley Hills, which intersect into the Diablo Range at the southern end, create an eastern boundary. There are two bays within the Ohlone territory, the San Francisco Bay and Monterey Bay, with small lakes, rivers, and creeks throughout the region (Schoenherr 1992).

The coastal ranges largely affect the climate of the Ohlone territory, creating regions of dense fog and rain shadows on eastern slopes. On the western side of the Coast Ranges, the ocean climate predominates (Schoenherr 1992). The cold waters of the Pacific create condensation that turns into fog, which is held in place by the coastal ranges and the ocean, creating a cold moist climate. In the northern area of the Ohlone territory, fog is able to penetrate in to the San Francisco Bay region, where it hits its eastern boundary, the Berkeley Hills. Fog is very influential on the environment because of its moisture. It has been noted that the fog drip in the Berkeley Hills equates to 10 inches of precipitation per year. Moving east, there is a rain shadow effect created by the coastal ranges, which creates a dry, hot climate in the interior (Schoenherr 1992).

There is a vertical relief-type vegetal pattern in the Ohlone territory, which consists of regions including: coastal scrub, pine forests, redwood forests, Douglass fir forests, chaparral, oak woodlands, and riparian woodlands (Figure 3). This vegetal pattern is created by the fog drip from the coast and the rain shadow past the Santa Cruz Mountains, and creates great diversity of plant and animal life (Schoenherr 1992). In addition to providing food resources, these plants were also used in various technologies, such as structures, bow and arrow, and netting (Harrington 1942; Levy 1978; Margolin 1978). Animal resources were extremely varied as well, with coastal areas harboring sea mammals, shellfish, and fish. Valley locations and ranges produced birds, lizards, various small and large mammals, as well as freshwater and brackish-water resources. Depending on where a person resided in the landscape, they typically had access to a specific set of local foods. Studies regarding diet and stable isotopes have shown and mapped out carbon and nitrogen isotopic signatures in a variety of San Francisco Bay locations, showing this geographic effect (Eerkens et al. 2013).

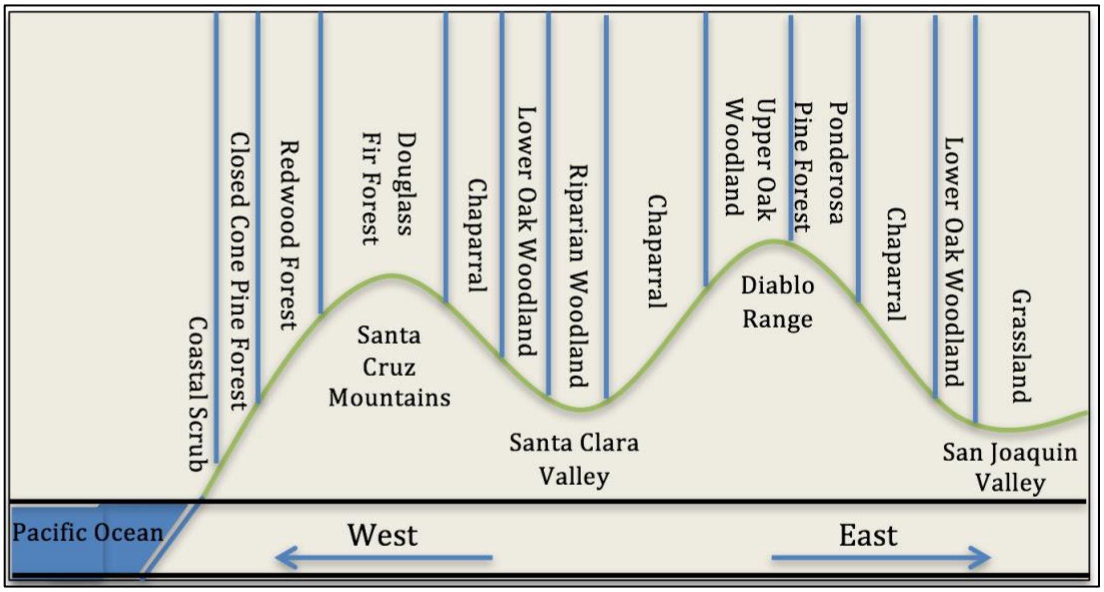

Figure 3: Vertical relief vegetation along Pacific Coast (adapted from Schoenherr, 1992).

The calculated effective temperature (ET) for the Ohlone region is 14 degrees Celsius (Bettinger 1991; NOAA 2014). Effective temperature relates to how distinguishable the seasons are and impacts plant and animal productivity (Bettinger 1991). In cross-cultural studies, Binford (1980) has shown that many societies living in environments with an ET of 14°C practice a semi-nomadic settlement pattern. In such an environment, it is expected that Ohlone communities were somewhat mobile, but would remain sedentary for extended periods throughout the year for acorn harvest and other cooperative tasks.

They generally remained within an established, small territory (Eerkens, Byrd, et al. 2013; Moratto 2004).

The Ohlone obtained their subsistence by hunting, gathering, and exploiting plants and animals from their environment (Harrington 1942; Levy 1978; Margolin 1978). During certain periods of the year, the Ohlone harvested resources from specific environmental regions, requiring mobility to gain access to these various food sources. Relationships with neighboring groups was another very important aspect of life for the Ohlone. They maintained relationships with neighboring communities, such as the Bay Miwok and Delta Yokuts, for trading goods, such as obsidian and shell beads, and built kin ties through marriage (Harrington 1942; Jones and Klar 2007; Moratto 2004).

2.4 Culture History

2.4.1 Ethnographic Records

To understand some of the parameters of population size, density, and territoriality for Ohlone groups in the Bay Area, archaeologists consider the observations of cultural patterns made in ethnographic and ethnohistoric contexts. The Ohlone population was estimated to be around 7,000 to 10,200 in A.D. 1770 (Kroeber 1925; Levy 1978) amounting to local densities as high as 45-70 persons per square kilometer (Kroeber 1939). Ohlone communities consisted of one or more kin-linked groups comprised of several small settlements within a recognized territory (Moratto 2004). Village groups were composed of 50 to 500 people (Harrington 1942). Each linguistic area was generally made up of multiple villages.

Ohlone families made residential movements throughout the year as different food resources became available, but these moves were never observed to be long distances (Harrington 1942). Individuals often died less than one mile from where they were born (Margolin 1978). Central California was an extremely prosperous area for natural resources important to the Ohlone, and there was no need to travel long distances to obtain resources since they could trade with other groups for items not available in their territory.

Annual movements of Ohlone groups revolved around the fall acorn harvests in groves (Kroeber 1925; Kroeber 1939; Margolin 1978). Small, likely kin-based, groups came together cooperatively for two to three weeks while this dietary staple was harvested and prepared for storage. Ohlone also harvested migratory waterfowl during the fall. After the acorn harvest ended, groups dispersed and moved back to smaller winter villages where they consumed their stored acorns, mushrooms, and various hunted animals during winter months. In the spring, groups harvested eggs from sea birds, chicks, migrating waterfowl, seeds, roots, and greens. During the summer, they collected berries, harvested various plants, and hunted animals. Hunting focused on a variety of bird species; land mammals including deer, elk, antelope, and canids; and marine and riverine resources such as waterfowl, fish, sea lion, and whale. In this rich environment, there was minimal pressure to move very far at any time during the year, as compared to many other hunter-gatherer societies (Bettinger 1991; Margolin 1978). Ohlone likely also managed production of acorns, seeds, berries, roots, and shoots through controlled burning, which resulted in plant regrowth, buildup of vegetation, and brought in other prey animals to graze (Anderson 2005; Harrington 1942).

Ohlone relied on a range of stone implements, including manos, metates, mortars, and flaked chert and obsidian stone tools, to assist hunting and processing endeavors (Harrington 1942). Minerals were harvested for pigments for a variety of uses, including tattooing. People also used organic plant materials such as tule to construct balsa boats (with double bladed paddles) to help them move across waterways, and grasses to make twined baskets and cordage for fishing nets to harvest salmon and other species. Skins from animals were used as bedding, blankets, and clothing during the cold portions of the year.

There were several types of structures that were recorded for the Ohlone, including assembly houses, dance enclosures, and sweathouses. The typical family house was a thatched dome structure that had a fireplace in the middle (Levy 1978). Many aspects of the material culture have been recorded in the archaeological record, as seen at Ryan Mound (Leventhal 1993).

2.4.2 Archaeological Record

2.4.2.1 The Lower and Upper Middle Period

Many aspects of culture are traced through material technology found in archaeological sites. The inclusion, spread, and changes in bead typologies can be attributed to cultural changes and characteristics of a population at a given time period. The Lower Middle Period began approximately 500 cal B.C. with a major disruption in symbolic integration systems (Jones et al. 2007). Split-beveled and tiny saucer *Olivella* beads replaced rectangular shell beads, which had been prominent through the entire Early Period beginning at 3500 cal B.C. (Jones et al. 2007). This replacement and shift in bead production could indicate a new phase of religious and decorative systems in the region, as the presence of beads related to status. Mortuary assemblages of the Early Middle Period contained few grave goods, but the saucer bead marks a cultural climax of the San Francisco Bay area. Over time, *Olivella* saucer beads became more common and circular *Haliotis* ornaments appeared in the archaeological record (Jones et al. 2007). Additionally, new bone tools and ornaments are seen in the archaeological record, including barbless fish spears, elk femur spatulae, tubes, whistles, and basketry awls. The basketry awls were used in the production and manufacture of coiled baskets. Mortars and pestles were the sole grinding implement (Jones et al. 2007).

There was a dramatic cultural shift at cal A.D. 430 at the beginning of the Upper Middle Period, which was marked by the collapse of the *Olivella* saucer bead trade network (Jones and Klar 2007). *Olivella* saucer beads were replaced with saddle beads that dominated the Central California bead market until A.D. 1000. The Meganos burial complex styles first appeared during this period also. These burial complexes were characterized by dorsal extended burials. New artifact types appeared, including show blades, fishtail charmstones, new *Haliotis* ornament forms, and mica ornaments. The climax of the Upper Middle Period is encapsulated by stylistic refinement of the small square saddle *Olivella* beads. During this time, the introduction of single-barbed bone fish spears, ear spools, and large mortars occurred. There is also an increase in charred seeds recovered from these sites. The period ends with a decrease in artifacts associated with graves, and devolution of the saddle bead template into a wide or tall bisymmetrical form (Jones et al. 2007).

2.4.2.2 The Initial Late Period: Phase I

The Initial Late period began around cal A.D. 1050, where, “culture moved up a notch in complexity from that of collectors who buried their dead with diverse, numerous, but fairly simple ornaments to collectors who invested large amounts of time in the creation of finely wrought wealth objects,” (Jones et al. 2007:116). This period was marked by a high degree of sedentism, status ascription, and ceremonial integration (Jones et al. 2007). There was much energy devoted to the markings of status and social stratification, and artifact typologies from this era are known as the Augustine pattern (Jones et al. 2007). This period produced fully shaped show mortars, new *Olivella* bead types, and an array of multi-perforated and bar-scored *Haliotis* ornaments. During this period, the Stockton Serrated point series was introduced (around A.D. 1250), which were the first arrow points. With the appearance of bow and arrow technology, biface and debitage production drastically decreased at the Napa Valley Glass Mountain quarries, but increased dramatically in the East Bay (Jones et al. 2007; Moratto 2004). The South Bay used local Franciscan chert and imported finished Napa obsidian points. The movement of Napa obsidian throughout the Bay indicates extensive trade routes and inter-connected social structures of the populations during this time. Larger population sizes are indicated by a greater number of settlement camps with more evidence of status among them (Moratto 2004). Some archaeologists even argue that Napa obsidian exchange was regulated by social elites (Jones et al. 2007).

With higher population densities, there was greater reliance on vegetal foods, such as acorns and small seeds. More indications of growing social stratification and increased wealth are seen in mortuary patterns. Partial cremation of individuals was often associated with burials that had the wealthiest grave offerings and goods (Jones et al. 2007).

2.4.2.3 The Terminal Late Period: Phase II

The last period before Spanish contact was the Terminal Late Period, which began at A.D. 1550 (Jones et al. 2007). This was marked by the abrupt disappearance of *Olivella* sequin and cup beads. The North Bay was the center of innovation in the Bay Area, however, many of these innovations did not make it far beyond that region with the exception of the toggle harpoon. Many of the innovations in the North Bay remained in that region, and only spread as far south as the Carquinez Straight. The desert side-notched projectile points spread into the South Bay from Central California to replace the Stockton serrated. The change in distribution of knowledge and artifact types during this period compared to others, is an indication that another upward cycle of regional integration was beginning when it was interrupted by Spanish settlement in 1776 (Jones et al. 2007). As described by Moratto (2004:283), “This was the emerging cultural pattern encountered and destroyed by the Spanish mission system and later historic developments.”

Although there has been a vast amount of information recorded in the archaeological record, there are still aspects of lifeways that are poorly understood. Methodologies other than the ones listed above can provide further insight into past lifeways and can broaden our knowledge and understanding of how people interacted. Stable isotope analysis of osseous tissue from human remains can provide further insight into the types of food that people consumed and therefore where they were on the landscape.

Isotopic research of strontium isotopes has suggested that matrilocality may have been practiced in the San Francisco Bay during the Middle Period, as seen at CA-SCL-287 (Eerkens et al. 2014). The strontium isotopic analysis of first molars compared to bone suggests that males frequently immigrated to the site location, whereas females resided there from birth. As explained, this pattern is consistent with the cultural preference for a matrilocal residence practice post-marriage (Eerkens et al. 2014).

2.5 Stable Isotope Analysis

2.5.1 Related Studies

The interdisciplinary field of using stable isotope analysis in conjunction with anthropology and archaeology began in 1977 (van der Merwe and Vogel 1977). Stable isotope analysis can be used to chemically describe human remains and measure frequencies of various isotopes in bone or teeth to determine patterns of behavior for the individual (DeNiro 1985; DeNiro and Schoeninger 1983; DeNiro 1987; Grimstead, Quade and Stiner 2016; Grimstead and Pavao-Zuckerman 2016; Slovak and Paytan 2011; Webb, White and Longstaffe 2013).

This study builds on and utilizes a culmination of methods that have been developing for decades. Various studies by DeNiro and colleagues (1983, 1985, 1987) developed baseline methods on the use of isotopes to extrapolate information. These methods outlined ways in which residues and osseous materials could provide information about past dietary habits (DeNiro 1985; DeNiro and Schoeninger 1983; DeNiro 1987).

DeNiro (1987) examined human skeletal remains from historic and prehistoric origin where there were documented dietary data available. The independent information on diet, based on traditional archaeolgoical approaches to dietary reconstrucation, allowed for baseline comparisons of isotopic data. Samples included populations who subsisted mainly on marine food sources, such as Alaskan natives, Haida, and Tilinglit. Individuals known to have consumed almost exclusively agricultural products were also examined, such as the Havihuh Native Americans from New Mexico. Lastly, the study included samples from the Bahamian fisher-agriculturalists. The results from this study produced information showing how certain types of diets are interpreted isotopically, through carbon and nitrogen, and how they relate to each other. This baseline study essentially allowed the stable isotopic analysis of osseous tissue and their results to place individuals on specific landscapes (DeNiro 1987).

Through initial studies, such as DeNiro (1987), isotopic data were proven to show dietary informaiton at the individual scale through broad patterns. Overtime, stable isotope ratios and analysis of carbon and nitrogen isotopes in human bone had become fairly frequent in archaeological reports with the majority producing these documents in North America (Schoeninger and Moore 1992). The inclusion of these results was related to researchers incquiring more information about the use of marine foods and introduction of maize in diet, and how and when those changes were made (Schoeninger and Moore 1992). As discussed by Schoeninger and Moore (1992), isotopic studies were beginning to be used to monitor the consumption of marine food and introduction of maize. In Mesoamerica and South America, isotopic studies were used in similar ways. In Europe, these same studies were being used to understand and document the shift from marine fishing and gathering to agriculture in coastal areas, alongside the introduction of millet in parts of eastern and southern Europe (Schoeninger and Moore 1992).

Webb and colleagues (2013) used a sample of 29 individuals from Cahuachi, Peru in the Andean Region to determine and infer relative changes in residence based on the spatial variability in the isotopic formation of food resources. Carbon and nitrogen stable isotope analysis was completed on bone collagen from individuals interred at this important civic-ceremonial center in the Nasca Region. The researchers confirmed that the average diet was a mix of C_3 and C_4 plant foods with a larger reliance on maize (Webb, White and Longstaffe 2013). Additionally, dietary reconstruction revealed the consumption of plant-derived protein and terrestrial animals. This study also included stable isotopic analysis of hair samples. The combination of the collagen isotopic data and hair samples revealed that this population showed distinctive patterns of dietary shifting, distinguishing seasonally changing diets from access to multiple food production regions, which the authors argue to be interpreted as a representation of flexibility as a risk-minimizing strategy through the interaction between food procurement and cultural mobility (Webb, White and Longstaffe 2013).

Slovak and Paytan (2011) included 32 individuals from the coastal site of Ancón, Peru dating to the Andean Middle Horizon in their study to investigate human dietary patterns and economic trends through stable isotopic data. Isotopic data from human bone collagen, human tooth enamel, and bone carbonate indicate that populations consumed a mixed diet comprised of mainly marine protein and C_4 resources with only marginal reliance on C_3 foods (Slovak and Paytan 2011). Despite their reliance on rich C_4 foods, such as maize, the environment would have not supported the cultivation of such resources, indicating that the populations either had access to more fertile lands up-valley where maize could be cultivated or that maize was traded in (Slovak and Paytan 2011).

Richards and collegues (2002) examined changes in diet during ones lifetime by stable isotopic analysis of teeth compared to bone. Studies showed that dietary shifts could be seen when teeth, which form at known times and are not reformatted, are compared to bone, which is reformatted during life (Richards, Mays and Fuller 2002). Weaning estimates, among other cultural traits, were able to be seen through these methods. The comparison of early forming osseous tissue to constantly reforming tissue allowed a comparison of dietary shifts throughout time (Richards, Mays and Fuller 2002).

Bartelink (2009) examined 51 individuals from CA-ALA-329, Ryan Mound, the site location of the present study. The study included nine males and nine females from the Early Period, ten males and eleven females from the Middle Period, and eight males and four females from the Late Period. The analysis used data from stable carbon and nitrogen isotopes from human bone to evaluate evidence of paleodietary change among late Holocene human populations. The results indicate significant temporal variation and indicate a shift in emphasis from high trophic-level marine protein toward a greater emphasis on terrestrial resources and lower trophic-level marine foods over the time periods analyzed. Additionally, carbon isotope values of bone apatite suggest an increased emphasis on vegetal resources during the later part of the sequence examined (Bartelink 2009).

Newsome and colleagues (2004) examined nine individuals from the Harkins Slough archaeological site located on Monterey Bay in Central California. This site is an Early to Middle Holocene coastal assemblage. Carbon and nitrogen isotopic data from human burials and associated archaeofauna were analyzed for input into a concentration-dependent isotope mixing model that is able to statistically discriminate among multiple food sources (Newsome et al. 2004). Human burials segregate into two distinct groups that lie in the early and middle Holocene, showing significant dietary differences. In the early Holocene, 70-80% of the diet was composed of marine food sources, as indicated by stable isotope analysis, whereas in the late Holocene marine resources only comprised 48-58% of the diet. Additionally, reliance on vegetal foods increased over time, as indicated by the isotopic data (Newsome et al. 2004).

As equipment advanced in the ability to analyze smaller amounts of material, more information was able to be obtained from osseous tissue (Eerkens, Berget and Bartelink 2011). The required collagen amount decreased, allowing for dentin layers to begin to be analyzed in their naturally occuring growth layers to predict a dietary chronology through a specific period of time. Eerkens and collegues (2011) reconstructed diet for six individuals at the Marsh Creek Site (CA-CCO-548) to attempt to determine the weaning age. First molars were serial sectioned from this sample population, along with a sample of bone to determine dietary change from the formation of the first molar to later in life, while the bone was reformatting. This study revealed that weaning age could be reconstructed for these six individuals. The earliest weaning age was at 1.1 years old, while the oldest in the sample was weaned after the age of four (Eerkens, Berget and Bartelink 2011). This study gave insight on the ability to use dietary reconstruction to obtain information about other cultural practices.

Eerkens and Bartelink (2013) continued to study the above site by using a sample of eight males and nine females to further determine and evaluate age of weaning and early childhood diets from a Middle Holocene site in Central California, CA-CCO-548. Serial sections of dentin collagen in first molars was examined and suggested females were fully weaned, on average, by 3.6 years of age, which is about 0.4 years later than males examined in the sample (Eerkens and Bartelink 2013). This suggests possible increased parental investment in female offspring. Alternatively, in later childhood years females consumed lower trophic-level foods than males. Overall, the data suggest that children from this site were enculturated early in life into their sex-specific diets with females consuming greater amounts of plant resources and males consuming greater amounts of higher-trophic level fish and meat protein (Eerkens and Bartelink 2013).

Eerkens and colleagues (2013) examined the Central California isotopic landscape to extrapolate how foods in different ecosystems and environments have specific and distinctive isotopic compositions. This study presents new bone collagen and apatite carbon and nitrogen stable isotope data from two Late Holocene sites (CA-SOL-11 and CA-SOL-69) near Suisun Marsh. Sixty-seven total individuals were examined from infancy to older adulthood including males, females, and indeterminate sex to examine specific isotopic signatures in brackish water regions. This study predicted the isotopic signature for brackish water environments, as compared to terrestrial, riverine, marine, and C_4 plant consumers. The stable isotopic brackish water foodweb lies between terrestrial and marine diets, as predicted (Eerkens, Mackie and Bartelink 2013).

Other studies using serial sectioning of human molars occurred in Eerkens and collegues study (2016) on carbon and nitrogen stable isotope analysis of third molars to determine mobility and consumption of shellfish at an inland location. Twelve burials from CA-SOL-11 were examined in this study to eludicate information on which subsets of the population were consuming shellfish resources that were recovered during excavations of the archaeological site (Eerkens, Sullivan and Greenwald 2016). The nearby Suisun Marsh is located 15 kilometers from CA-SOL-11, which would have required great investment to obtain shellfish resources. The results from this study indicated that individuals likely did not travel as groups to gather resources, but suggest higher inter-individual variation in diet (Eerkens, Sullivan and Greenwald 2016). The serial sectioning of third molars allowed dietary reconstruction to understand who was consuming this resource and when. Results indicated that individuals generally consumed the same resource during the reconstructed time. This may have been due to food preference, availability of resources, or territorality (Eerkens, Sullivan and Greenwald 2016).

Additionally, isotopic studies have been used to determine post-marriage residance patterns, as seen by Eerkens and collegues (2014), at a Middle Period Site in the southern San Francisco Bay. The process of strontium isotope uptake is similar to carbon and nitrogen isotopes, where the food and water consumed contribute to the osseous tissues.

These can later be extracted and examined. Strontium isotopes from early growing teeth and bone were collected and analyzed from six females, seven males, and one indeterminate sexed individual. The data revealed that males were much more mobile than females, which the researchers argue indicate matrilocality (Eerkens et al. 2014). This study relates similarly to the present study, as both seek to reconstruct mobility as insight into post-marriage residence patterns.

2.5.2 Stable Isotopic Applications

During an individual's life, one consumes food and water, which contain isotopes of specific ratios. Bodies absorb these isotopes, which in turn create specific chemical signatures in their osseous structures (Bartelink et al. 2014; Slovak and Paytan 2011). Depending on where consumption occurs and the type of food (trophic level, and marine versus terrestrial), different isotope signatures will be recorded (Eerkens et al. 2013; Newsome et al. 2004). Bone constantly reforms; hence, if a bone is broken, it will regrow and heal. Because of this, a person's bone will reflect approximately the past five to twenty years of their dietary history (Bartelink et al. 2014; DeNiro 1985; DeNiro and Schoeninger 1983; DeNiro 1987; Eerkens et al. 2014; Eerkens and Bartelink 2013; Eerkens, Berget and Bartelink 2011; Eerkens, Sullivan and Greenwald 2016; Eerkens, Byrd, et al. 2013; Eerkens, Mackie and Bartelink 2013).

As discussed briefly previously, teeth, alternatively, form once during a lifetime and are never reformed. This means that isotopic signatures in teeth reflect diet only in the time they form in the body, which relates to a specific age (Eerkens et al. 2013). Teeth grow in layers over time allowing researchers to examine these layers independently to learn about what types of food an individual ate when the layer was forming, and where on the landscape they ate that food (Bartelink et al. 2014; Eerkens et al. 2013; Grimstead and Pavao-Zuckerman 2016; Grimstead, Quade and Stiner 2016; Newsome et al. 2004; Slovak and Paytan 2011; Webb, White and Longstaffe 2013). Dentin is the tooth tissue that is used for this study. There are three types of dentin, primary dentin, secondary dentin, and tertiary dentin (Zilberman and Smith 2001). Primary dentin is examined for stable isotopic analysis as it is formed in association with enamel or cementum apposition, while the tooth is forming. Secondary dentin is formed later in life and may be associated with a reduction in the number of functioning odontoblasts. Because of the time it is formed, secondary dentin is not considered or examined for this study but is removed prior to analysis. Lastly, tertiary dentin is produced as a response to trauma in the tooth; such as a carious lesion (Zilberman and Smith 2001).

Bone collagen, found in skeletal remains, $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios indicate the isotope ratio of an animals' diet. Additionally, various groups of foods have different ratios of carbon and nitrogen isotopes. Because of this, the isotope ratios of collagen in the skeletal remains reflect the foods that that individual ate (DeNiro 1985). Importantly, bone collagen isotope ratios are not modified by postmortem processes, allowing for fossilized bone to be analyzed.

Carbon and nitrogen isotopes are commonly analyzed from human remains to give insight on the foods that individuals consumed. Carbon isotopes inform on the marine versus terrestrial aspect of the diet and nitrogen refers to the trophic level of the foods consumed (Eerkens et al. 2013; Gannesa, Martinez del Riob and Koch 1998; Koch, Zachos and Gingerich 1992). With the vast number of ecosystems in the vicinity of the Ryan Mound, researchers can identify what foods would have been available in various areas, allowing identification of where individuals resided based on their diet (DeNiro 1987; Eerkens et al. 2013).

Another aspect of stable isotope analysis that makes it so useful compared to other archaeological methods is that researchers can examine traits on the individual level, as opposed to only the entire population. This allows the inference of much more information regarding populations, because the distribution of characteristics from individuals can be studied.

Carbon isotopes represent the source of carbon an individual is consuming, such as C3 vs. C4 plants (DeNiro and Schoeninger 1983; DeNiro 1987; Eerkens et al. 2014; Eerkens and Bartelink 2013; Eerkens, Berget and Bartelink 2011; Eerkens, Sullivan and Greenwald 2016; Eerkens, Mackie and Bartelink 2013). In prehistoric Central California, there was little consumption of C4 plants, such as maize (Eerkens, Mackie and Bartelink 2013; Jones and Klar 2007; Kroeber 1925; Kroeber 1939; Levy 1978; Moratto 2004). Instead, elevated $\delta^{13}C$ carbon isotopic signatures represent the consumption marine-derived carbon, which overlaps signatures for C4 plants (Bartelink 2009; DeNiro 1987; Eerkens, Mackie and Bartelink 2013). Individuals who consume more brackish water foods will show intermediate $\delta^{13}C$ values. Further, individuals residing in riverine areas with no marine resources have very low $\delta^{13}C$, as seen through Eerkens and collegues study (2013) that examined 67 individuals to determine a base isotopic landscape signature for much of the environment between the marine regions and terrestrial areas

(Eerkens, Mackie and Bartelink 2013). In other words, the $\delta^{13}C$ signature increases as the salinity of the water increases, as seen in Figure 4.

In addition, Eerkens and colleagues (2013) noted that nitrogen isotopes can be used as indicators to identify the trophic level of the foods consumed. As individuals consume foods with higher trophic levels, their $\delta^{15}N$ (nitrogen isotope) signature increases by about 3-4‰ with each trophic level. In terrestrial systems, there are typically three trophic levels: plants, herbivores, and carnivores. In contrast, there are many more trophic levels in aquatic systems allowing higher enrichments of $\delta^{15}N$. Because of the increase in the number of trophic levels in marine environments, even plants in marine and coastal environments tend to be higher in $\delta^{15}N$ when compared to plants growing in terrestrial environments, as seen in Figure 5.

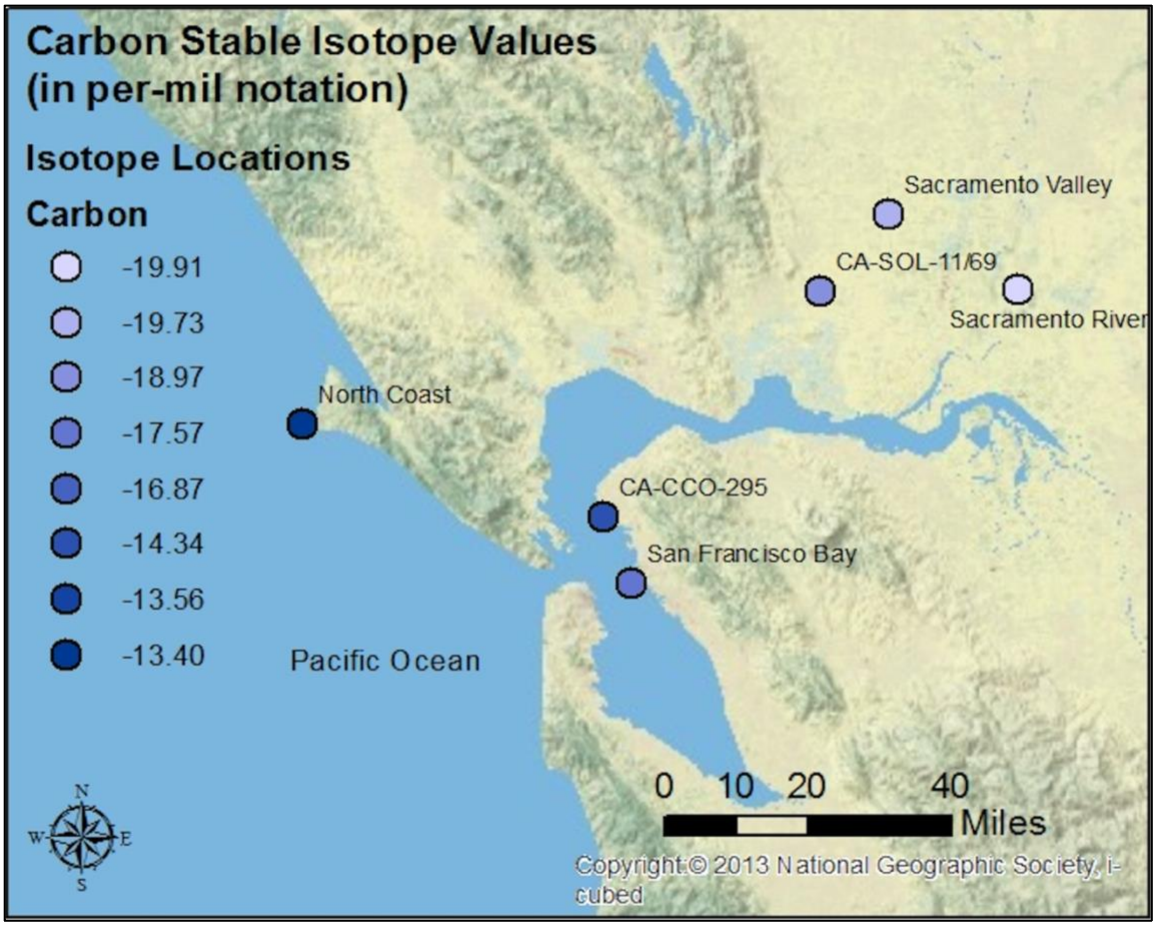

Figure 4: Carbon isotopes in the San Francisco Bay Area (data from Eerkens et al. 2013).

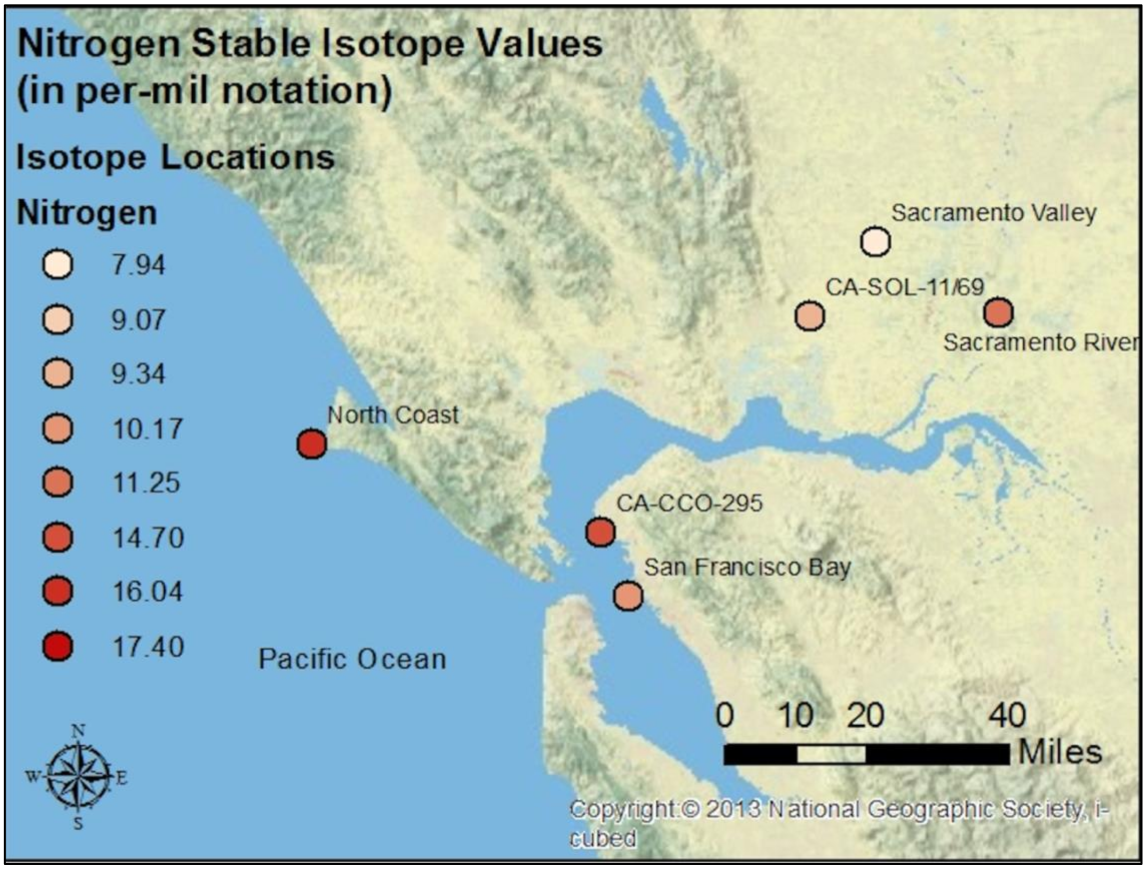

Figure 5: Nitrogen isotopes in the San Francisco Bay Area (data from Eerkens et al. (2013).

Combined, carbon and nitrogen isotopes provide a variety of environmental signatures, as seen in Figure 6. Individuals who exploit resources from a fresh water riverine environment, far from the ocean, such as large fish, will have depleted $\delta^{13}C$ because of the lack of marine input, as well as an increased $\delta^{15}N$ signature because of the high trophic level (Eerkens, Mackie and Bartelink 2013). However, the trophic level will not be as high as an individual who consumed high amounts of marine mammal, who will have elevated $\delta^{15}N$ and $\delta^{13}C$ signature.

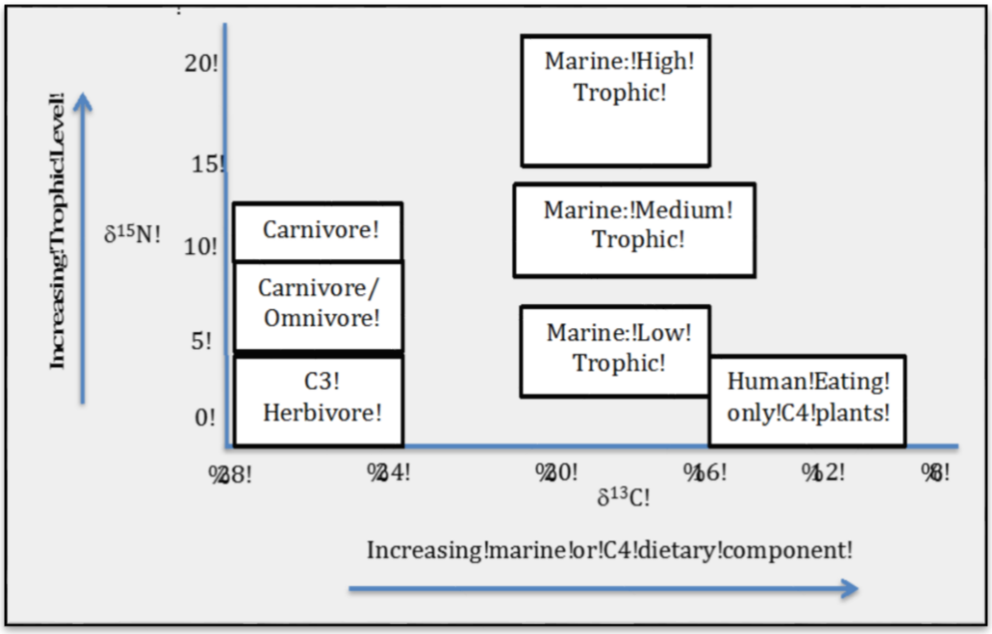

Figure 6: Carbon and nitrogen isotope food-web.

This study builds on the specific methods of serial sectioning human molars to create a dietary chronology of an individual during a specific period of their life outlined in Eerkens and Bartelink (2013). Teeth are composed of three materials: enamel, dentin, and cementum (Hillson 1996). Primary dentin is the portion of the tooth that makes up the interior, grows in predictable layers over time, and never reformats. In this study, secondary and tertiary dentin is not considered or analyzed. Because of the formation patterns of teeth, researchers can examine these growth layers independently to examine changes in diet, and therefore geographic location, over a period of the individual's lifetime.

With the ability to determine what an individual ate based on their isotopic signatures, and therefore where they were living, researchers have the tools to reconstruct mobility.

This methodology allows insight into what foods various subsets of the population were consuming, and when they were consuming those foods based on the particular tooth or bone analyzed, thus creating the ability to determine environmental location during specific windows of life.

CHAPTER 3: THEORETICAL PERSPECTIVES

3.1 Introduction

Marriage, kinship, and mobility are all social strategies set forth to aid in the ability of a community to survive. Mobility allows individuals the framework to have access to necessary items to harbor longevity, especially with environmental conditions that are uncertain. Additionally, marriage and kinship can help survival by creating alliances and trade partnerships with other communities to aid in offsetting inevitable risks (Fox 1967). Precontact Native Americans who resided in California were hunter-gatherers who relied on their environment and produced all necessary material culture for survival. Although the San Francisco Bay Area harbored a diverse array of resources for native people during the Early and Middle Period, over time, growing population densities, overexploitation of mammals, and territorial circumscription impacted subsistence strategies for the groups densely packed into this landscape (Bartelink 2009). Mobility on the landscape, including seasonal logistical movements or longer-term migrations, was one answer to the ever-changing dilemma of food and resource insecurity (Eerkens et al. 2013). These movements on the landscape allowed the inhabitants of the precontact San Francisco Bay Area to thrive in their local environments.

3.2 Kinship and Marriage

Kinship and marriage facilitate ties with exogamous communities throughout the region who can be relied upon during times of uncertainty aid in survival (Bettinger 1991; Eerkens et al. 2014; Fox 1967; Harrington 1942; Hill 1970; Jones and Klar 2007; Margolin 1978; Walker et al. 2011). As stated by Walker and colleagues, “marriage is a fundamental cornerstone of human economic, social, and kinship networks" (2011:1). Because most societies are not incestuous, small communities, which are mainly family groups, must introduce marriage and reproduction partners from the outside (Fox 1967; Hill et al. 2011; Marlowe 2005; Walker et al. 2011). Reproduction, domination, and the avoidance of incest create the basic structures of social organization. These factors would have created social ties to various groups throughout the Bay Area as partners would have left their home to move in with their spouse. Whether the mobility was seen in males or females, or both, these distinctions reveal much more about the social structure, network, and culture of the individuals of CA-ALA-329.

3.3 Matrilocality

Many accounts report that females owned and operated the acorn-producing oak groves throughout the San Francisco Bay Area (Jackson 1991; Margolin 1978; McGuire and Hildebrandt 1994). These groves provided most of the sustenance for the inhabitants. Acorns were processed only during the fall season, stored, and relied upon throughout the year. With female ownership and production, it is feasible that mothers trained their daughters how to process and prepare this important resource. Additionally, because of the investment in females to teach these production techniques, they would have been a valuable part of the economic structure (Ember 2014). The combination of the ownership of groves and granaries by females, with the investment in learning the procedures, indicate that females likely controlled many aspects of the social system (Eerkens et al. 2014; Ember 2014; Jackson 1991; Walker et al. 2011). Generally, if there is a great investment in a specific sex to teach and train important skills, it will be seen in the marriage patterns, as societies do not want to lose an individual that has had so much investment in cultural training (Ember 2014).

Hunter-gatherer populations which rely more on fishing and hunting for sustenance are more likely patrilocal societies, whereas societies which rely on gathering are generally matrilocal (Bettinger 1991; Binford 1980; Ember 2014). Other matrilineal hunter-gatherer populations exhibit this pattern with regards to pottery and the investment in females to teach them the complex techniques, as seen in the structural, functional and evolutionary analysis of Broken K Pueblo (Hill 1970). Essentially, according to ethnographic records, investment in particular sex-based cultural traits or resources strongly dictates marriage patterns, social structure, and thus mobility.

3.4 Summary

Kinship allows for a network of related beings that can rely on each other. The development of this network, through marriage and reproduction, allows for more stability and dependability in uncertain circumstances, where food resources are dependent on the environmental conditions. Marriage and cultural ties allow for groups to rely on each other during uncertain times (Fox 1967). The specific characteristics of marriage also inform largely on the society and the cultural traits that are present.

The three factors of marriage, mobility, and kinship aid in the survival of a community. The individuals interred at Ryan Mound participated in many cultural activities that could be linked to matrilocal society characteristics. Specifically, the female investment in the ability to process and produce reliable food sources aided in the favorability of investment in female learning, and thus create the conditions that favor a matrilocal society.

CHAPTER 4: METHODOLOGY

4.1 Introduction

The research focus for this study included determination of the marriage and residence patterns of the individuals interred at Ryan Mound, as inferred from stable isotope analysis of human remains. To examine shifts in residence this study looks for significant shifts in diet over the course of an individual's lifetime. Because the San Francisco Bay Area has a diverse ecosystem with many micro-environments, diet could be used as a proxy to determine landscape mobility. Hence, as you move to a different location, you are eating different food. Stable isotope analysis of carbon and nitrogen isotopes allows examination and tracking of dietary change throughout a period of time. To answer the research questions, individuals for this study were selected who had distinctive osteological indicators of sex. Ten males and ten females were selected, ranging from all the three time periods at Ryan Mound.

4.2 Selection of Burial Samples

The Muwekma Ohlone, the most likely descendants of the source population for this study, were consulted for permission to conduct partially destructive, but also instructive, analyses on human remains. The tribe granted full support for this project and testing. They are interested in obtaining more information about their ancestors through such studies (see Appendix A for letter of support).

The sample included only adult individuals with intact third molars whose sex could be estimated with a high degree of confidence. Age and sex determinations were completed for the entire burial population by R. Jurmain using standard osteological criteria (Bass 1995; Buikstra and Ubelaker 1994; Leventhal, Jurmain, et al. 2009; Ubelaker 1989). The sex assessments were augmented by metric analysis with age assessments determined primarily through pubic symphysis remodeling, auricular surface remodeling, and ectocranial cranial suture closure (Brooks and Suchey 1990; Dittrick and Suchey 1986; Katz and Suchey 1986; Leventhal, Jurmain, et al. 2009; Todd 1920; Todd 1921). Adolescent and young adults were aged through the evaluation of the later stages of epiphyseal union (Leventhal, Jurmain, et al. 2009; Lovejoy et al. 1985).

A list of potential individuals was sorted by time period so that burials could be selected from the Middle, Phase I, and Phase II periods. This list included Phase II (Male=31, Female=20), Phase I (M=39, F=39), and Middle (M=16, F=14). The list was then sorted by number of loose teeth. In an effort to try to reduce damage to existing burials, burials with numerous loose teeth were examined first to extrapolate the possibility of utilizing teeth which were not embedded in the mandible or maxilla, to avoid further damage. Most teeth were removed from individuals who had loose teeth. In order to sample an equal number of males and females from each period, some teeth had to be removed directly from bone.

The final sample included three males (burials: 249, 273, and 244) and three females (burials: 231, 263, and 251) from the Middle Period, four males (burials: 168, 252, 128, 110) and four females (167, 281, 74, and 132) from Phase I, and three males (burials: 64, 61, and 102) and three females (burials: 2, 274, and 62) from Phase II. The third molars were taken from either the right or left side, and from either the mandible or maxilla. The basic identification information for each burial is listed below in Table 1, and photographs are available in Appendix B.

4.3 Burial Information

Most burials were primary inhumations in some degree of flexure. Associated artifacts ranged from none, to limited, to large assemblages of *Olivella*, bone, and stone tool technologies. Additionally, the radiocarbon dating generally confirmed the initially established period dates. Table 1, below, provides further information on the burial numbers, estimated ages, sex, period, and tooth selected for analysis.

Table 1: Burial Information.

Burial #	**Age**	**Sex**	**Period**	**Tooth**
231	20-30	F	Middle	Upper left third molar
263	25+	F	Middle	Upper right third molar
251	25-35	F	Middle	Upper left third molar
249	35-44	M	Middle	Lower right third molar
273	20-31	M	Middle	Lower right third molar
244	39-44	M	Middle	Upper right third molar
167	30-40	F	Phase I	Lower left third molar
281	35-45	F	Phase I	Lower left third molar
74	25-44	F	Phase I	Lower right third molar
132	31-40	F	Phase I	Upper right third molar
252	30+	M	Phase I	Lower left third molar
168	30+	M	Phase I	Lower right third molar
128	30+	M	Phase I	Lower right third molar
110	30-35	M	Phase I	Upper left third molar
2	35+	F	Phase II	Lower left third molar
274	18-20	F	Phase II	Lower left third molar
62	31-40	F	Phase II	Lower left third molar
64	30-39	M	Phase II	Lower left third molar
61	35-50	M	Phase II	Upper right third molar
102	21-30	M	Phase II	Upper left third molar

4.4 Sample Preparation

Third molars were removed from the burials and prepared for serial sectioning at the UC Davis Archaeometry Laboratory and analyzed for $\delta^{13}C$ and $\delta^{15}N$ stable isotopes at the UC Davis Stable Isotope Facility. The results were reported back in per-mil notation for all burial samples. Age ranges were statistically applied to serial sections to show a dietary trend for each individual throughout the age ranges of 8.5-21.5 years, which is the typical growth period of a third molar (Hillson 1996). Dietary trends for each individual were compared and analyzed for shifts in diet to determine who was mobile when, and on what landscape they were obtaining resources. Understanding these shifts in diet, and thus mobility, can give insight into marriage patterns for this precontact population.

Sample preparations followed procedures and protocol established in Eerkens et al. (2011) and were completed at the archaeometry laboratory of Dr. Eerkens at UC Davis. Third molars were selected and cleaned of any calculus, which is calcified plaque, and adhering sediment. The tooth was cut in half longitudinally to expose the interior, from the crown to the root tip with a slow-speed diamond-coated saw. Measurements of the dentin-enamel junction, cementum-enamel junction, and overall length of the tooth were recorded after the tooth was cut. These measurements were necessary for later analyses to determine age ranges for serial sections. A photograph of the tooth was also taken before and after cutting. The enamel and cementum were removed with a hand-held drill, leaving only the dentin. Enamel was saved for potential future studies and was returned to the curation facility at San José State University with the CA-ALA-329 burials. Any secondary and tertiary dentin was removed with a hand-held drill, to prevent results being skewed by later-forming dental tissue. The tooth was sonicated in deionized water (dH_2O) to remove any other materials or debris from the tooth. The remaining dentin was then demineralized in a solution of 0.5 M hydrochloric acid (HCl) in a refrigerator (5°C), which was changed every day to every other day for one to two weeks, or until the tooth was soft enough (slightly firmer than gelatin) to proceed to the next step.

Once the tooth was demineralized, it was rinsed with dH_2O to remove any additional HCl, sliced with a razor blade in approximately one-millimeter parallel increments, representing roughly six-month to one-year intervals of time, depending on the thickness and location of the serial section, as seen in Figure 7. The root tip, dentin-enamel junction (DEJ), and cementum-enamel junction (CEJ) allowed for age assignments to the sectioned dentin because they form at known ages (apical root tip = 21.5 years, CEJ = 14 years, DEJ = 8.5 years). Each section was assigned a median age based on its spatial relationship to these tooth landmarks.

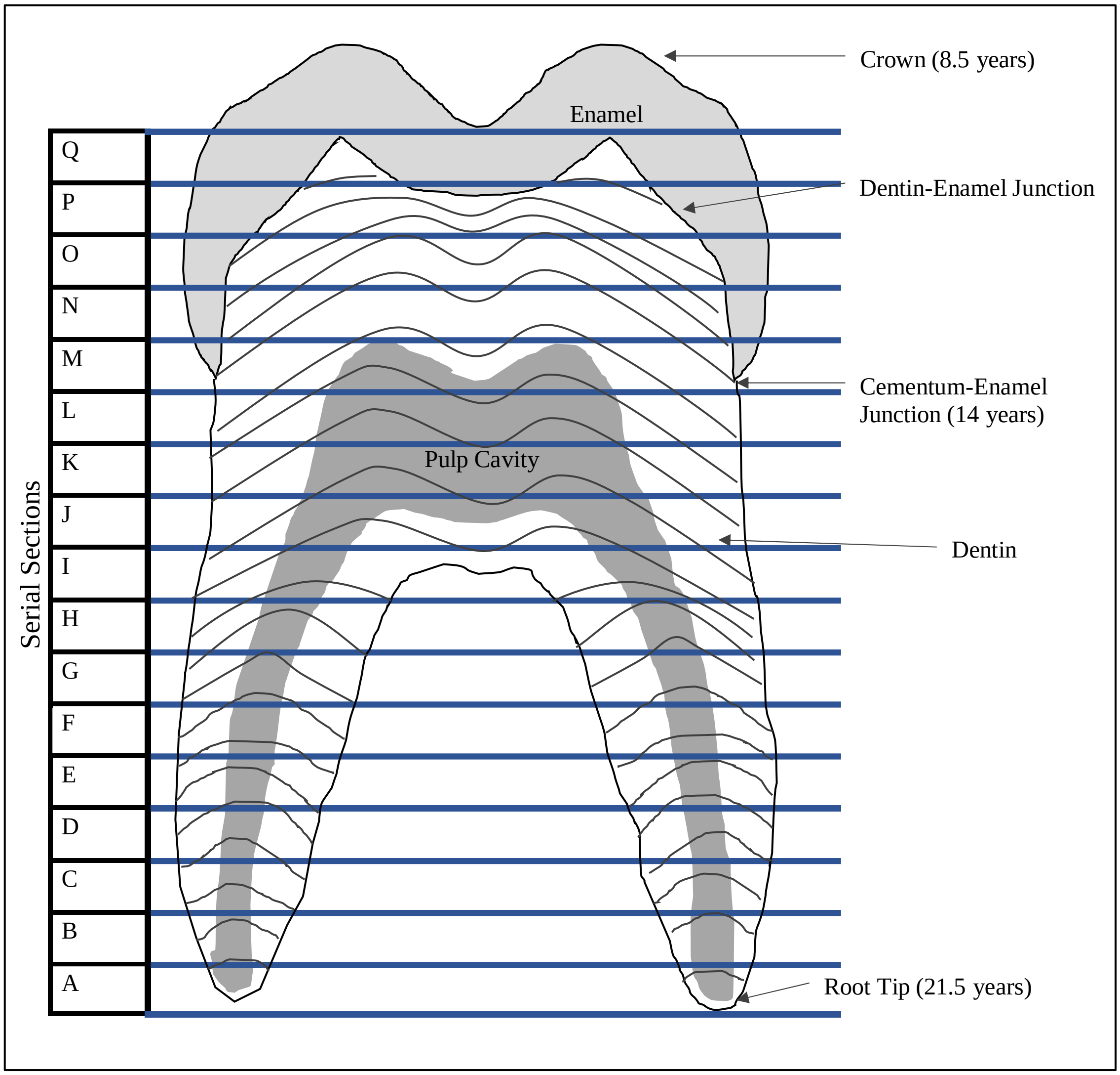

Figure 7: Tooth cross-section (adapted from Eerkens et al. 2013).

The serial sections were placed into separate vials and immersed in 0.125 M NaOH (sodium hydroxide) for 24 hours to remove any humic acids. The sample was rinsed with dH_2O to remove any additional solution and placed in a slightly acidic (pH3) water solution in separate vials and put in an oven set to 70°C to solubilize the collagen. The solubilized solution was freeze-dried to remove any water remaining, resulting in pure human collagen ready for stable isotopic testing. See Appendix C for expanded information for each burial.

4.5 Sample Submission

The samples were then taken to the Stable Isotope Facility (SIF) at UC Davis where 0.8 – 1.2 mg of collagen is weighed out from each serial section sample for stable C and N isotope analysis. The samples are measured by a continuous-flow mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ration mass spectrometer). A total of 254 serial section samples were submitted from the 20 third molars from the CA-ALA-329 burials. Some serial sections from select burials had to be combined to gain enough human collagen for submission. Combining sections increases the amount of time represented by a particular isotopic analysis. Burials 61, 102, 128, and 274 had serial sections that had to be combined for submission.

4.6 Analysis and Classification

Results from SIF were reported in per-mil notation (parts per thousand) for both carbon and nitrogen isotopes for each serial section submitted, reported in Appendix D. Before resuming analysis, the ratio of total carbon and total nitrogen (C/N) by weight was assessed to address the quality of the human collagen that was submitted. C/N values between 2.9 to 3.6 are considered to be well preserved for human collagen (DeNiro 1985). The total carbon, reported in micrograms (ug), is divided by the total nitrogen (ug), which is multiplied by (14/12) to obtain an atomic mass. Values here were consistently between 3.2 and 3.6, which is in an acceptable range for human collagen (DeNiro 1985).

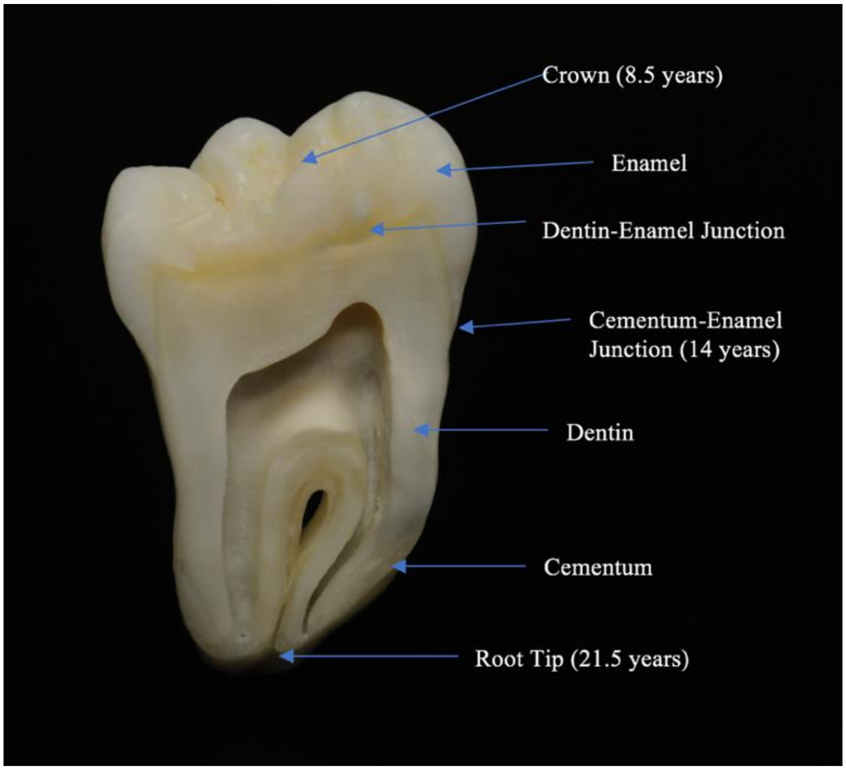

Figure 8: Tooth growth landmarks (adapted from Eerkens et al. 2013).

The isotopic values then had to have ontogenetic ages assigned, as seen in Appendix E. Before and while cutting the third molars into serial sections, measurements were taken. Pre-drilling measurements provided information on the dentin-enamel junction (DEJ), cementum-enamel junction (CEJ), the maximum length, the occlusal surface, and the weight for each tooth. This information, along with the length of the serial section, allowed to statistically apply age ranges for each serial section (Eerkens, Berget and Bartelink 2011). Tooth growth begins at the occlusal surface, so it is assumed that portion is formed at 8.5 years old. The tooth finishes growth at the root tip at 21.5 years old, as seen in Figure 8. In addition, the CEJ forms at 14 years old. Measurements are taken for these three landmarks (refer to Appendix E for measurements).

For example, burial 251 had a CEJ of 13.41mm, and a DEJ of 17.8mm. It is assumed that the portion of the tooth between the root tip and the CEJ grows at a different rate than the portion between the CEJ and DEJ. To account for these varying growth rates, each section is calculated independently to give the most accurate results. For this tooth, the growth rate was calculated from the root tip to the CEJ as 0.5593 years/mm and the CEJ to DEJ as 1.421 years/mm. The measurements taken during sectioning, or the range that each serial section is cut into, are used. The first serial section (SSa) is 0-2.30 mm, meaning the serial section is 2.3 mm long. The second serial section (SSb) is 2.30-3.33 mm, meaning the serial section is 1.03 mm long. The distance from the DEJ for each serial section is then calculated. The first one is 15.5 mm from the DEJ (DEJ – length of SSa). The SSb is 14.47 mm from the DEJ (SSa length from DEJ – SSb length). Because the serial sections are essentially ranges, the average is calculated for each one (i.e., the middle point of the serial section). For example, the first serial section is 2.3 mm long, so it is reported as the average, or 1.15 mm, as reporting the section as 0 or 2.30 mm would be less accurate. The distance from the average of the serial section to the DEJ, the root tip, and the CEJ is reported. Then the average age can be calculated for each serial section (Eerkens, Berget and Bartelink 2011). For sections between the root tip and CEJ, the formula is as follows:

$$Age = 21.5\ yrs - (years/mm \times\ avg. from\ root\ tip),$$

for sections between the CEJ and DEJ the formula is as follows:

$$Age = 8.5 + (years/mm \times avg. from\ DEJ).$$

These previous steps and calculations were repeated for each tooth to apply average ages to each serial section. The age for each section was identified to each reported value for $\delta^{13}C$ and $\delta^{15}N$. The age, δC13, and $\delta^{15}N$ were graphed together to show dietary change over time.

This graphical representation of the data allows for accurate assessment of the data for shifts in diet over time. Shifts that are greater than two standard deviations above or below the average for a tooth are interpreted as a significant change in diet potentially associated with a long-term movement across the landscape.

4.7 Examination of Graphical Data and Normal Range

As discussed in the previous section, ages were assigned to each serial section using various statistical methods. To understand the data collected, graphs were created of the carbon and nitrogen values for each burial along with the ages applied to each value. This resulted in graphs that plot $\delta^{13}C$ and $\delta^{15}N$ on the y-axis with age on the x-axis. There are two plotted lines present on the graph with blue indicating $\delta^{13}C$, and red indicating $\delta^{15}N$. Each line indicates the isotope values through time. With the data in this form, shifts in diet for each burial are able to be examined.

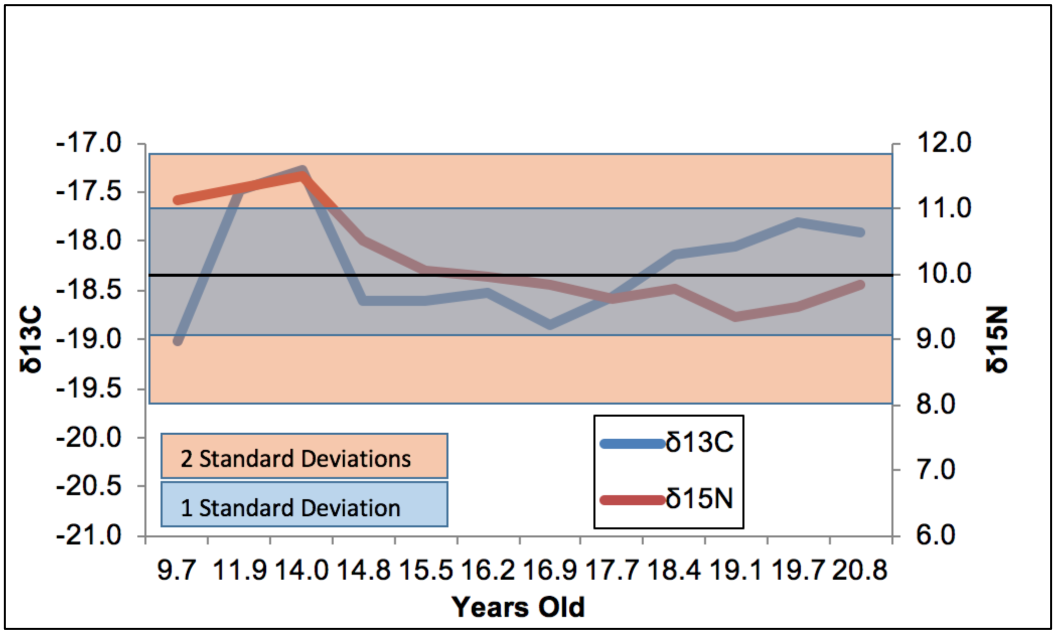

Figure 9: Carbon and nitrogen isotopic values for female burial 231.

In addition, boxes were added for what was estimated to be a "local" range to aid in the understanding of diet and location, as seen in Figure 9, which exhibits the isotopic signature for female burial 231. Local ranges were calculated based on only carbon isotope values for bone collagen for males and females from Bartelink's (2006) data, under the assumption that an adult buried at the site had likely lived there for some time prior to death and would display a "local" dietary signature. The average bone collagen value was calculated with a standard deviation. Local ranges, applicable to only carbon values, are interpreted as those that are within one standard deviation of the average, for both males and females. Thus, values further than one standard deviation from the average was considered to be "non-local" and hence likely to represent a residential shift away from the CA-ALA-329 location (Knudson et al. 2009). Shifts greater than two standard deviations are even more likely to represent a geographic shift. Average $\delta^{13}C$

signature for males was -17.51‰ with a standard deviation of 0.68‰. Average $\delta^{13}C$ signature for females was -18.36‰ with a standard deviation of 0.64. Thus, the standard deviation range for males is -16.82‰ to -18.19‰, and females is -17.71‰ to -19.0‰. The two-standard deviation range for males is -16.1‰ to -18.9‰, and for females is -17.1‰ and -19.6‰. Examination of starting and ending points provided useful for understanding enrichment and depletion age to see if individuals were coming in to CA-ALA-329 or leaving, essentially allowing mapping of who was moving where, and at what time in their life they were making that movement. These inferences are adapted from other studies that have examined stable isotopes of carbon and nitrogen in precontact contexts and determined signatures based on location (Eerkens et al. 2013; Knudson et al. 2009).

CHAPTER 5: RESULTS

5.1 Introduction

The twenty individuals included in this study showed various trends in the nitrogen and carbon stable isotope reconstructions. The results from the carbon and nitrogen stable isotope data revealed serial section isotopic measurements which allowed for an analysis of isotopic data throughout the years of 8.5 to 21.5 years old, as well as throughout the three temporal periods, Middle Period, Phase I, and Phase II. As stated before, the isotopic values of carbon and nitrogen relate directly to the food that is being consumed, and thus, a change in isotopic signatures represents a change in diet. The isotopic values for females in the Middle Period and Phase I showed little change in ranges for an individual throughout the reconstructed time. When compared to the females in the Middle Period and Phase I, males of these same periods showed more variation in the values of carbon and nitrogen isotopes. Furthermore, these shifts and variations for males in the Middle Period and Phase I are clustered around the age ranges of sexual maturity. Additionally, female isotopic values for these time periods remained closer to the local signature as compared to male diet. Lastly, both male and female isotopic signatures from individuals in Phase II showed numerous major shifts during the years of 8.5 to 21.5 years old.

5.2 Middle Period Burials

Burials from the Middle Period included three females (Burials 251, 231, and 263) and three males (Burials 244, 249, and 273). Most of the data points for female diets lie with the local range with few signs of enrichment or changes in diet throughout the years of 8.5 to 21.5 years old, as seen in Figures 10 (Burial 251 – female) and 11 (273 – male). By contrast, males show more dramatic changes in their diet.

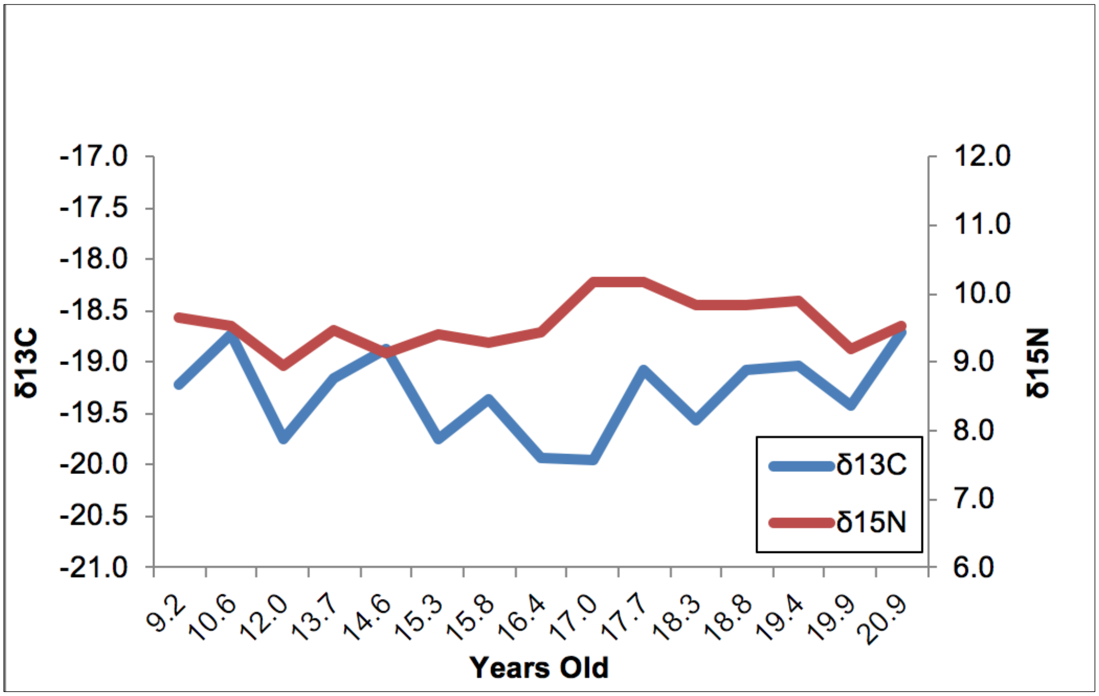

Figure 10: Burial 251. Female. Diet showing stability.

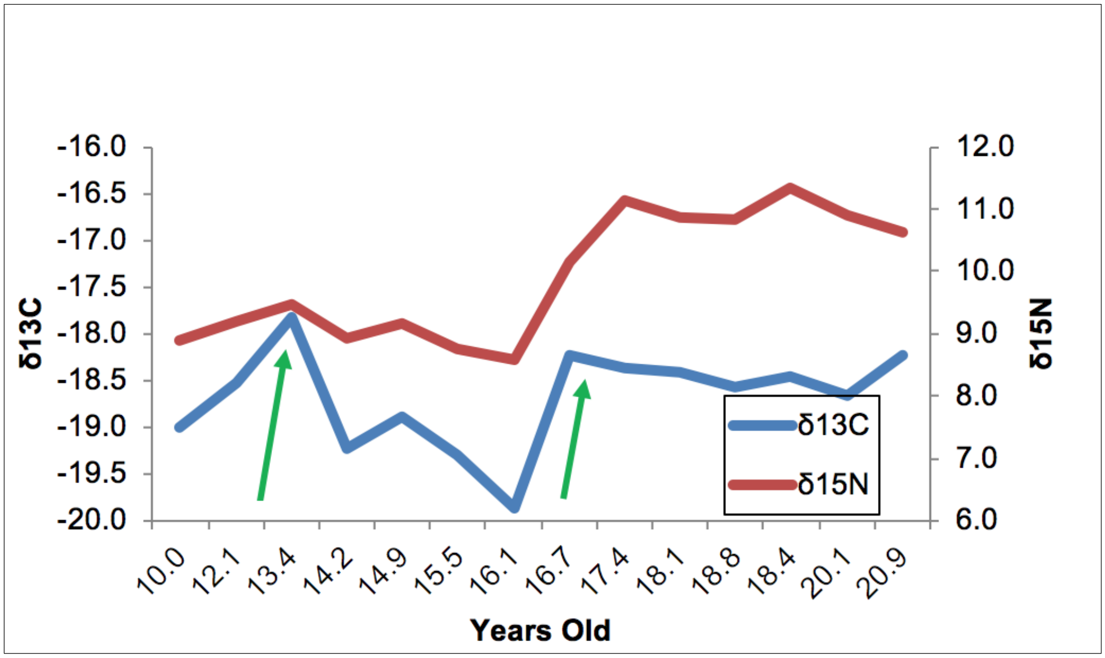

Figure 11: Burial 273. Male. Diet showing shifts at 12 and 17 years old.

5.3 Females in Middle Period

5.3.1 Burial 231

Burial 231, aged 20-30 years old, shows a somewhat stable diet through the ages of 8.5 to 21.5 years old. There is an enrichment of $\delta^{13}C$ seen at 11 years old and a slow depletion of $\delta^{15}N$ seen after 11 years old. The $\delta^{15}N$ starts 1 sig above the $\delta^{13}C$ but balances out and remains stable for the remainder of the analyzed ages. Overall, the isotopic values remain stable through the sampled ages and the carbon signature remains in the local signature with no changes during sexual maturity (Figure 12).

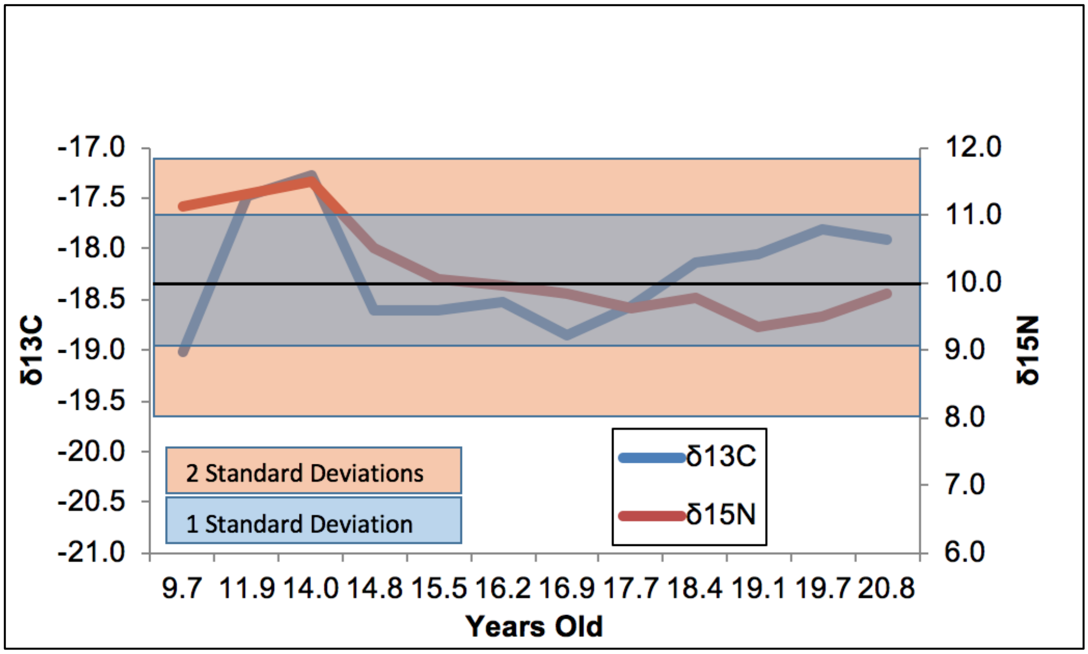

Figure 12: Burial 231. Female. Graphical data.

5.3.2 Burial 263

Burial 263, aged 25+ years old, has a somewhat stable diet through the ages of 8.5 to 21.5 years old. There is an enrichment of $\delta^{13}C$ seen at age 16 with a possible second enrichment seen at 20. There is no major change in $\delta^{15}N$. The $\delta^{13}C$ seems to have more variability for this individual, where the $\delta^{15}N$ remains very stable. The majority of the $\delta^{13}C$ remains in the local signature; there are slight periods where it dips below. However, these changes are slight and could just be the result of sampling error. Overall, this individual shows a local signature for the reconstructed time period, in addition to a fairly stable diet (Figure 13).

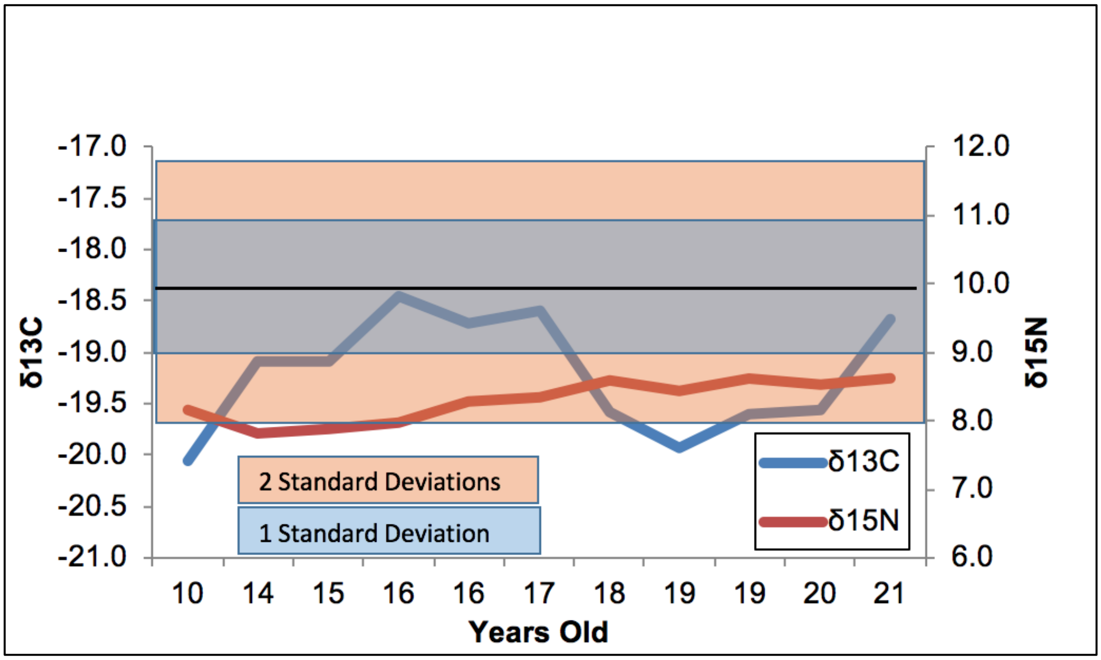

Figure 13: Burial 263. Female. Graphical data.

5.3.3 Burial 251

Burial 251, aged 25-35 years old, has a somewhat stable diet through the ages of 8.5-21.5 years old. There is no enrichment seen in $\delta^{13}C$ or $\delta^{15}N$ during the analyzed period. The $\delta^{13}C$ begins with 1 sig below the $\delta^{15}N$. The $\delta^{13}C$ is somewhat U-Jagged shaped with values increasing and decreasing, but not enough to indicate a change in location. The $\delta^{15}N$ remains flat and stable throughout the time period. For the most part, the $\delta^{13}C$ remains within the local range with slight dipping down below the local range, but again these changes are slight. Overall, this diet is fairly stable and remains mostly in the local range (Figure 14).

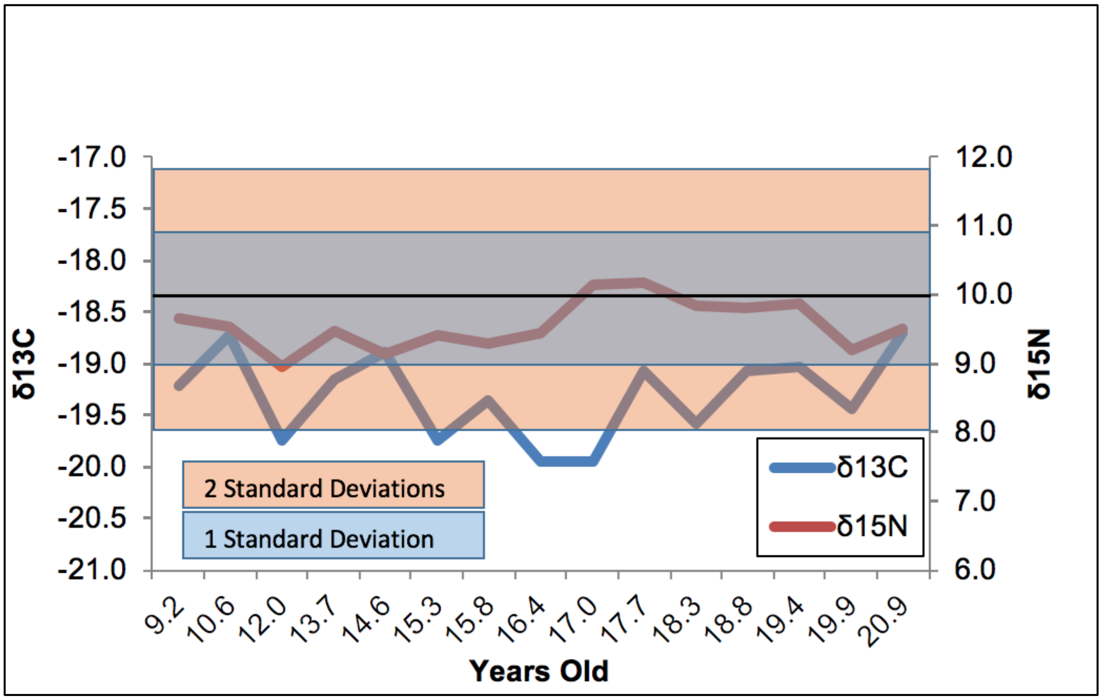

Figure 14: Burial 251. Female. Graphical data.

5.4 Males in the Middle Period

5.4.1 Burial 249

The dietary reconstruction for burial 249, aged 35-44 years old, has many shifts throughout the time period analyzed. There is an enrichment in both $\delta^{13}C$ and $\delta^{15}N$ at age 18 years old for this individual. Both $\delta^{13}C$ and $\delta^{15}N$ show a U-shaped trend through time. Most of the diet is not in the local range temporally. The $\delta^{13}C$ dips into the local signature between the ages of 14 and 18. Overall, this diet lacks in stability through the ages of 8.5 to 21.5 years old (Figure 15).

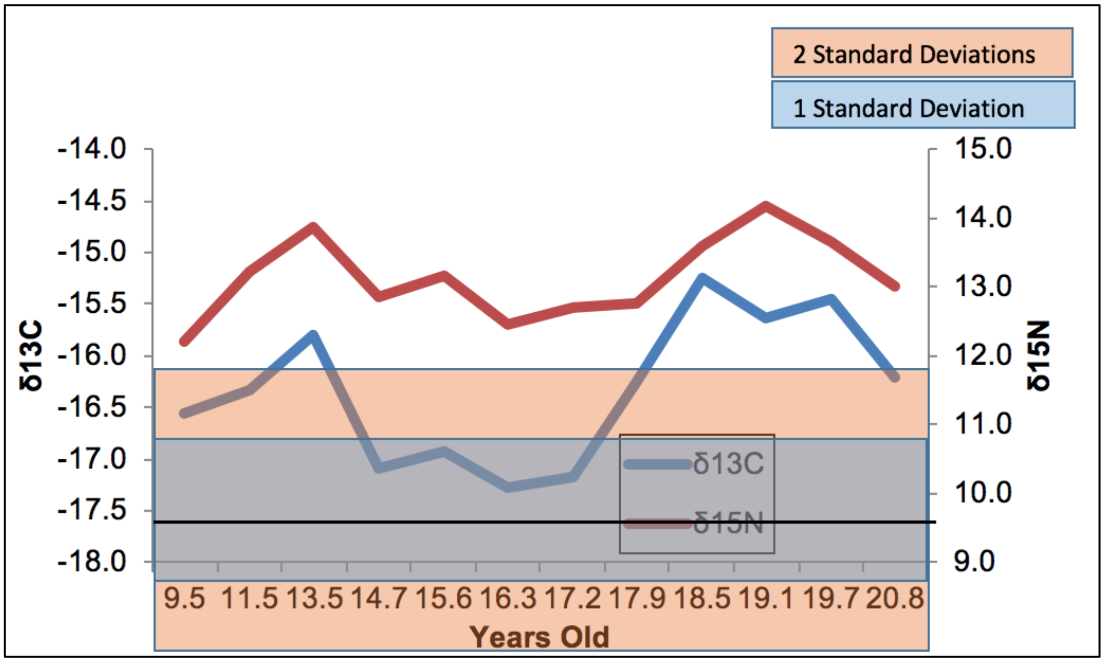

Figure 15: Burial 249. Male. Graphical data.

5.4.2 Burial 273

Burial 273, aged 20-31 years old, shows shifts in diet throughout the tested age ranges. There is an enrichment in both $\delta^{13}C$ and $\delta^{15}N$ at age 17 for this individual. The $\delta^{13}C$ tends to have a bumpy trend to the graph, while the $\delta^{15}N$ has a slow increase over time that tapers off to a flatter level around age 18. The δ13C signature shows two spikes of entering the local signature, once at around 13, and again at around 17 years old (Figure 16).

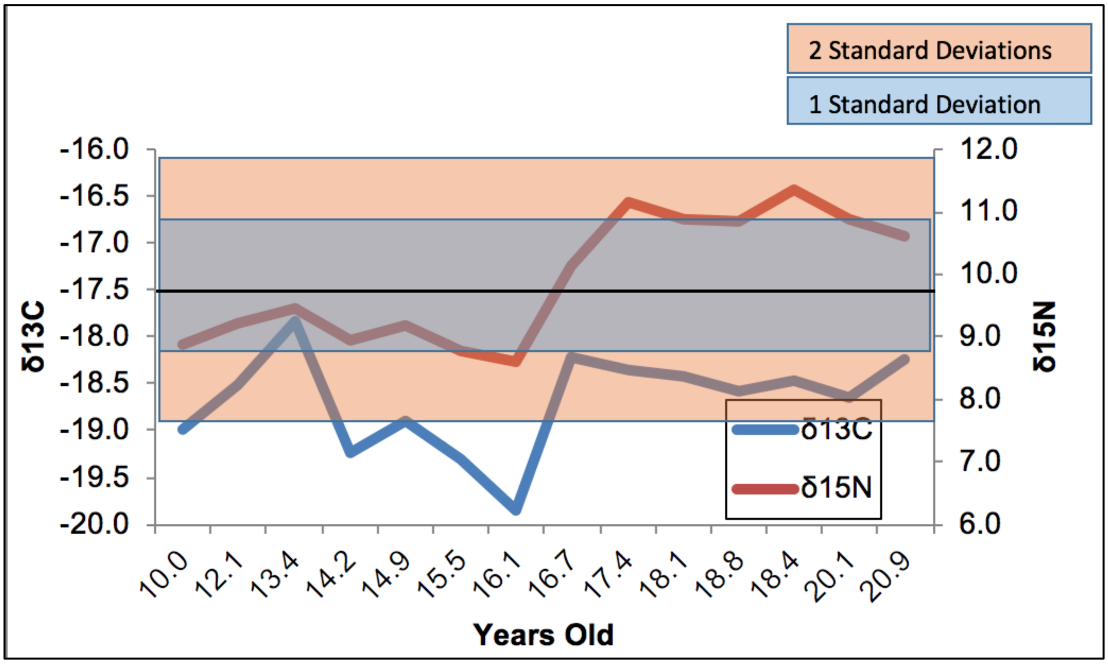

Figure 16: Burial 273. Male. Graphical data.

5.4.3 Burial 244

Burial 244, aged 39-44 years old, shows shifts in diet throughout the ages of 8.5 to 21.5 years old. The graph shows a U-shaped trend with a depletion in $\delta^{13}C$ around age 15. Virtually all of the $\delta^{13}C$ points lie within the local range for this individual (Figure 17).

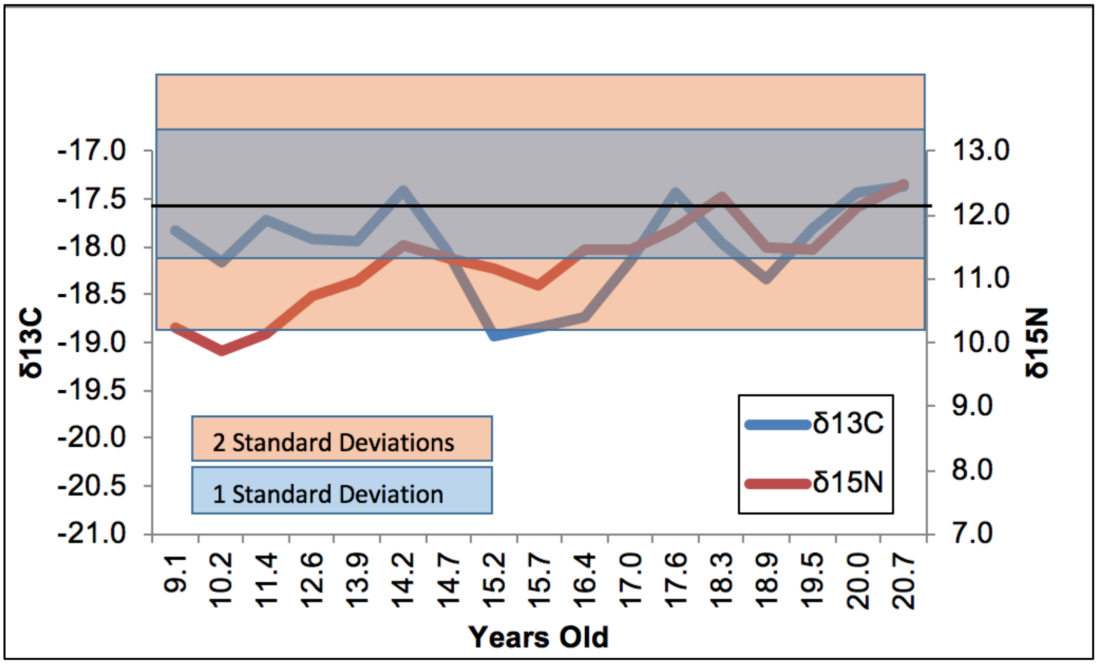

Figure 17: Burial 244. Male. Graphical data.

5.5 Phase I Burials

Burials from Phase I, again, indicate a stable female diet throughout the years of 8.5 to 21.5, and more variable male diets, as seen in Figures 18 and 19. Figure 18 (Burial 281 – female) shows a stable diet, where Figure 19 (Burial 252 – male) shows two changes in diet at the ages 15 and 19, as indicated with the green arrows.

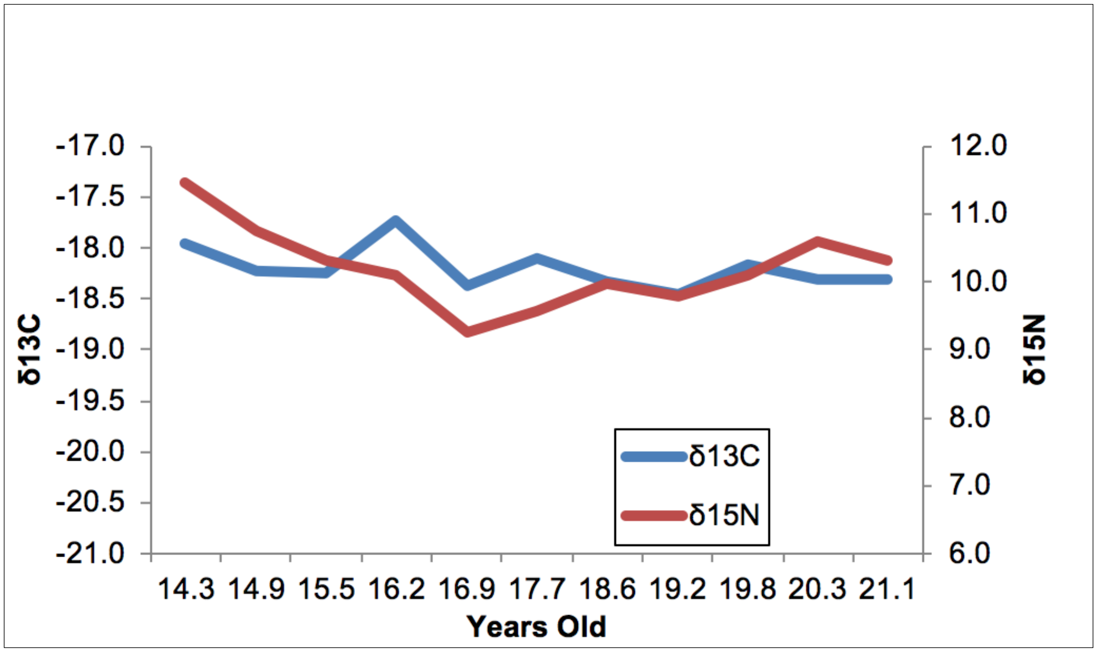

Figure 18: Burial 281. Female. Diet showing stability.

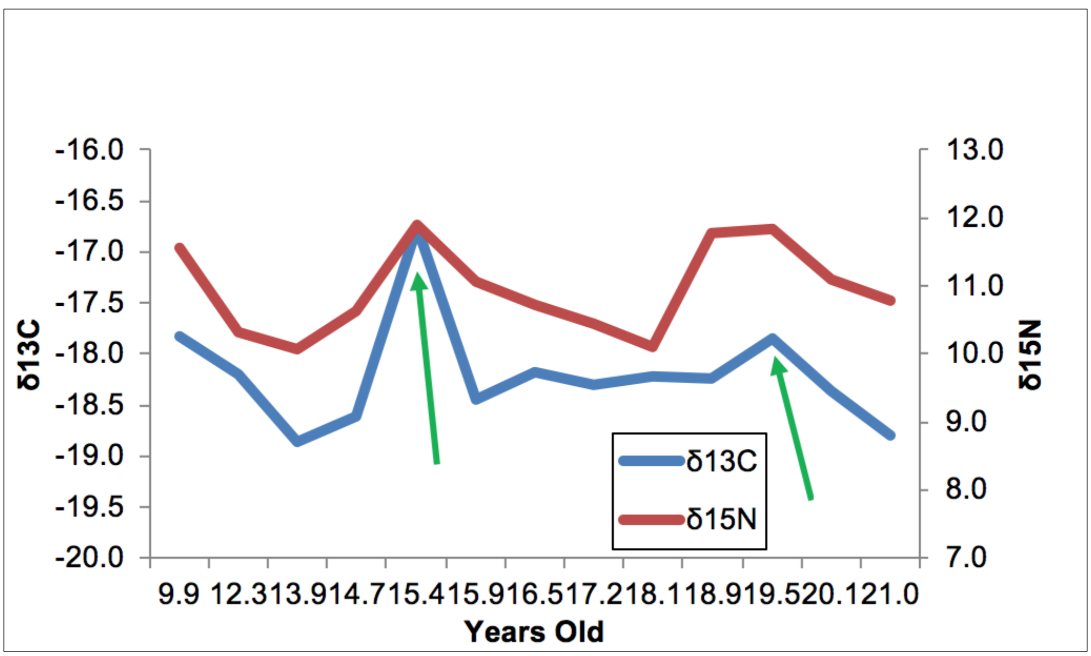

Figure 19: Burial 252. Male. Diet showing shifts at 15 and 19 years.

5.6 Females in Phase I

5.6.1 Burial 167

Burial 167, aged 30-40 years old, shows a diet that has some minor shifts through the time reconstructed. Most of the $\delta^{13}C$ values lie within the normal range. There is an enrichment seen at ages 15-16 years old for both $\delta^{13}C$ and $\delta^{15}N$. The graph is somewhat N-shaped (Figure 20).

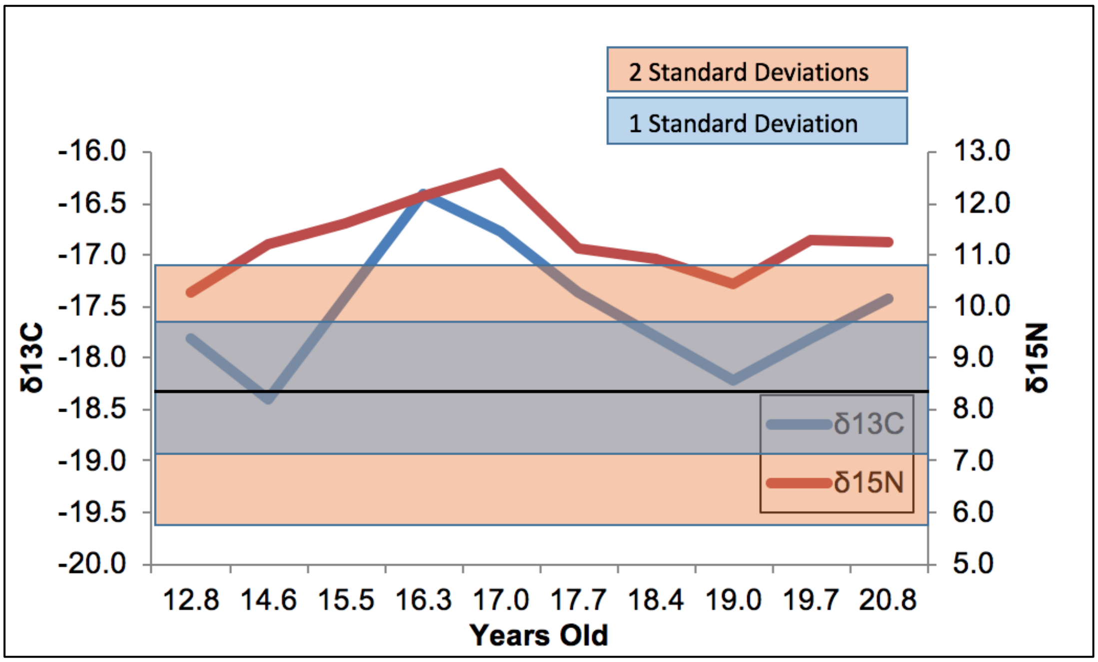

Figure 20: Burial 167. Female. Graphical data.

5.6.2 Burial 281

Burial 281, aged 35-45 years old, shows a very stable diet through time. The entire reconstruction for $\delta^{13}C$ lies within the normal range for this location; specifically, within one standard deviation of the average. There is a slight, slow depletion in $\delta^{15}N$ through age 17, where the diet then begins to enrich again (Figure 21).

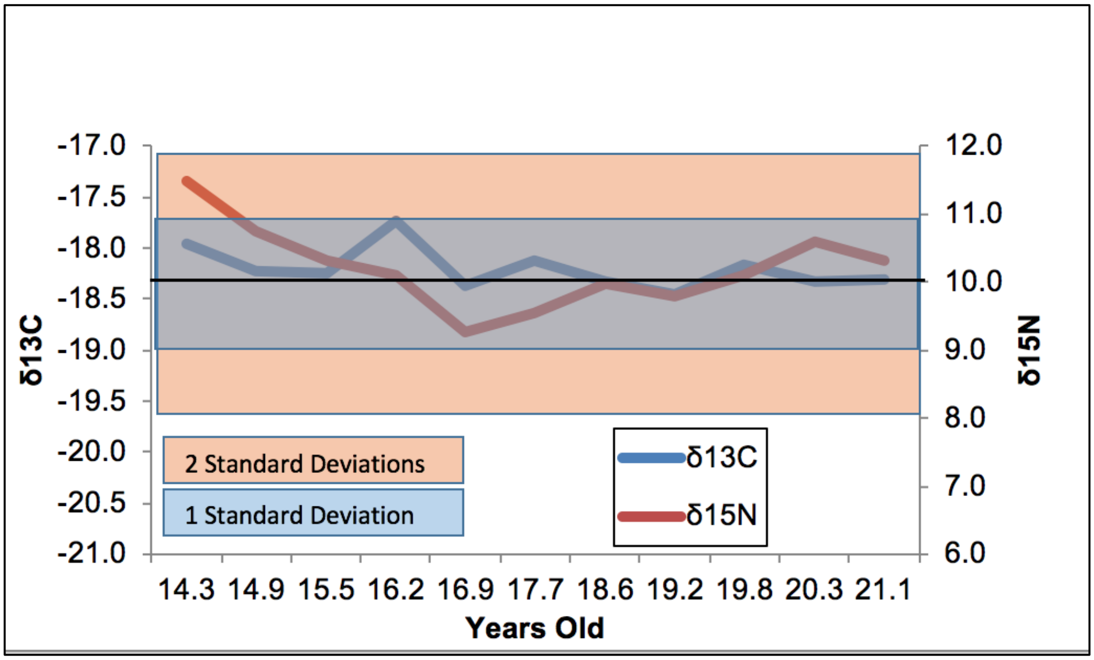

Figure 21: Burial 281. Female. Graphical data.

5.6.3 Burial 74

Burial 74, aged 25-44 years old, shows a very stable diet through time. There are slight shifts through the ages of 8.5 to 21.5 years old, but the $\delta^{13}C$ diet remains within the local range (Figure 22).

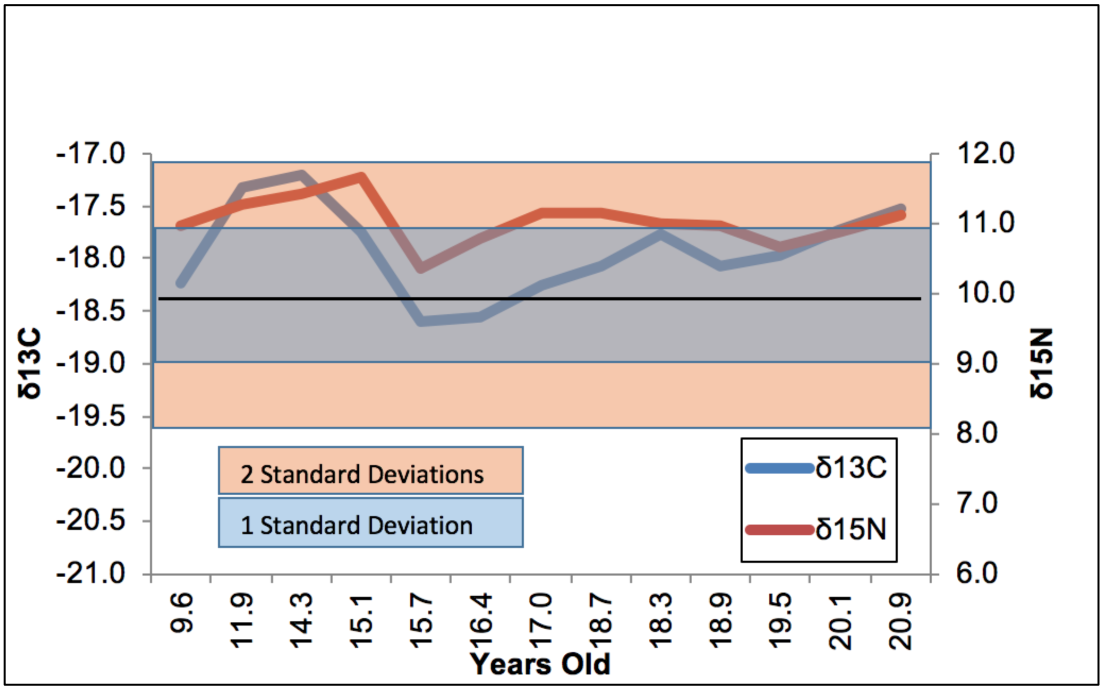

Figure 22: Burial 74. Female. Graphical data.

5.6.4 Burial 132

This burial, aged 31-44 years old, shows a stable diet throughout the time frame reconstructed. There are small shifts seen in the isotopic reconstruction. In addition, this burials' $\delta^{13}C$ isotopic data remains within the local range for the entire reconstructed period (Figure 23).

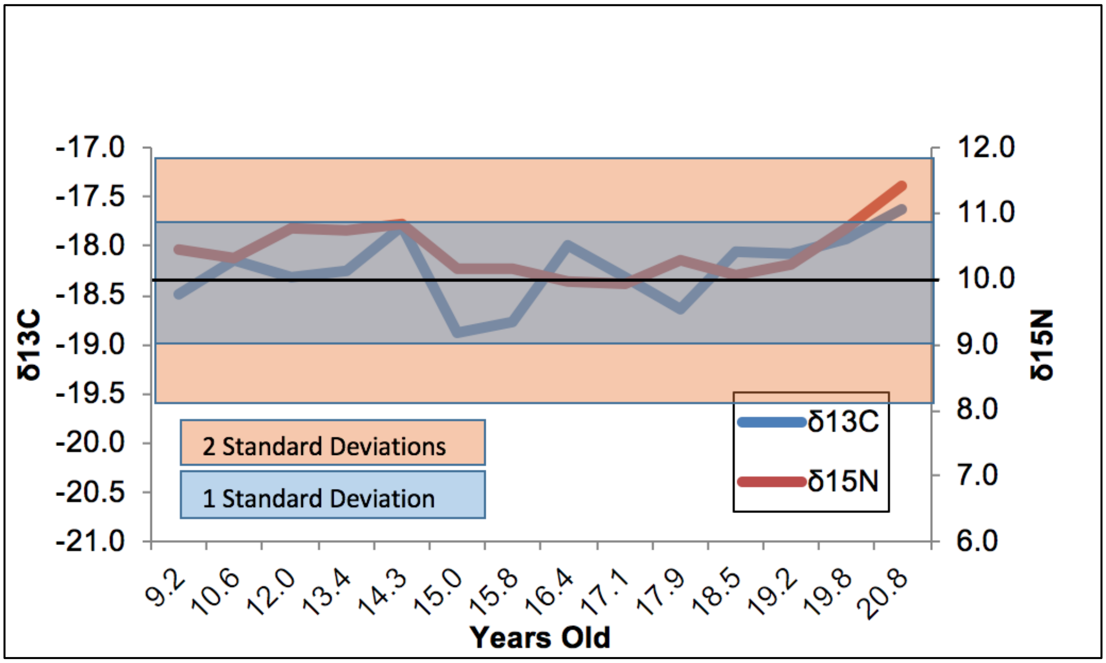

Figure 23: Burial 132. Female. Graphical data.

5.7 Males in Phase I

5.7.1 Burial 252

Burial 252, who was aged 30+ years old, has a somewhat varied diet that shifts throughout the time analyzed. There is an enrichment in $\delta^{13}C$ and $\delta^{15}N$ at age 15. The overall shape of the graph is bumpy with frequent shifts (Figure 24).

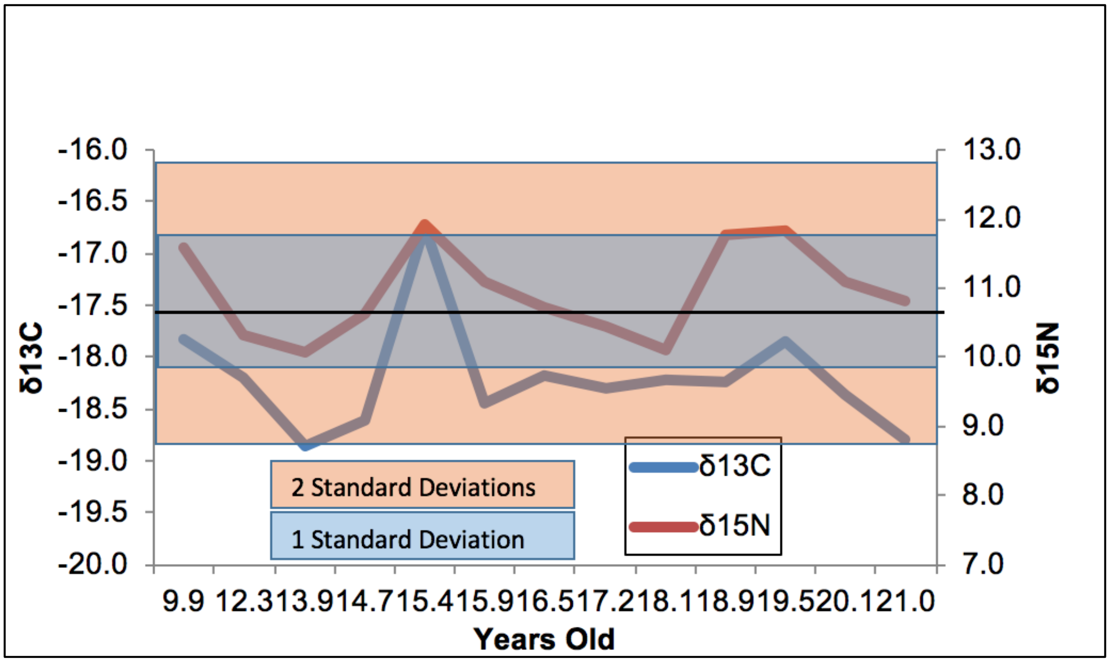

Figure 24: Burial 252. Male. Graphical data.

5.7.2 Burial 168

Burial 168, aged 30+ years old, shows a fairly enriched diet, compared to the local signature, for most of the temporal period. There is an enrichment in $\delta^{13}C$ and $\delta^{15}N$ at age 15-16 years old. The $\delta^{15}N$ remains enriched during the entire period of 8.5-21.5 years old. The shape of the graph shows frequent shifts in isotopic values, and thus diet with a spike around 15-16 years old (Figure 25).

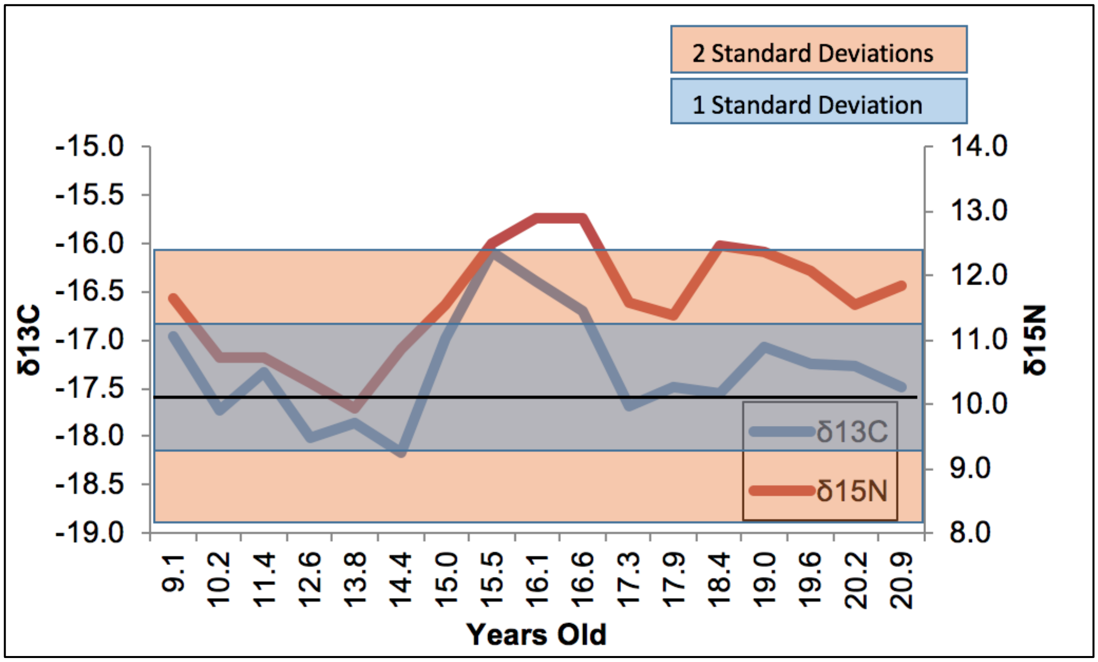

Figure 25: Burial 168. Male. Graphical data.

5.7.3 Burial 128

Burial 128, aged 30+ years old, shows a fairly depleted diet in $\delta^{13}C$ and $\delta^{15}N$, compared to the local signature, for the ages of 8.5 to 21.5 years old. Most all of the $\delta^{13}C$ data points lie below one or two standard deviations of the local signature. According to the $\delta^{13}C$ data, there is an enrichment around 11 years old, that brings the signature within the local range. However, the preservation of human collagen in this burial was poor, many serial sections had to be combined to gain enough collagen to submit samples to the Stable Isotope Facility. Because of this, there is reduced detail in the dietary reconstruction (Figure 26)

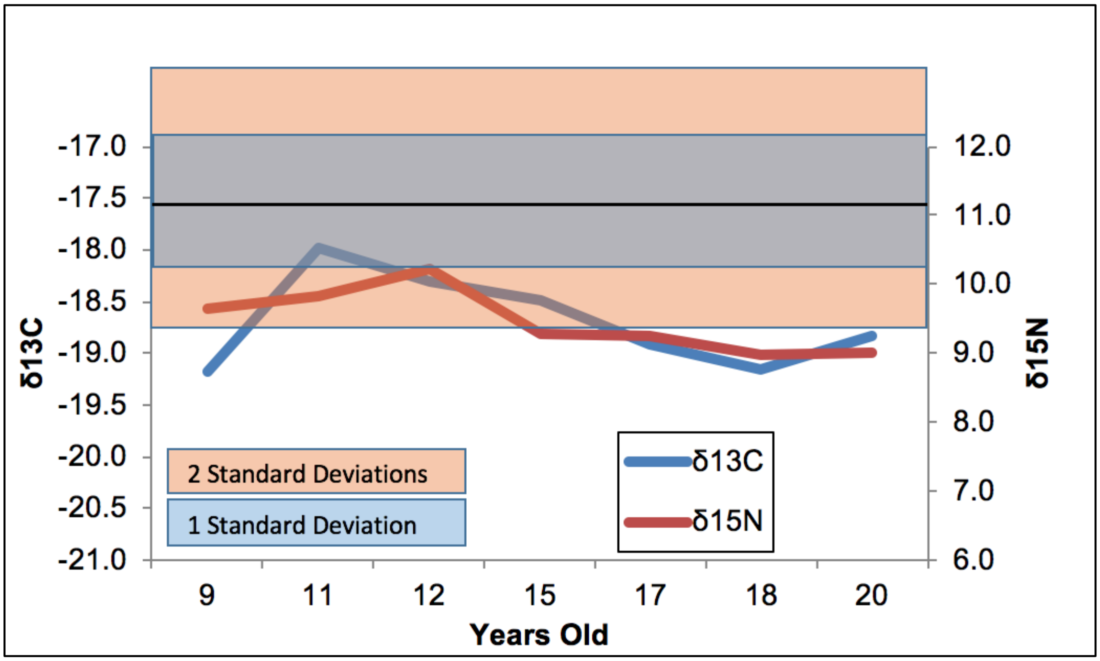

Figure 26: Burial 128. Male. Graphical data.

5.7.4 Burial 110

Burial 110, aged 30-35 years old, shows an individual with a fairly stable diet throughout the years of 8.5 to 21.5 years old. There is one period of enrichment at around 14 to 15 years old. There is a period of time where the carbon lies outside of the range of one standard deviation (Figure 27).

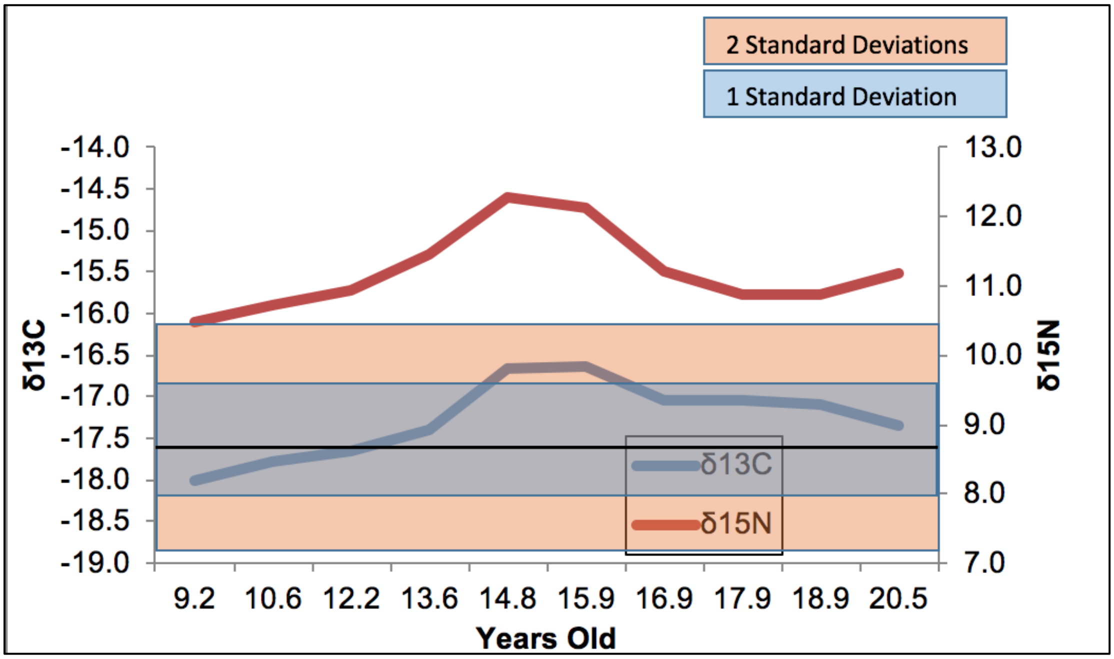

Figure 27: Burial 110. Male. Graphical data.

5.8 Phase II Burials

There were three females (Burial 2, 274, and 62) and three males (Burial 64, 61, and 102) examined for Phase II. Unlike the previous two temporal periods, these burials exhibit much more isotopic variation for both males and females. Shifts are indicated by green arrows on Figures 28 (Burial 2 – female) and 29 (Burial 61 – male).

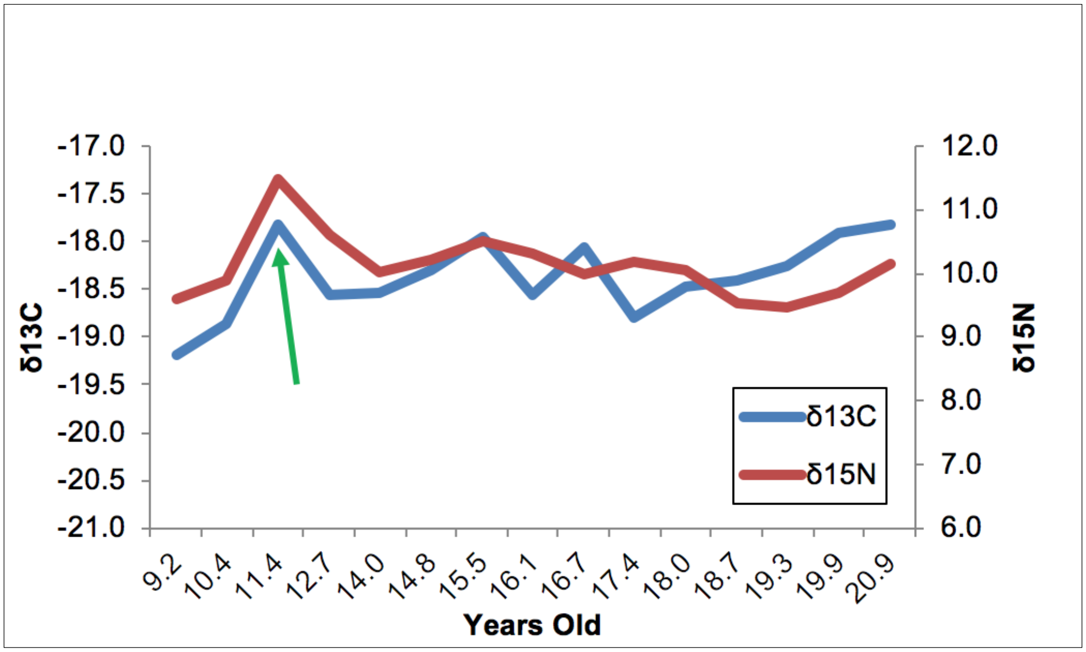

Figure 28: Burial 2. Female. Dietary stability.

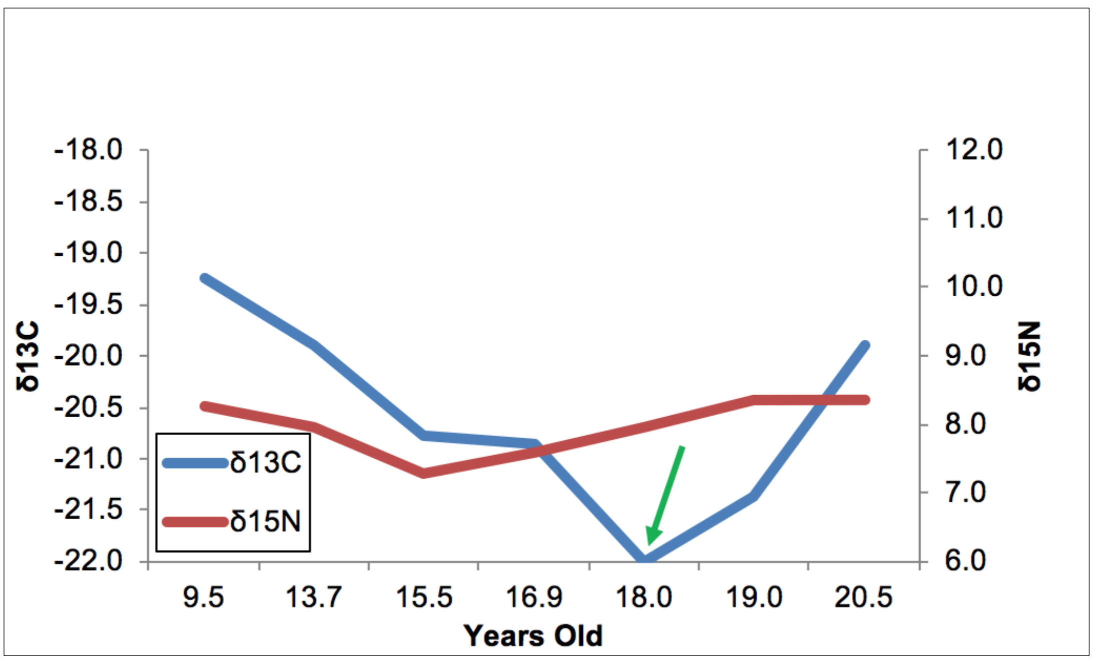

Figure 29: Burial 61. Male. Dietary stability.

5.9 Females in Phase II

5.9.1 Burial 2

The $\delta^{13}C$ values for burial 2, who was aged 35+ years old, lies within one standard deviation from the average range for the local signature for most of the reconstructed years of 8.5 to 21.5 years old. There is one period where the $\delta^{13}C$ is below at around age 9, and one period where the $\delta^{15}N$ is enriched at age 11. The spike at age 11 indicates an enrichment in the diet for both $\delta^{13}C$ and $\delta^{15}N$ (Figure 30).

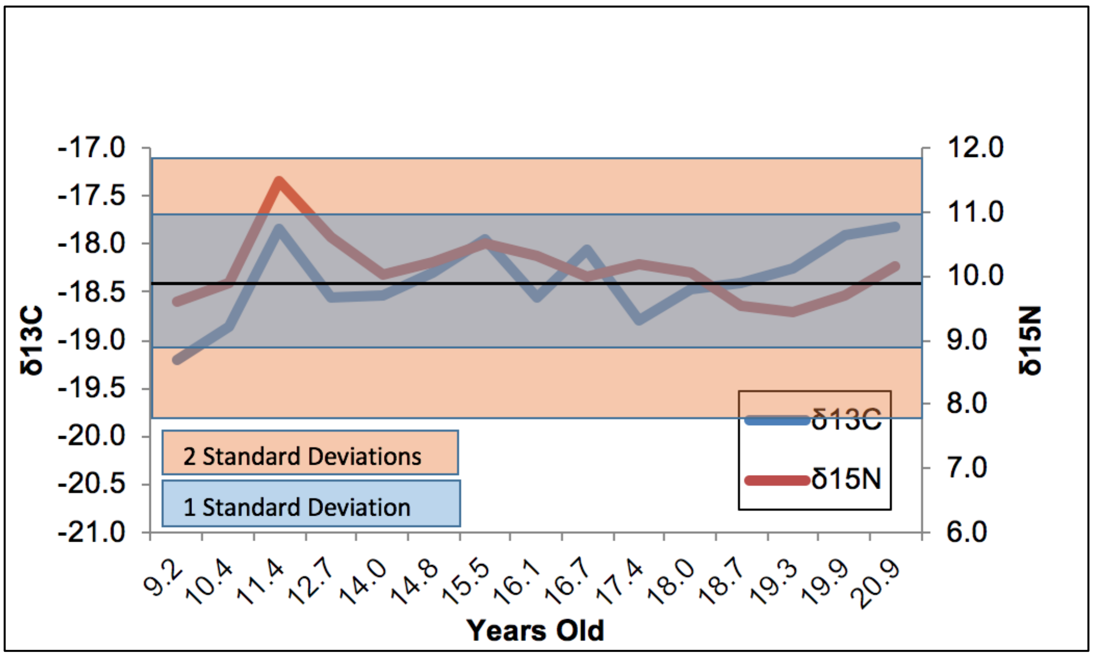

Figure 30: Burial 2. Female. Graphical data.

5.9.2 Burial 274

Burial 274, who was aged 18-20 years old, has a substantially varied diet. There is a definite enrichment at age 15 to 16 years old with frequent shifts in diet. Many of the $\delta^{13}C$ values are outside of one or two standard deviations from the local range (Figure 31).

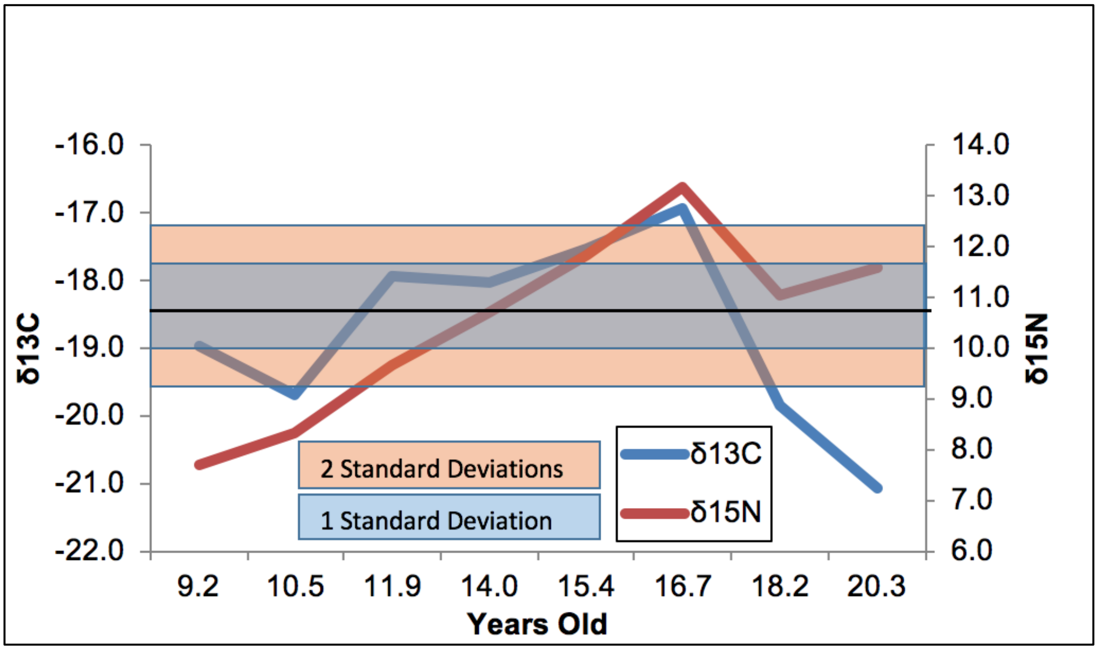

Figure 31: Burial 274. Female. Graphical data.

5.9.3 Burial 62

Burial 62, who was aged 31-40 years old, shows a very stable diet. The entire graphical data for $\delta^{13}C$ and $\delta^{15}N$ is flat with $\delta^{13}C$ values within one standard deviation from the average. The isotopic values show no major changes in diet (Figure 32)

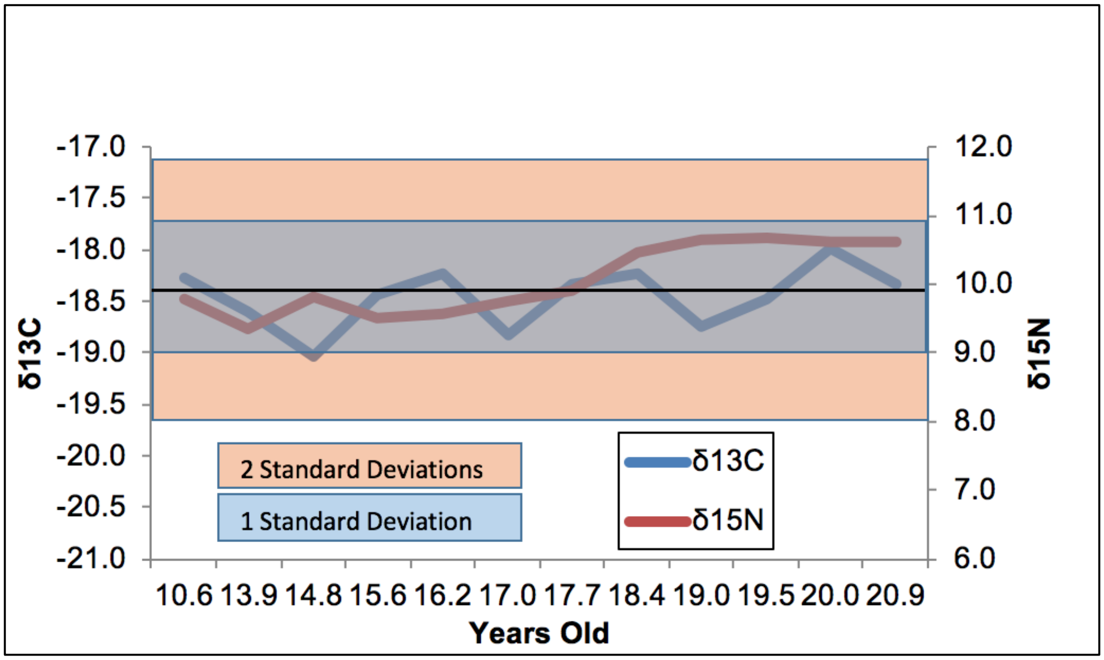

Figure 32: Burial 62. Female. Graphical data.

5.10 Males in Phase II

5.10.1 Burial 64

Burial 64 shows a fairly stable diet; despite a few spikes in $\delta^{13}C$. The $\delta^{13}C$ tends to lie within one standard deviation of the average with one major depletion at around 19 years old. The $\delta^{15}N$ data is generally stable (Figure 33).

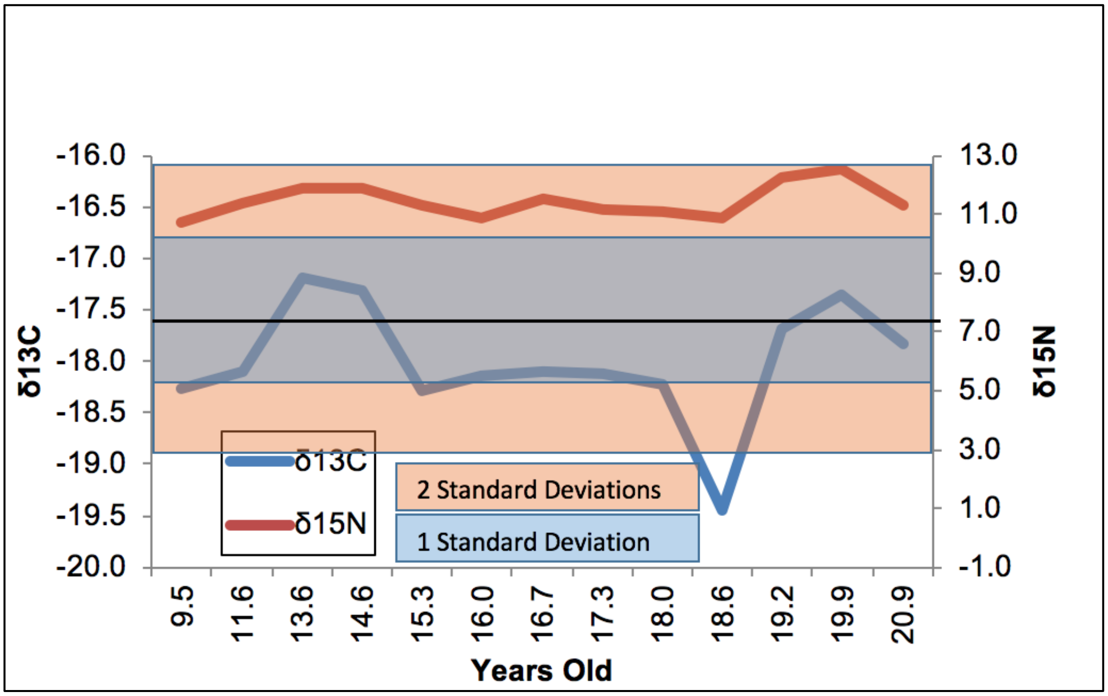

Figure 33: Burial 64. Male. Graphical data.

5.10.2 Burial 61

Burial 61, aged 35-50 years old, shows a depleted diet through the ages of 8.5 to 21.5 years old. Every $\delta^{13}C$ value is two standard deviations below the local range. There is a depletion at age 19 years old in $\delta^{13}C$ (Figure 34).

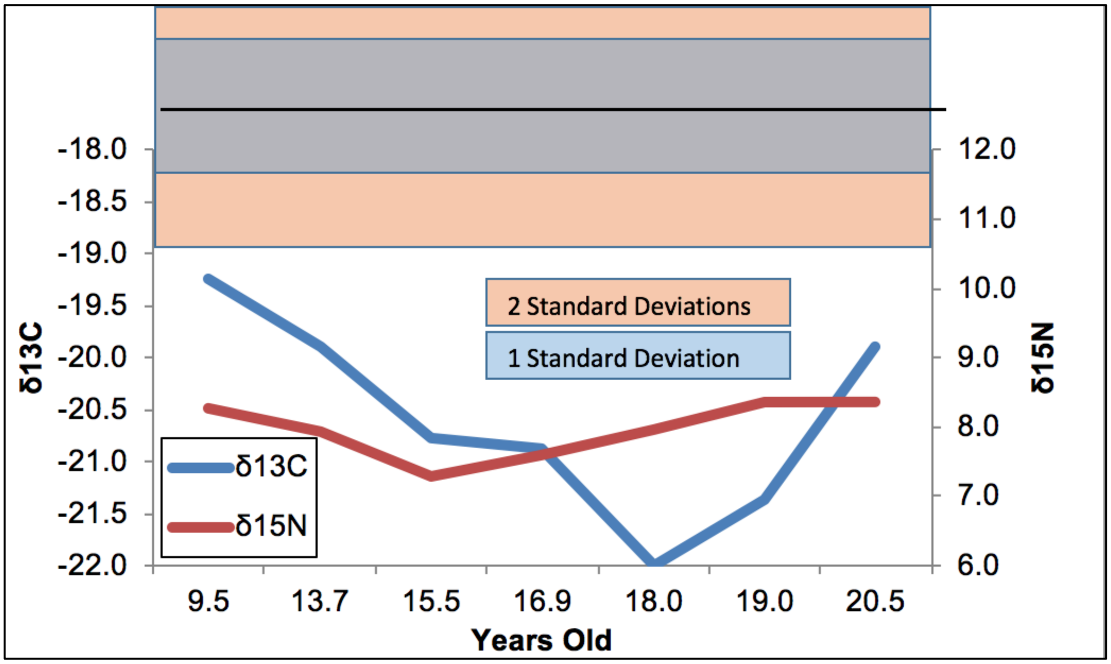

Figure 34: Burial 61. Male. Graphical data.

5.10.3 Burial 102

Burial 102, aged 21-30 years old, shows a depleted diet through the ages of 8.5 to 21.5 years old. Most $\delta^{13}C$ values are between one and two standard deviations of the local signature with only a few lying in the local range. There is a depletion seen around age 17 in $\delta^{13}C$ (Figure 35).

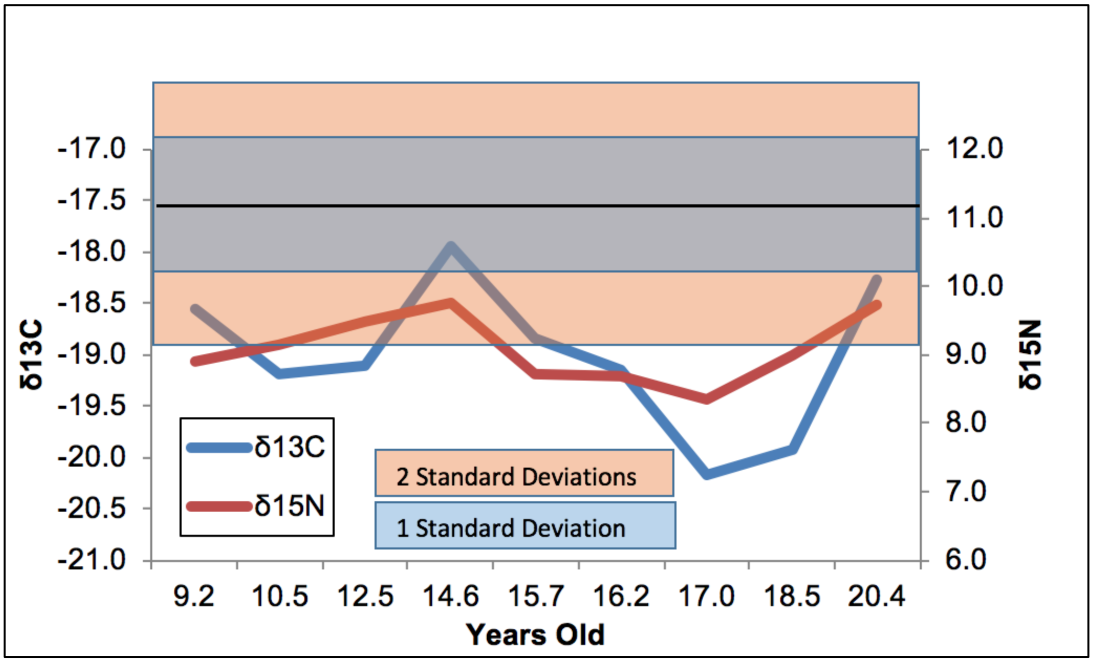

Figure 35: Burial 102. Male. Graphical data.

5.11 Summary

Overall, during the Middle Period and Phase I female diet remained more stable, as compared to male diet. The signature for female $\delta^{13}C$ diet additionally fell closer to the local range, as measured from bone collagen, during these periods. Male diet, however, showed more dietary shifts, especially around sexual maturity. Lastly, during Phase II, both male and female diet were more variable with many shifts seen throughout the years of 8.5-21.5 years old for the examined individuals.

CHAPTER 6: DISCUSSION

6.1 Introduction

The data from this study provide new evidence for diachronic changes in mobility and subsistence patterns as individuals transitioned from childhood to young adulthood. Sex-biased patterns suggest different experiences for males than females in this phase of life. Following the methods of Eerkens et al. 2014 to infer matrilocality for burials in other sites of the Bay Area, this study is consistent with matrilocality for the Ryan Mound community during the Middle Period and Phase I through stability of carbon and nitrogen isotopes for females, but not males. Changes in female isotopic signatures from these earlier periods to Phase II suggest an increase in female mobility in this later period. This section will explore potential explanations for these patterns and the cultural implications for these inferences. These preliminary patterns prompt further study of the Ryan Mound and other California sites of the Middle Period to Late Period Phase II to gain a more complete picture and understanding of precontact lifeways.

The changing diet for males may be inferred as shifts in diet choice coinciding with significant movement across the landscape around the age of sexual maturity. Such shifts could be the result of exogamous matrilocal marriage patterns. Perhaps males joined communities living around the Ryan Mound at the time of their sexual maturity.

6.2 Temporal Analysis of Females versus Males

In the Middle Period and Phase I, females tended to have more consistent and stable diets within the estimated local range for $\delta^{13}C$. This indicates that females likely lived in the same place through the second decade of life. In contrast, male diets were much more variable during the Middle Period and Phase I. In numerous cases, males are seen with isotopic enrichment in the teenage years with five out of the seven male burials from this time period showing significant enrichment in $\delta^{13}C$ above the local range, especially between the ages of 11 to 18 years old.

This pattern is captured in the range of isotopic values for males and females within a tooth. The average range for $\delta^{13}C$ for females in the Middle Period is 1.5‰, compared to 1.9‰ for males. Larger ranges are also seen for $\delta^{15}N$ with averages at 1.4‰ for females, and 2.4‰ for males. This trend continues into Phase I, where the average range of $\delta^{13}C$ for females is 1.3‰, compared to males at 1.7‰. $\delta^{15}N$ shows similar data for Phase I with female ranges averaging at 1.3‰ and males at 2.0‰. These values are consistent with greater residential mobility for males.

This pattern changes during Phase II with female range averages for $\delta^{13}C$ at 2.2‰, and males average 2.4‰. $\delta^{15}N$ female range averages 3.0‰, and the male range averages 1.40‰. This is consistent with the interpretation that both sexes were residentially mobile, but especially females during Phase II. These changes in mobility patterns could be due to spread of foreign diseases, colonization by Spanish Missionaries, or increase in population densities.

6.3 Summary

Overall, the dietary patterns for the twenty individuals examined indicates that matrilocality was the preferred post-marriage residential pattern for the Middle Period and Phase I. This pattern is seen through the stable diet of females during this period, and the shifts in male diet around the ages of sexual maturity. The residential pattern changes, however, during Phase II, when both male and female diets show increased mobility during the ages of 8.5-21.5, indicating a cultural shift, perhaps due to some type of external pressure on the communities in the Ryan Mound during that time period.

CHAPTER 7: CONCLUSIONS

7.1 Introduction

Overall, this study aimed to understand the complex relationships of precontact individuals from one earthen-mound burial site, Ryan Mound (CA-ALA-329), by examining human stable isotopes to elucidate mobility through time. Marriage and residence patterns are important aspects of a population's culture and are not often understood or recorded in precontact Native American populations. These relationships can give insight into social relationships through mobility patterns, as well as a vast web of connectedness from which individuals of this time participated. There is very little information in existing ethnographic reports on the residence patterns and mobility of the Ohlone, who spanned from the San Francisco Bay Area to the Monterey Bay Area. This study utilizes stable isotope analysis of a sample of burials from the Ryan Mound. Human third molar serial sections were examined using carbon and nitrogen isotopic analysis to examine the landscape mobility of individuals over half-year to 1-year intervals and overall diet.

The examination of $\delta^{13}C$ and $\delta^{15}N$ from 20 individuals, 10 males and 10 females, from the Middle Period, Phase I, and Phase II, suggests that during the Middle Period and Phase I, females were less mobile than males. This could indicate that the population of CA-ALA-329 was practicing matrilocality. The absence of shifts in diet and thus mobility of females during the years of sexual maturity indicates that they remained living with their families during at least the early stages of marriage. In contrast, males show shifts in their diet, and thus mobility, during the years of sexual maturity, as seen in shifts of $\delta^{13}C$ and $\delta^{15}N$ stable isotopes.

Phase II showed something different, however, indicating that some other external factors may have pressured populations to move around more than they had in previous periods. This timeframe aligns with the spread of European diseases, Spanish colonization, and increased food insecurity, which could have caused populations, both male and female, to become more mobile.

Further studies could include a larger sample size for the three periods at Ryan Mound, as well as a broader scope of analysis with examination of sites from similar periods located nearby or surrounding the San Francisco Bay Area. Despite the limited sample size, this study provides invaluable insight on the practices of precontact populations at Ryan Mound, and a greater understanding of the culture history of California.

7.2 Implications of Matrilocality

The results of this thesis demonstrated stable diet for females, with enhanced male mobility during the Middle Period and Phase I, and erratic diet and mobility for both males and females during Phase II. The examination consisted of stable isotope analysis of both $\delta^{13}C$ and $\delta^{15}N$ to gain information on marine input in the diet, as well as trophic level, which give insight on location of the foods consumed. Serial sectioning of third molars allowed viewing windows of six-month to one-year intervals of time from the ages of 8.5 years old to 21.5 years old. The data revealed that the female diet through the periods of the Middle Period and Phase I showed less variability than male diet with signatures lying closer to a local signature for CA-ALA-329. Many of the female burials showed no major shift in diet throughout the examined time frame, whereas many males during the Middle Period and Phase I showed an isotopic enrichment during the ages of sexual maturity. During Phase II, data are consistent with greater mobility for both males and females. Females showed either no change in diet, or enrichments in both $\delta^{13}C$ and $\delta^{15}N$ between 11 years old and 16 years old in Phase II, where males showed no changes or depletion around 17 and 19 years old.

The data presented in this study imply that females were less mobile during the Middle Period and Phase I of the Late Period, while males had greater shifts in diet, and thus mobility, around sexual maturity. This indicates that the inhabitants of CA-ALA-329 were most likely practicing matrilocality during these two periods. Additionally, theoretical models predict that hunter-gatherer societies that forage are more likely to be matrilocal (Eerkens et al. 2014; Ember 2014; Hill 1970).

Acorn meal was a resource that was processed during certain months and relied upon year-round as a significantly large portion of their diet (Levy 1978). Many precontact Native California groups relied largely on acorns and oak groves for much of their sustenance, as did the CA-ALA-329 population. A society dependent on large amounts of gathered foods would benefit from a matrilocal post-marital residence pattern. The investment in teaching young girls how to process acorns properly to avoid toxins and provide food for their families would have taken a considerable about of time and energy, and thus mothers would want to have their daughters remain close by (Fox 1967; J. N. Hill 1970).

Moreover, not only does female diet remain stable during the years of 8.5 to 21.5 years old as seen in the stable isotopic investigations, male diet shifts to closer to the local stable isotopic signature of CA-ALA-329. This indicates that females remained local to CA-ALA-329, while males had a different stable isotopic signature during childhood, and made a landscape shift, as seen in dietary reconstructions, to CA-ALA-329.

Other studies in Central California have inferred that as population sizes rose and density increased in this region, lower ranked foods were more relied upon (Bartelink 2009). These foods would have included acorns, would have been an important resource, and would have been greatly depended upon. Additionally, matrilocality at CA-ALA-329 informs on the social structures of all nearby people during those times. These social structures and relationships provide more information on how groups would have interacted and the types of cultural transmission that would have taken place with males' increased landscape mobility (Hill 1970). These social structures and ties would prove important during Phase II of the Late Period when mobility increased for all individuals. Many years of matrilocality would have created ties with many nearby groups that could be relied upon during times of food insecurity, disease, and invasions to allow for cultural stability and continuation.

Understanding the pressures that the individuals faced during Phase II allows a framework for addressing the shifts in diet. Disease was spreading through the region from Spanish Missionaries, who were also colonizing California. As studies have shown, there was also an intensification in resources, as lower ranking foods were being utilized during later years, which could signal food insecurity (Bartelink 2009). These pressures could have promoted movement to continue cultural traditions and access to foods.

7.3 Limitations and Future Research

Future studies should examine a larger sample size for each temporal period to gain further insight on the mobility patterns of the precontact Ohlone at CA-ALA-329. Because the burial count is so large for CA-ALA-329, examination of just one temporal period might have yielded more complete data than examining all three temporal periods. To expand on this study, the same methodology could be applied to numerous Ohlone sites, or other various sites throughout the Bay Area region, to gain a more complete picture of precontact landscape mobility and begin to inform on connections between groups through movement. This would be especially interesting to examine individuals from North Bay, East Bay, and South Bay locations to attempt to see a similar pattern as is seen with trade routes and Napa obsidian. Ideally, this study could be completed for a multitude of Bay Area sites to better understand the mobility of numerous groups from various time periods. Similarly, examination of other teeth could have indicated more data as to childhood diet, which could have helped establish birth location. Additionally, examination of strontium, oxygen, and sulfur isotopes could have given additional measures of mobility.

7.4 Research Outcomes

This information will be disseminated to various audiences. It will be given to the Muwekma Ohlone to hopefully allow them to gain further insight on their past. This information will also be useful to the academic community to allow for greater understanding of precontact people and their interactions. As discussed previously, there is little information known about marriage and residence patterns. This information can start to inform on greater relationships between various precontact groups, how they related with each other, and moved among the landscape. This study greatly enhances our understanding of precontact lifeways, allowing researchers and tribal groups to understand more about the social organization and residential patterns of the individuals interred at Ryan Mound.

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APPENDIX A: Letter from Muwekma Ohlone

MUWEKMA OHLONE INDIAN TRIBE

OF THE SAN FRANCISCO BAY AREA REGION

(A Previous Federally Recognized Tribe)

'Innu Huššištak Makiš Mak-Muwekma *"The Road To The Future For Our People"*

October 21, 2015

Dr. Roberto Gonzalez, Chair
Department of Anthropology
San Jose State University

Dear Dr. Gonzalez and Anthropology Faculty

It is my pleasure to write this letter of support for Dr. Cara Monroe's graduate student Ms. Nicole Fournier from Washington State University at Pullman, who is requesting access to one of our ancestral burial populations from CA-ALA-329 for purposes of conducting ancient DNA studies for her doctoral study.

As the elected chairwoman and Most Likely Descendant (MLD) for the Muwekma Ohlone Tribe of the San Francisco Bay Area our tribal leadership and the over 550 BIA documented enrolled members not only have a vested interest in scientific and anthropological investigations relative to our ancestral heritage sites within our aboriginal territory, but we have also actively participated in and supported such scientific research on a multitude of projects in cooperation with San Jose State, Stanford and Santa Clara Universities..

The particular ancestral heritage site under investigation, CA-ALA-329 (the Ryan Mound), located in the Coyote Hills was excavated by San Jose State University from 1962 to 1968. This site falls within the heartland of our aboriginal and historic territory. As with previous studies conducted by Dr. Brian Kemp, Dr. Cara Monroe, Dr. Lorna Pierce, Dr. Robert Jurmain, Dr. Eric Bartelink, Karen Gardner, Alan Leventhal, and San Jose State University Anthropology students, such additional investigation pertaining to the many of our ancestral heritage cemetery sites is fully encouraged by our Tribal Council, especially when our tribal members are either directly involved the research projects or when we ultimately, but rarely, receive a copy of the results and/or final report.

Recently Dr. Monroe completed her doctoral dissertation on one of our ancestral heritage cemetery sites (CA-SCL-38) which was excavated by our tribe. Based upon her scientific research she was able to map the ancient DNA spanning the past 4000 years from several other ancestral heritage sites from the Bay Area. Her study was based upon the skeletal remains that we made available to her for her study from sites excavated by our tribe.

P.O. Box 360791, Milpitas, California 95036

By proposing to conduct ancient DNA on our ancestral remains from CA-ALA-329, which is a unique cemetery mound, the results will, no doubt, be a major contribution to both our Tribe and the scientific community.

Furthermore, by conducting this study which can also include additional (AMS) radio-carbon dating and the ancient DNA analysis, we anticipate the results will enhance our understanding and knowledge of our ancestral life ways and intermarriage over the past several millennia. It is our desire to continue to engage in meaningful scientific collaborations with Dr. Monroe and her colleagues as well as the faculty and students at San Jose State University on this project and others in the future. The present proposal is a case in point.

On another note, Mr. Leventhal has informed me that Anthropology graduate student Ms. Kelli Sullivan, would also like to sample the CA-SCL-329 ancestral remains for her Master's research project in conjunction with Ms. Nicole Fournier. The Tribe formally supports her research proposal after it has been formulated and accepted by the Anthropology Department.

Should you have any questions, please feel free to contact me rcambra@muwekma.org, Tribal Administrator Ms. Norma Sanchez nsanchez@muwekma.org (408-616-0442), or Monica V. Arellano, Vice-Chairwoman, marellano@muwekma.org.

Sincerely,

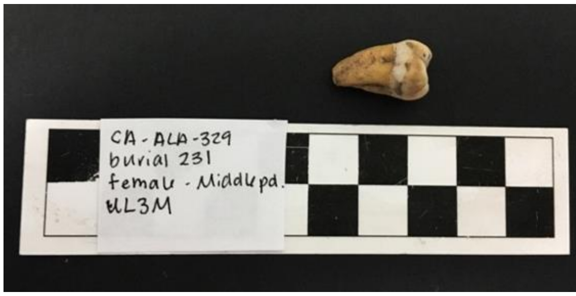
Rosemary Cambra, Chairwoman

Cc: Muwekma Tribal Council
Heritage Resources file: CA-ALA-329
Dr. Cara Monroe

P.O. Box 360791, Milpitas, California 95036

APPENDIX B: Burial Photographs

Burial 231



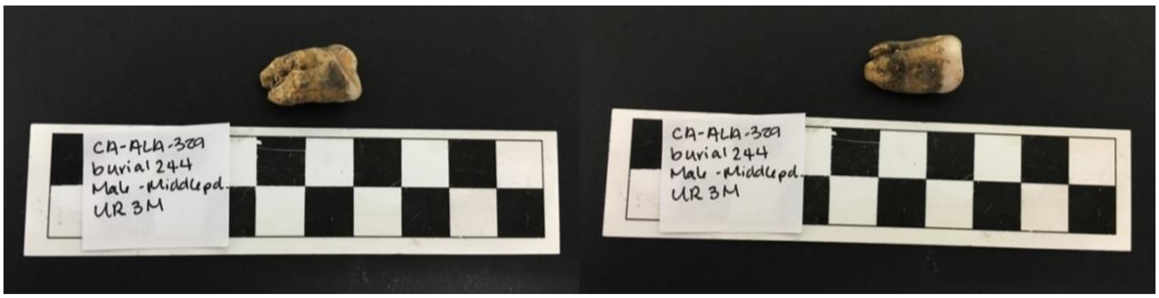
Burial 263

Burial 251

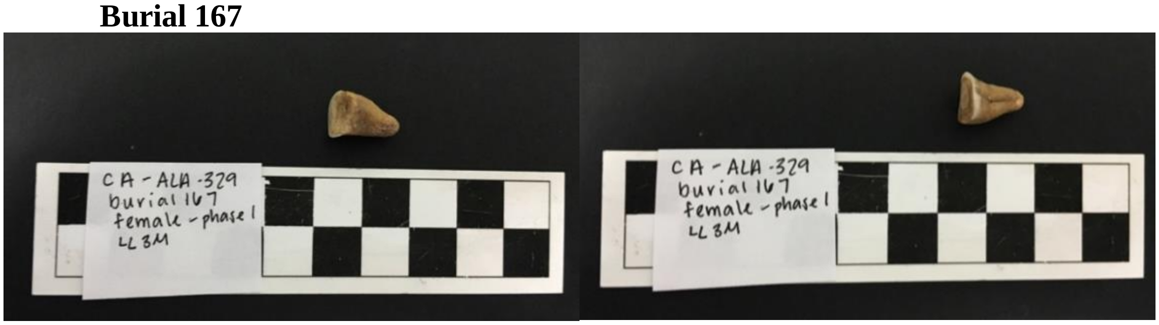
Burial 249

Burial 273

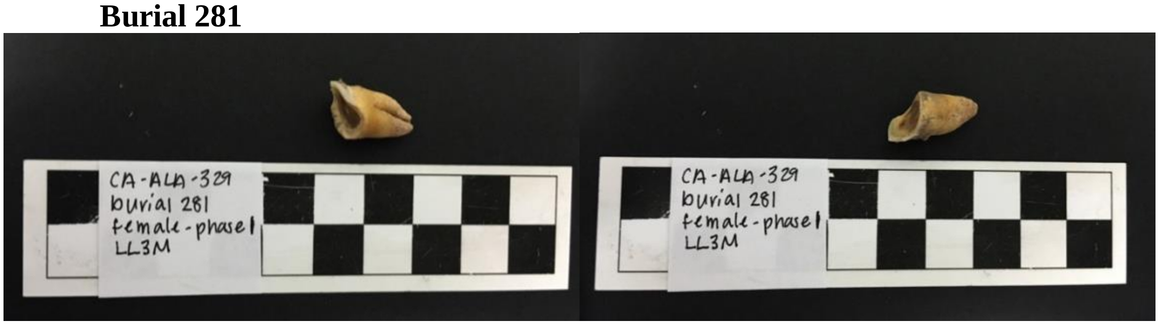
Burial 244



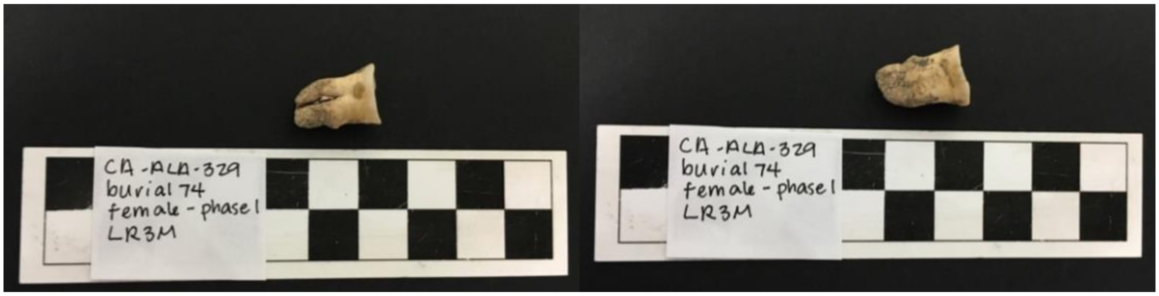
Burial 167



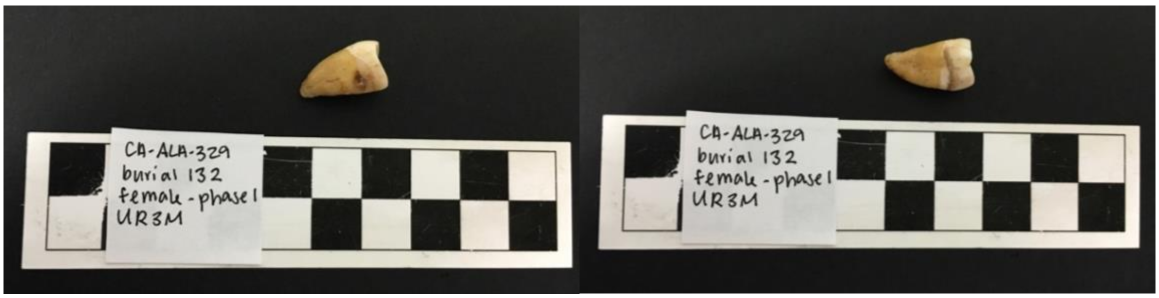
Burial 281



Burial 74

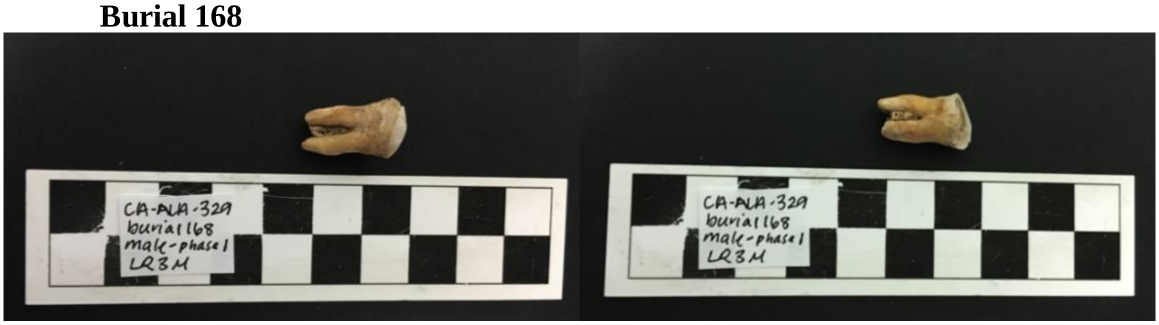


Burial 132

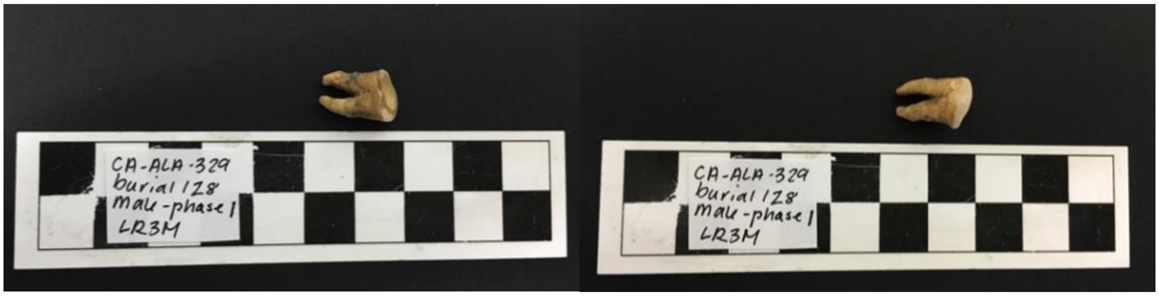


Burial 252

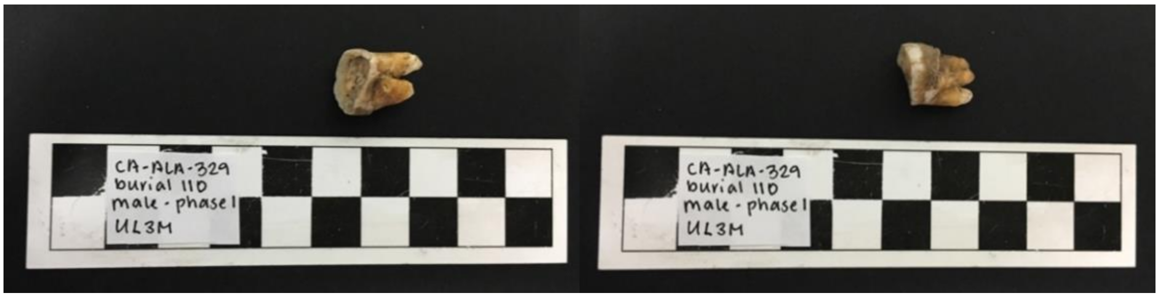
Burial 168



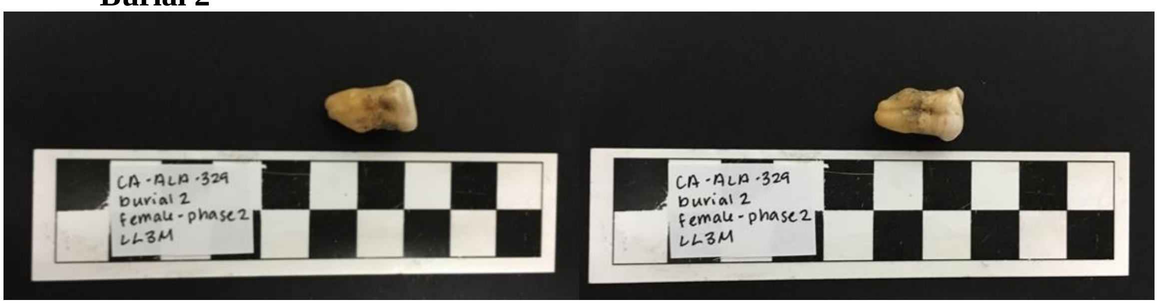
Burial 128



Burial 110



Burial 2



Burial 274

Burial 62

Burial 64

Burial 61

Burial 102

APPENDIX C: Tooth Notes

Burial	Notes
251	Intact root tip and occlusal surface. Almost no wear on enamel. Tooth was cut so there is part of one root with a whole root. Crown fractured into four pieces - stopped drilling. Some enamel is remaining because of fracturing.
128	Occlusal Surface completely worn down through enamel on left side especially at cross section. Occlusal surface worn through the enamel. Some of the enamel remains on the sides of the tooth on the left side at the cross section. Root tip intact
2	Intact root tip and occlusal surface. Almost no wear on enamel.
231	Occlusal Surface not able to be clearly measured. Completely intact root tip and occlusal surface on enamel. Possible carious lesion in center of occlusal surface on crown. Crown crumbled around carious lesion. Removed as much enamel as possible, but entire crown broke off into four pieces. Still have some enamel remaining. Two large pieces should be able to fit back in, smaller pieces can be crown bulk.
167	Tooth broken long ways from root tip to crown. Root is fully intact, besides break. Very little enamel remaining on left side. Occlusal surface through the enamel into dentin. No enamel saved- not enough present to collect.
110	Enamel worn down into dentin. Root tip partially intact - looks as if part of the bottom broke off - 2 roots fused together. Crown intact occlusal surface ground down into dentin - enamel remains on sides of crown, not top.
274	Occlusal surface intact in enamel. Only one spot where its worn through. Root intact. Also, has partial root from other half due to ability to cut. Very thin portions remaining from another root tip - going to drill off. Root tip intact.
168	Occlusal surface worn through the enamel. Enamel remains on the outer sides of tooth. Possible intact DEJ on right side but hard to tell. Root tip intact.
244	Root tip intact. Crown intact. Small amount of wear on left crown side, through the enamel.
64	Root tip intact with additional smaller root tip. Occlusal surface part way through enamel into dentin in center of crown. Slight crack in root tip.
61	Occlusal surface worn down past enamel - enamel remains on right side at cross section only. Root tip intact
249	Root tip intact - maybe slightly broken down on left side moving from bottom up. Crown intact - part of enamel worn down to dentin on occlusal surface, especially on left side.
102	Root tip intact. Enamel worn down on top/right. Dentin exposed. Left side of crown broke off.
252	Occlusal surface worn through enamel in portions of crown. Intact root tip.

281	Almost no enamel remaining. Occlusal surface in dentin- no DEJ present at all. Root tip intact. Very fragile - tooth broke during drilling. Right upper outside quadrant broke off.
273	Occlusal surface worn through enamel into dentin. Only enamel remaining on outer sides. Root intact with additional half root present.
132	Root tip and crown intact. Narrow small section of tooth.
74	Intact root tip. Occlusal surface worn into dentin and through enamel in the center. Enamel remains on outside.
62	Root tip intact occlusal surface worn through enamel into dentin. Enamel remaining on outer surface.
263	Root tip intact - enamel worn down on top of tooth (occlusal surface), only remaining enamel on right side at the cross section, moving around the back.

APPENDIX D: Carbon and Nitrogen Isotopic Values from the SIF

Sample ID	d13C‰	C Amount (ug)	d15N‰	N Amount (ug)	Amount (mg)
64a	-17.84	307.262	11.27	101.46	0.928
64b	-17.36	346.23	12.50	117.05	1.068
64c	-17.69	338.72	12.25	113.36	1.031
64d	-19.44	210.86	10.86	75.60	0.759
64e	-18.22	403.27	11.09	137.16	1.062
64f	-18.12	413.86	11.17	140.86	1.112
64g	-18.10	359.43	11.54	120.33	0.821
64h	-18.14	425.47	10.85	144.96	1.136
64i	-18.28	474.35	11.27	163.43	1.128
64j	-17.32	372.70	11.87	127.72	0.916
64k	-17.19	411.93	11.89	140.86	1.048
64l	-18.11	489.18	11.40	167.95	1.245
64m	-18.26	442.97	10.68	150.30	1.036
64z	-17.58	322.83	10.65	106.79	0.917
74a	-17.52	334.04	11.12	110.90	0.903
74b	-17.73	466.47	10.87	160.56	1.245
74c	-17.97	419.66	10.66	142.91	0.991
74d	-18.08	449.80	10.96	150.30	1.108
74e	-17.78	376.50	10.99	125.26	0.886
74f	-18.07	451.76	11.14	152.76	1.074
74g	-18.25	459.59	11.15	154.40	1.101
74h	-18.55	475.34	10.78	163.43	1.133
74i	-18.59	458.61	10.37	153.99	1.133
74j	-17.75	445.89	11.66	151.53	1.079
74k	-17.20	371.75	11.43	125.26	0.921
74l	-17.33	384.12	11.27	127.31	0.926
168a	-17.50	430.32	11.85	142.50	1.056
168b	-17.26	324.70	11.56	106.79	0.853
168c	-17.25	334.97	12.07	111.31	0.861
168d	-17.07	397.51	12.38	131.83	1.003
168f	-17.48	352.82	11.39	118.28	0.866
168g	-17.68	456.65	11.59	152.76	1.084
168i	-16.40	462.54	12.90	156.04	1.209
168j	-16.08	348.11	12.49	115.00	0.828
168k	-16.98	364.16	11.55	121.16	0.891
168l	-18.17	522.09	10.87	181.49	1.245
168m a	-17.86	384.12	9.93	126.90	0.913
168n	-18.01	484.23	10.33	163.84	1.204
168o	-17.34	372.70	10.74	125.26	0.976
168p	-17.72	471.39	10.72	158.51	1.177
168q	-16.97	350.94	11.64	118.28	0.819

168z	-17.41	487.20	11.59	162.20	1.208
110a	-17.35	422.56	11.17	142.50	1.117
110b	-17.09	360.37	10.89	121.16	1.048
110c	-17.03	365.11	10.88	122.39	0.985
110d	-17.03	404.23	11.21	136.75	1.07
110e	-16.64	357.54	12.14	119.10	0.884
110f	-16.66	470.41	12.28	160.15	1.185
110g	-17.41	494.15	11.45	168.36	1.2
110h	-17.66	342.47	10.92	114.59	0.785
110i	-17.77	440.04	10.71	148.24	1.023
110j	-18.00	491.17	10.47	170.41	1.153
168e	-17.55	476.32	12.47	158.51	1.144
168h	-16.69	431.29	12.91	146.60	1.021
168m b	-17.94	442.97	10.97	145.78	1.007
281a	-18.30	460.58	10.31	153.58	1.187
281b	-18.32	467.45	10.59	158.10	1.15
281c	-18.16	361.32	10.10	119.92	0.917
281d	-18.45	415.79	9.79	142.09	0.998
281e	-18.32	433.23	9.98	144.96	1.041
281f	-18.11	340.60	9.56	111.72	0.811
281g	-18.36	435.17	9.27	144.96	1.026
281h	-17.73	402.31	10.11	136.34	0.924
281i	-18.25	477.31	10.30	161.38	1.13
281j	-18.23	453.71	10.76	152.35	1.053
281k	-17.95	500.11	11.47	169.59	1.181
281l	-18.10	440.04	10.25	145.37	1.032
61abc	-19.89	294.12	8.35	97.76	1.112
61de	-21.37	192.27	8.37	66.99	0.888
61fg	-22.00	166.84	7.95	58.37	0.744
61hi	-20.87	251.22	7.60	82.99	0.889
61jkl	-20.78	241.29	7.27	83.81	0.855
61mno	-19.90	478.30	7.95	163.02	1.297
61p	-19.24	334.97	8.26	112.95	0.876
102abc	-18.26	348.11	9.74	115.00	1.283
102def	-19.91	226.02	8.99	77.25	0.805
102gh	-20.16	235.89	8.35	79.71	0.785
102i	-19.14	320.04	8.68	108.02	0.875
102j	-18.83	370.80	8.73	124.03	1.052
102klm	-17.94	376.50	9.77	127.31	1.004
102no	-19.10	267.56	9.48	91.20	0.892
102p	-19.20	537.17	9.14	184.37	1.38
102q	-18.55	367.00	8.90	125.26	0.973
74m	-18.22	504.09	10.98	171.64	1.15
64n	-18.55	476.32	10.58	162.20	1.107
62a	-18.34	485.22	10.62	163.43	1.349

62b	-17.99	337.78	10.63	113.77	0.853
62c	-18.47	351.88	10.67	117.46	0.943
62d	-18.75	272.12	10.65	94.07	0.733
62e	-18.24	481.26	10.45	166.71	1.22
62f	-18.34	496.13	9.90	167.54	1.204
62g	-18.83	570.63	9.74	197.50	1.366
62h	-18.23	403.27	9.57	137.57	0.936
62i	-18.44	508.08	9.52	172.46	1.242
62j	-19.04	641.80	9.82	227.47	1.53
62k	-18.61	490.17	9.34	169.59	1.121
62l	-18.26	444.54	9.79	145.27	1.017
62z	-17.32	370.78	10.04	120.57	1.032
231a	-17.91	366.01	9.85	118.93	0.938
231b	-17.80	288.16	9.50	94.81	0.787
231c	-18.06	289.08	9.33	95.22	0.766
231d	-18.13	407.38	9.77	132.90	0.979
231e	-18.56	506.35	9.61	168.86	1.26
231f	-18.85	536.79	9.84	179.26	1.287
231g	-18.52	527.62	9.95	178.43	1.303
231h	-18.61	604.99	10.05	208.92	1.508
231i	-18.61	548.04	10.50	185.92	1.358
231j	-17.27	412.24	11.51	136.19	1.009
231k	-17.49	395.76	11.32	131.25	1.002
231l	-19.01	548.04	11.12	187.18	1.35
231m	-18.69	414.18	10.56	135.78	0.971
231n	-18.24	430.78	9.62	142.38	1.085
244a	-17.36	446.51	12.48	146.92	1.129
244b	-17.44	474.26	12.12	158.08	1.217
244c	-17.80	483.25	11.48	160.98	1.187
244d	-18.34	575.85	11.49	197.62	1.431
244e	-17.96	609.17	12.30	210.60	1.499
244f	-17.43	407.38	11.79	134.14	0.979
244g	-18.14	473.27	11.45	158.91	1.132
244h	-18.74	540.88	11.45	184.67	1.281
244i	-18.85	521.53	10.88	176.76	1.258
244j	-18.94	537.81	11.17	185.09	1.33
244k	-18.06	399.63	11.31	131.25	0.95
244l	-17.41	345.12	11.51	112.38	0.79
244m	-17.94	496.28	10.95	167.20	1.189
244n	-17.93	515.45	10.74	176.35	1.247
244o	-17.72	327.22	10.13	109.51	0.805
244p	-18.15	398.66	9.86	132.90	0.95
244q	-17.83	358.39	10.22	118.52	0.96
252a	-18.79	486.25	10.80	163.88	1.343
252b	-18.36	421.00	11.09	140.73	1.19

252c	-17.84	388.05	11.83	128.38	0.964
252d	-18.24	566.55	11.77	192.60	1.403
252e	-18.22	399.63	10.12	132.49	0.966
252f	-18.30	420.03	10.45	139.90	1.024
252g	-18.19	492.26	10.73	166.79	1.208
252h	-18.44	594.55	11.08	206.83	1.482
252i	-16.75	339.45	11.91	112.38	0.826
252j	-18.61	603.94	10.63	210.18	1.472
252k	-18.86	513.42	10.08	176.35	1.214
252l	-18.19	461.34	10.32	157.25	1.11
252m	-17.83	489.25	11.57	165.13	1.139
128abcd	-18.83	377.48	9.02	126.73	1.074
128e	-19.15	290.93	8.98	96.03	0.831
128fgh	-18.91	399.63	9.25	130.84	1.11
128ij	-18.49	499.30	9.28	170.53	1.389
128kl	-18.31	240.74	10.21	82.60	0.701
128m	-17.98	375.57	9.82	123.86	0.89
128n	-19.17	591.42	9.63	205.15	1.439
74n	-18.10	474.26	11.04	160.98	1.086
274abc	-21.06	123.35	11.59	44.20	0.731
274def	-19.86	178.56	11.02	64.36	0.772
274gh	-16.95	235.34	13.19	83.82	0.946
274ij	-17.54	468.29	11.83	157.67	0.83
274kl	-18.04	259.77	10.69	89.52	0.744
274m	-17.95	370.78	9.67	123.04	0.967
274n	-19.69	588.30	8.33	205.57	1.43
274o	-18.96	384.20	7.71	127.97	0.925
251a	-18.71	280.80	9.52	94.81	0.75
251b	-19.43	527.62	9.20	183.01	1.382
251c	-19.02	514.44	9.88	176.76	1.345
251d	-19.07	485.25	9.83	165.13	1.191
251e	-19.57	564.49	9.84	195.11	1.356
251f	-19.07	467.29	10.18	157.25	1.115
251g	-19.95	636.54	10.16	224.05	1.538
251h	-19.94	608.13	9.44	213.12	1.503
251i	-19.36	490.26	9.30	165.96	1.158
251j	-19.74	615.47	9.42	215.64	1.497
251k	-18.88	436.67	9.13	149.40	1.028
251l	-19.15	496.28	9.48	168.03	1.177
251m	-19.75	576.89	8.95	202.22	1.415
251n	-18.73	316.93	9.54	107.06	0.745
251o	-19.22	471.27	9.66	159.33	1.125
251p	-19.22	529.66	9.46	183.01	1.223
251q	-19.38	565.52	9.73	195.53	1.33
2a	-17.82	415.16	10.14	137.84	1.017

2b	-17.91	347.95	9.70	114.42	0.858
2c	-18.26	404.47	9.45	134.96	0.993
2d	-18.41	468.29	9.53	157.67	1.134
2e	-18.46	499.30	10.06	168.03	1.196
2f	-18.80	604.99	10.18	207.25	1.457
2g	-18.05	390.94	10.00	128.38	0.898
2h	-18.55	496.28	10.31	167.62	1.164
2i	-17.96	361.24	10.52	118.93	0.851
2j	-18.30	470.28	10.21	161.81	1.087
2k	-18.53	517.47	10.02	174.68	1.225
2l	-18.56	511.40	10.62	174.68	1.218
2m	-17.83	453.42	11.49	153.53	1.048
2n	-18.86	484.25	9.90	164.71	1.12
2o	-19.20	566.55	9.59	200.13	1.329
132a	-17.62	302.96	11.42	101.34	0.758
132b	-17.93	407.38	10.78	136.19	1.017
132c	-18.08	411.25	10.21	135.06	1.016
132d	-18.05	417.09	10.07	137.52	1.064
132e	-18.65	565.53	10.29	197.19	1.402
132f	-18.32	484.97	9.92	161.79	1.178
132g	-17.99	364.04	9.95	119.44	0.858
132h	-18.78	515.95	10.15	177.42	1.213
132i	-18.88	558.40	10.14	190.60	1.362
132j	-17.79	456.25	10.84	151.09	1.096
132k	-18.24	527.01	10.75	180.72	1.257
132l	-18.33	474.04	10.76	159.32	1.133
132m	-18.15	396.72	10.32	132.18	0.942
132n	-18.49	290.45	10.44	98.91	0.829
249a	-16.21	436.61	13.01	143.69	1.089
249b	-15.45	371.70	13.64	121.91	0.982
249c	-15.64	484.97	14.17	165.49	1.206
249d	-15.25	382.26	13.58	124.78	0.94
249e	-16.26	390.93	12.77	131.36	0.909
249f	-17.18	606.56	12.69	213.67	1.512
249g	-17.28	605.53	12.46	207.90	1.444
249h	-16.93	534.07	13.16	181.54	1.253
249i	-17.08	573.70	12.86	200.48	1.35
249j	-15.81	532.06	13.86	180.72	1.222
249k	-16.34	571.65	13.22	201.31	1.331
249l	-16.55	483.97	12.22	165.08	1.108
249m	-16.97	571.65	11.98	194.72	1.338
273a	-18.23	352.60	10.62	116.98	0.91
273b	-18.65	479.00	10.89	157.67	1.234
273c	-18.46	476.03	11.34	160.55	1.159
273d	-18.58	566.55	10.84	196.77	1.404

273e	-18.41	568.59	10.87	195.95	1.375
273f	-18.36	558.40	11.15	191.83	1.382
273g	-18.23	336.46	10.14	112.46	0.797
273h	-19.86	526.01	8.59	179.48	1.331
273i	-19.30	476.03	8.77	159.73	1.198
273j	-18.89	490.94	9.18	163.84	1.165
273k	-19.23	595.23	8.93	205.42	1.453
273l	-17.83	344.04	9.46	115.33	0.822
273m	-18.52	504.92	9.21	170.02	1.168
273n	-18.99	535.08	8.87	181.95	1.23
263a	-18.67	400.59	8.61	133.41	1.016
263b	-19.55	573.70	8.53	198.83	1.418
263c	-19.60	532.06	8.61	178.25	1.317
263d	-19.94	570.63	8.43	195.54	1.379
263e	-19.58	583.93	8.59	203.78	1.405
263f	-18.59	391.89	8.34	130.95	0.906
263g	-18.73	512.94	8.27	175.37	1.247
263h	-18.45	400.59	7.98	132.18	0.935
263i	-19.09	585.99	7.88	205.01	1.449
263j	-19.09	479.00	7.81	159.32	1.086
263k	-20.07	596.26	8.15	206.25	1.396
263z	-19.44	597.29	8.51	204.19	1.412
167a	-17.43	431.72	11.24	144.10	1.056
167b	-17.82	526.01	11.30	179.89	1.307
167c	-18.22	499.92	10.45	167.96	1.269
167d	-17.78	528.02	10.90	179.89	1.282
167e	-17.36	516.95	11.13	174.95	1.287
167f	-16.77	494.93	12.60	167.55	1.153
167g	-16.41	385.15	12.14	126.84	0.895
167h	-17.41	504.92	11.60	171.25	1.184
167i	-18.39	622.08	11.21	216.14	1.47
167j	-17.81	409.31	10.29	137.93	0.93
167z	-17.93	593.17	11.25	202.95	1.477

APPENDIX E: Serial Section Measurements and Values

Burial	Serial Section	Measurement (mm)	Age	δ^{13}C‰	δ^{15}N‰
251	a	0-2.30	20.9	-18.71	9.52
	b	2.30-3.33	19.9	-19.43	9.20
	c	3.33-4.33	19.4	-19.02	9.88
	d	4.33-5.21	18.8	-19.07	9.83
	e	5.21-6.31	18.3	-19.57	9.84
	f	6.31-7.45	17.7	-19.07	10.18
	g	7.45-8.54	17.0	-19.95	10.16
	h	8.54-9.64	16.4	-19.94	9.44
	i	9.64-10.64	15.8	-19.36	9.30
	j	10.64-11.59	15.3	-19.74	9.42
	k	11.59-12.95	14.6	-18.88	9.13
	l	12.95-14.29	13.7	-19.15	9.48
	m	14.29-15.29	12.0	-19.75	8.95
	n	15.29-16.29	10.6	-18.73	9.54
	o	16.29-17.28	9.2	-19.22	9.66
128	abcd	0-5.10	19.9	-18.83	9.02
	e	5.1-6.2	17.9	-19.15	8.98
	fgh	6.2-9.2	16.6	-18.91	9.25
	ij	9.2-11.13	15.0	-18.49	9.28
	kl	11.13-13.04	13.4	-18.31	10.21
	m	13.04-14.08	11.1	-17.98	9.82
	n	14.08-15.28	9.4	-19.17	9.63
2	a	0-2.06	20.9	-17.82	10.14
	b	2.06-3.06	19.9	-17.91	9.70
	c	3.06-4.06	19.3	-18.26	9.45
	d	4.06-5.06	18.7	-18.41	9.53
	e	5.06-6.06	18.0	-18.46	10.06
	f	6.06-7.26	17.4	-18.80	10.18
	g	7.26-8.26	16.7	-18.05	10.00
	h	8.26-9.11	16.1	-18.55	10.31
	i	9.11-10.15	15.5	-17.96	10.52
	j	10.15-11.51	14.8	-18.30	10.21
	k	11.51-12.55	14.0	-18.53	10.02

	l	12.55-13.98	12.7	-18.56	10.62
	m	13.98-14.98	11.4	-17.83	11.49
	n	14.98-15.98	10.4	-18.86	9.90
	o	15.98-17.26	9.2	-19.20	9.59
231	a	0-2.27	20.8	-17.91	9.85
	b	2.27-3.28	19.7	-17.80	9.50
	c	3.28-4.18	19.1	-18.06	9.33
	d	4.18-5.4	18.4	-18.13	9.77
	e	5.4-6.4	17.7	-18.56	9.61
	f	6.4-7.58	16.9	-18.85	9.84
	g	7.58-8.72	16.2	-18.52	9.95
	h	8.72-9.72	15.5	-18.61	10.05
	i	9.72-10.87	14.8	-18.61	10.50
	j	10.87-12.05	14.0	-17.27	11.51
	k	12.05-13.0	11.9	-17.49	11.32
	l	13.0-14.1	9.7	-19.01	11.12
167	a	0-2.2	20.8	-17.43	11.24
	b	2.2-3.45	19.7	-17.82	11.30
	c	3.45-4.49	19.0	-18.22	10.45
	d	4.49-5.59	18.4	-17.78	10.90
	e	5.59-6.59	17.7	-17.36	11.13
	f	6.59-7.69	17.0	-16.77	12.60
	g	7.69-8.85	16.3	-16.41	12.14
	h	8.85-10.49	15.5	-17.41	11.60
	i	10.49-11.49	14.6	-18.39	11.21
	j	11.49-12.96	12.8	-17.81	10.29
110	a	0-2.02	20.5	-17.35	11.17
	b	2.02-3.08	18.9	-17.09	10.89
	c	3.08-4.08	17.9	-17.03	10.88
	d	4.08-5.08	16.9	-17.03	11.21
	e	5.08-6.18	15.9	-16.64	12.14
	f	6.18-7.30	14.8	-16.66	12.28
	g	7.30-8.33	13.6	-17.41	11.45
	h	8.33-9.96	12.2	-17.66	10.92

	i	9.96-11.19	10.6	-17.77	10.71
	j	11.19-12.43	9.2	-18.00	10.47
274	274abc	0-4.16	20.3	-21.06	11.59
	274def	4.16-7.55	18.2	-19.86	11.02
	274gh	7.55-9.56	16.7	-16.95	13.19
	274ij	9.56-12.11	15.4	-17.54	11.83
	274kl	12.11-14.43	14.0	-18.04	10.69
	274m	14.43-15.48	11.9	-17.95	9.67
	274n	15.48-16.48	10.5	-19.69	8.33
	274o	16.48-17.53	9.2	-18.96	7.71
168	a	0-2.07	20.9	-17.50	11.85
	b	2.07-2.95	20.2	-17.26	11.56
	c	2.95-4.11	19.6	-17.25	12.07
	d	4.11-5.24	19.0	-17.07	12.38
	e	5.24-6.27	18.4	-17.55	12.47
	f	6.27-7.38	17.9	-17.48	11.39
	g	7.38-8.54	17.3	-17.68	11.59
	h	8.54-9.7	16.6	-16.69	12.91
	i	9.7-10.7	16.1	-16.40	12.90
	j	10.7-11.73	15.5	-16.08	12.49
	k	11.73-12.75	15.0	-16.98	11.55
	l	12.75-13.77	14.4	-18.17	10.87
	m	13.77-14.8	13.8	-17.86	9.93
	n	14.8-15.9	12.6	-18.01	10.33
	o	15.9-16.92	11.4	-17.34	10.74
	p	16.92-17.95	10.2	-17.72	10.72
	q	18.97-18.99	9.1	-16.97	11.64
244	a	0-1.70	20.7	-17.36	12.48
	b	1.7-2.67	20.0	-17.44	12.12
	c	2.67-3.65	19.5	-17.80	11.48
	d	3.65-4.71	18.9	-18.34	11.49
	e	4.71-5.91	18.3	-17.96	12.30
	f	5.91-6.98	17.6	-17.43	11.79
	g	6.98-8.18	17.0	-18.14	11.45

	h	8.18-9.38	16.4	-18.74	11.45
	i	9.38-10.44	15.7	-18.85	10.88
	j	10.44-11.38	15.2	-18.94	11.17
	k	11.38-12.25	14.7	-18.06	11.31
	l	12.25-13.19	14.2	-17.41	11.51
	m	13.19-14.25	13.9	-17.94	10.95
	n	14.25-15.41	12.6	-17.93	10.74
	o	15.41-16.43	11.4	-17.72	10.13
	p	16.43-17.43	10.2	-18.15	9.86
	q	17.43-18.43	9.1	-17.83	10.22
64	a	0-1.89	20.9	-17.84	11.27
	b	1.89-3.03	19.9	-17.36	12.50
	c	3.03-4.09	19.2	-17.69	12.25
	d	4.09-5.0	18.6	-19.44	10.86
	e	5.0-6.12	18.0	-18.22	11.09
	f	6.12-7.06	17.3	-18.12	11.17
	g	7.06-8.16	16.7	-18.10	11.54
	h	8.16-9.14	16.0	-18.14	10.85
	i	9.14-10.27	15.3	-18.28	11.27
	j	10.27-11.5	14.6	-17.32	11.87
	k	11.5-12.64	13.6	-17.19	11.89
	l	12.64-13.98	11.6	-18.11	11.40
	m	13.98-15.18	9.5	-18.26	10.68
61	61abc	0-3.93	20.5	-19.89	8.35
	61de	3.93-5.84	19.0	-21.37	8.37
	61fg	5.84-8.06	18.0	-22.00	7.95
	61hi	8.06-10.15	16.9	-20.87	7.60
	61jkl	10.15-13.46	15.5	-20.78	7.27
	61mno	13.46-16.52	13.7	-19.90	7.95
	61p	16.52-17.55	9.5	-19.24	8.26
249	a	0-2.33	20.8	-16.21	13.01
	b	2.33-3.33	19.7	-15.45	13.64
	c	3.33-4.39	19.1	-15.64	14.17
	d	4.39-5.35	18.5	-15.25	13.58

	e	5.35-6.4	17.9	-16.26	12.77
	f	6.4-7.6	17.2	-17.18	12.69
	g	7.6-9.05	16.3	-17.28	12.46
	h	9.05-10.12	15.6	-16.93	13.16
	i	10.12-11.70	14.7	-17.08	12.86
	j	11.70-13.71	13.5	-15.81	13.86
	k	13.71-16.02	11.5	-16.34	13.22
	l	16.02-18.28	9.5	-16.55	12.22
102	102abc	0-4.26	20.4	-18.26	9.74
	102def	4.26-7.71	18.5	-19.91	8.99
	102gh	7.71-10.01	17.0	-20.16	8.35
	102i	10.01-11.03	16.2	-19.14	8.68
	102j	11.03-12.01	15.7	-18.83	8.73
	102klm	12.01-15.32	14.6	-17.94	9.77
	102no	15.32-17.51	12.5	-19.10	9.48
	102p	17.51-18.61	10.5	-19.20	9.14
	102q	18.61-19.71	9.2	-18.55	8.90
252	a	0-1.65	21.0	-18.79	10.80
	b	1.65-2.52	20.1	-18.36	11.09
	c	2.52-3.50	19.5	-17.84	11.83
	d	3.5-4.57	18.9	-18.24	11.77
	e	4.57-5.95	18.1	-18.22	10.12
	f	5.95-7.15	17.2	-18.30	10.45
	g	7.15-8.14	16.5	-18.19	10.73
	h	8.14-8.99	15.9	-18.44	11.08
	i	8.99-9.8	15.4	-16.75	11.91
	j	9.8-11.0	14.7	-18.61	10.63
	k	11.0-12.26	13.9	-18.86	10.08
	l	12.26-13.8	12.3	-18.19	10.32
	m	13.8-16.31	9.9	-17.83	11.57
281	a	0-1.78	21.1	-18.30	10.31
	b	1.78-2.88	20.3	-18.32	10.59
	c	2.88-3.93	19.8	-18.16	10.10
	d	3.93-4.92	19.2	-18.45	9.79

	e	4.92-6.3	18.6	-18.32	9.98
	f	6.3-8.18	17.7	-18.11	9.56
	g	8.18-9.54	16.9	-18.36	9.27
	h	9.54-10.81	16.2	-17.73	10.11
	i	10.81-12.01	15.5	-18.25	10.30
	j	12.01-13.11	14.9	-18.23	10.76
	k	13.11-14.59	14.3	-17.95	11.47
273	a	0-1.72	20.9	-18.23	10.62
	b	1.72-2.59	20.1	-18.65	10.89
	c	2.59-3.62	19.5	-18.46	11.34
	d	3.62-4.57	18.8	-18.58	10.84
	e	4.57-5.52	18.2	-18.41	10.87
	f	5.52-6.59	17.5	-18.36	11.15
	g	6.59-7.68	16.8	-18.23	10.14
	h	7.68-8.5	16.2	-19.86	8.59
	i	8.5-9.3	15.7	-19.30	8.77
	j	9.3-10.3	15.1	-18.89	9.18
	k	10.3-11.46	14.4	-19.23	8.93
	l	11.46-12.61	13.4	-17.83	9.46
	m	12.61-13.81	12.1	-18.52	9.21
	n	13.81-16.44	10.0	-18.99	8.87
132	a	0-2.12	20.8	-17.62	11.42
	b	2.12-3.18	19.8	-17.93	10.78
	c	3.18-4.14	19.2	-18.08	10.21
	d	4.14-5.1	18.5	-18.05	10.07
	e	5.1-6.29	17.9	-18.65	10.29
	f	6.29-7.34	17.1	-18.32	9.92
	g	7.34-8.46	16.4	-17.99	9.95
	h	8.46-9.51	15.8	-18.78	10.15
	i	9.51-10.70	15.0	-18.88	10.14
	j	10.7-11.7	14.3	-17.79	10.84
	k	11.7-12.85	13.4	-18.24	10.75
	l	12.85-14.08	12.0	-18.33	10.76
	m	14.08-15.28	10.6	-18.15	10.32
	n	15.28-16.53	9.2	-18.49	10.44

74	a	0-2.01	20.9	-17.52	11.12
	b	2.01-2.99	20.1	-17.73	10.87
	c	2.99-3.96	19.5	-17.97	10.66
	d	3.96-5.25	18.9	-18.08	10.96
	e	5.25-6.24	18.3	-17.78	10.99
	f	6.24-7.44	17.6	-18.07	11.14
	g	7.44-8.48	17.0	-18.25	11.15
	h	8.48-9.68	16.4	-18.55	10.78
	i	9.68-10.78	15.7	-18.59	10.37
	j	10.78-11.82	15.1	-17.75	11.66
	k	11.82-13.8	14.3	-17.20	11.43
	l	13.8-15.0	11.9	-17.33	11.27
	m	15.0-16.2	9.6	-18.22	10.98
62	a	0-2.0	20.9	-18.34	10.62
	b	2.0-2.89	20.0	-17.99	10.63
	c	2.89-3.77	19.5	-18.47	10.67
	d	3.77-4.68	19.0	-18.75	10.65
	e	4.68-5.86	18.4	-18.24	10.45
	f	5.86-7	17.7	-18.34	9.90
	g	7-8.14	17.0	-18.83	9.74
	h	8.14-9.36	16.3	-18.23	9.57
	i	9.36-10.5	15.6	-18.44	9.52
	j	10.5-11.97	14.8	-19.04	9.82
	k	11.97-13.22	13.9	-18.61	9.34
	l	13.22-15.25	10.6	-18.26	9.79
263	a	0-2.13	20.8	-18.67	8.61
	b	2.13-3.17	19.9	-19.55	8.53
	c	3.17-4.17	19.2	-19.60	8.61
	d	4.17-5.2	18.6	-19.94	8.43
	e	5.2-6.2	18.0	-19.58	8.59
	f	6.2-7.5	17.3	-18.59	8.34
	g	7.5-8.8	16.4	-18.73	8.27
	h	8.8-10.0	15.7	-18.45	7.98
	i	10.0-11.3	14.9	-19.09	7.88

	j	11.3-13.2	13.8	-19.09	7.81
	k	13.2-15.68	10.4	-20.07	8.15

APPENDIX F: Pre-Drilling Measurements

Burial	Sex	Tooth	Max Length (mm)	CEJ (mm)	DEJ min (mm)	DEJ max (mm)	OS min (mm)	OS max (mm)	Weight (g)
251	F	UL3M	18.6	15.62	17.44	16.4	18.1		0.9817
128	M	LR3M	15.39	11.68	14.34		11.1	15.39	0.3478
2	F	LL3M	17.59	12.91	15.63	14.6	16.86		0.6929
231	F	UL3M	19.46	12.68	17.02	15.74	17.49		0.8459
167	F	LL3M	13.97	12.06	not present		13		0.4732
110	M	UL3M	13.39	7.69	13.15	not present	13.15		0.6674
274	F	LL3M	17.62	13.35	15.72	14.99	16.29		0.6131
168	M	LR3M	20.01	14.66	18.49		20.01	15.01	0.7521
244	M	UR3M	20.11	14.6	18.63	17.67	19.49		0.794
64	M	LL3M	17.95	12.67	14.67	not present	14.88		0.6196
61	M	UR3M	19.28	15.36	17.61	not present	16.18		0.2606
249	M	LR3M	18.49	12.81	17.7	not present	16.29		0.9287
102	M	UL3M	21.43	15.2	19.76		17.78		0.5352
252	M	LL3M	17.26	12.14	15.5		14.19		0.5557
281	F	LL3M	14.6	14.57	not present		13.78		0.5305
273	M	LR3M	17.09	11.9	16		16.9	13.8	0.3944
132	F	UR3M	18.03	12.61	14.65	17.07	18.03		0.3385
74	F	LR3M	16.96	13.75	13.4	16.24	15.61		0.9038
62	F	LL3M	16.55	12.96	not present		14.08		0.5382
263	F	UR3M	17.23	13.63	16.59		14.7		0.7362

- Max Length refers to the longest portion of the tooth, generally from the crown to the root tip.
- CEJ refers to the cementum-enamel junction.
- DEJ refers to the dentin-enamel junction. There can be varying measurements for this, so the maximum and minimum were recorded.
- OS refers to the occlusal surface, which can also have varying lengths.