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THE SERVANTS OF MACHU PICCHU: LIFE HISTORIES AND POPULATION DYNAMICS IN LATE HORIZON PERU

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Doctor of Philosophy

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An Abstract of
A dissertation submitted to the Faculty of the Graduate
School of Emory University in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

Department of Anthropology

2008

Abstract

This study elucidates variation in early-life diet and geographic origin among the population from the Inca site of Machu Picchu, Peru. In use during the 15th and 16th centuries, Machu Picchu was one of several royal estates inhabited by permanent servants, though their specific social class was unknown. A central aspect of political economy in the Inca Empire was the large-scale relocation of populations, in different numbers and different ways according to assigned social class. Moreover, the Inca used particular social classes, such as the *mitmacona*, *acllacona* and *yanacona*, to circumvent traditional reciprocal obligations of elites to their subjects; the ability to accurately profile these different social class in Inca-period skeletal populations, given that they were moved around the empire in different ways, stands to drastically improve interpretations of demography and function in ancient Andean populations. However, identifying population movement in ancient populations is difficult, due to the limitations and ambiguities inherent to common forms of archaeological and osteological evidence. Recently, isotopic analysis has shown promise in resolving this issue in Europe and parts of Mesoamerica, but this research is in its infancy in Andean South America.

The Machu Picchu skeletal population is large, well-preserved and archaeologically well-contextualized; based on mortuary and osteological analyses, other researchers (Burger et al. 2003) have suggested that this population consists of *yanacona*. However, these other forms of data cannot unequivocally address this question, and Spanish colonial documents suggest more than one social class could have been present at Machu Picchu. The aims of this study are therefore twofold: (1) to isotopically test the hypothesis that these individuals are *yanacona*, and (2) to formulate a methodological and analytical framework for reconstructing residence/immigration, subsistence and health at Machu Picchu that can be applied to other skeletal populations.

To satisfy these aims, I characterized stable (nonradioactive) isotopes of carbon, nitrogen, oxygen, strontium and lead in preserved tooth enamel and dentine from a large segment of the burial population. In doing so, I was able to profile the diet and region of origin during infancy and childhood from the remains of individuals who died as adults. I also synthesized my own and previously-published data on sex, cemetery context, and pathological conditions of the cranium and dentition. Results show an unprecedented range of variation in the backgrounds of the population: almost all of the individuals in the study population were born elsewhere and immigrated to Machu Picchu after childhood. Moreover, several individuals appeared to have migrated to multiple regions during childhood. They consumed very different diets, which had complex relationships with their estimated region of origin and the prevalence of pathological conditions in their skeletal and dental tissues. Multivariate statistical analyses suggest not only the causal factors involved with certain pathological conditions, but also specific regions from which segments of the population were drawn. Importantly, the distribution of isotopic data for all of the elements studied is wide and stochastic, matching the expected distribution of *yanacona*. This stands as one of the most complex isotopic and osteological studies in the Andes, and is the first to use biochemical data to assess class-mediated migration. It joins a burgeoning body of research that utilizes biochemical and osteological analyses to paint a more nuanced picture of political economy, subsistence and health in ancient states.

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Acknowledgements

Many people were integral to the creation and completion of this dissertation; though the *when* and *what* of their roles were varied, each was indispensible.

My Ph.D. committee, jointly chaired by Drs. George J. Armelagos and John D. Kingston, and including Drs. Gordon F. McEwan and Daniel Sellen, was exceptional at all steps in my graduate career. I was truly lucky to have such a blend of scholarship, mentorship, dependability and camaraderie among the four of them, and whatever successes I have in my career will ultimately trace back to their tutelage and support.

Several other members of the anthropology department at Emory University were instrumental players in my graduate career, including Drs. Sally Gozoules, Craig Hadley, Carol Worthman, Patricia Whitten and Peter Brown, as well as Dr. Pat Marsteller at the Emory Center for Science Education. Their skills and patience in reviewing grant proposals, providing statistical advice, troubleshooting, pep talks, and other such assistance are most heartily appreciated. My fellow graduate students in anthropology, including Dr. Amanda Thompson, Ana Schaller de la Cova, Sarah Barks, Jennifer Sweeney, Molly Zuckerman, Jennifer Mascaro, the ladies of the post-field seminar… really, all of them, brought their invaluable insights and enthusiasm to reciprocally editing proposals, attending practice presentations, giving supportive pep talks, throwing great parties and in general making grad school fun. The members of the anthropology staff at Emory – Debra Keyes, Yvan Bamps, Sally Pattison-Cisna and Dee Hruschka – were equally exceptional in their guidance, reliability and good humor, and I will always treasure rejuvenating conversations with Miriam Willis.

I am extremely grateful to the curators and staff of the Peabody Museum of Natural History at Yale University, including Drs. Richard L. Burger and Andrew Hill, Lucy C. Salazar, Dr. Roger H. Colten, and Maureen DaRos, for permission and assistance in my collection of osteological data and tissue samples; I am also grateful to Marjorie Sullivan and Dr. Melissa Tedone for their warm hospitality during my lengthy stints in Connecticut. Froilan Inturriaga Guzman provided invaluable assistance in procuring food samples from the generous farmers in Huacarpay, Peru, for which I will always be grateful. Laboratory analysis of my samples could not have taken place without the expertise and collaboration of Drs. Jason Curtis, George Kamenov and John Krigbaum, as well as the laboratory assistance of Benjamin Valentine, of the University of Florida Gainesville, all of which is greatly appreciated.

I will be forever grateful to my parents, Dr. Jefferson and Lynn Turner, and my sister Ashley Turner, for their pragmatic advice and undying support at all steps of my graduate training; to say that I couldn't have done it without them is a vast understatement. I would like to thank our cats, Whately and Wendell, for giving me a healthy dose of perspective through their frequent reminders that they, not my thesis, are the center of the universe. Finally and most importantly, I would like to thank my husband, Matt Livermore, for his patience, support, understanding and devotion in walking this long and ultimately satisfying road with me; words cannot adequately express my gratitude.

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Chapter 1: Introduction

The Spanish invasion of Peru in 1532 brought about the abrupt end of the largest state to ever exist in the Western Hemisphere, that of *Tawantinsuyu* (the Land of the Four Quarters), the Inca imperial state. *Tawantinsuyu* covered over two million square kilometers of diverse Andean landscape and assimilated approximately 12 million people from dozens of ethnic backgrounds (Moseley, 1992; Rowe, 1946). Its cities were monumental feats of architecture and engineering and its wealth and splendor dazzling, which are all the more significant given that the Inca existed as an imperial state for just under a century. However, much of Inca life was sufficiently foreign to Spanish observers as to seem without Old World analogs, making it difficult to grasp and accurately portray the nuances of the empire. This was compounded by cultural biases and linguistic barriers on the part of chroniclers and indigenous informants, resulting in limited understandings of Inca origins, statecraft and cultures (Covey, 2003; Urton, 1990).

Early analyses of the Inca state relied on indigenous recounting of Inca history, economy, politics and spirituality as recorded by Spanish chroniclers such as Father Bernabé Cobo (1890-1895 [1653]; 1964 [1653]), Garcilaso de la Vega (1959 [1609]), Cieza de Leon (1962 [1550]; 1984 [1553]; 1985 [1553]) and others. Centuries later, archaeological research complemented modern analyses of these documentary sources, adding to our knowledge of this ancient state and its people (Bauer, 1992; D'Altroy, 1992; Earle et al., 1987; Julien, 2000; Malpass, 1993; McEwan, 2006; McEwan et al., 2002; Murra, 1980; Rostworowski de Diez Canseco, 1999; Rowe, 1946; Stanish, 2001a;

Stanish, 2001b). However, there is still much about life in *Tawantinsuyu* that remains unknown, especially as it applies to those countless thousands whose menial lot in life went relatively unnoticed by Spanish chroniclers. Since the fate of any civilization rests largely on the shoulders of its subjects, reconstructing the lives of both elites and nonelites can provide invaluable insights into larger political, economic and social processes.

For example, we know from ethnohistorical analyses of Spanish colonial documents that the Inca economy depended heavily on taxation through tributary labor, mobilizing an enormous labor pool for agricultural and textile production, large-scale building projects, and military campaigns (Murra, 1982; Rowe, 1982; Wachtel, 1982). Interestingly, whether people were relocated as individuals or as groups depended on their assigned social status and the associated roles and responsibilities of each. Further, we know that the state sometimes moved groups or entire communities, part-and-parcel to far-flung regions in order to quash resistance to Inca rule, or to colonize areas emptied of such dissidents with loyal subjects. Archaeological studies of earlier Andean societies suggest that the Inca based much of their statecraft on altering or enhancing pre-existing forms, particularly from the Wari state of central Peru and the Tiwanaku state of the Bolivian highlands. It is therefore reasonable to assume that population movement to this degree, and potentially movement linked to social class, has precursors in Andean antiquity. While *Tawantinsuyu* may therefore not be the first state to forcibly move its subjects around, this practice of large-scale, state-mandated movement through large geographic areas seemed to reach its zenith during the Inca imperial period, and formed a central aspect of imperial political economy (Wachtel, 1982).

From the perspectives of those being moved, Inca imperial dictates may have translated into major changes to individuals' lives. The central Andes encompasses a wide range of environments, ranging from hyper-arid coastal desert to fertile montane valleys, high-altitude sierra and stark *altiplano* (Brush, 1982). Depending on where an individual grew up, movement from one environment to another could have resulted in drastically different modes of subsistence and perhaps nutritional status, as well as exposure to new environmental stressors including altitude, temperature and environmental parasites. In a larger political economic context, during the latter decades of Inca rule, elites may have increased movement of individuals and populations of particular social classes, such as *yanacona* retainers and *mitmacona* labor colonists, in order to circumvent ancient structures of reciprocity between the state and subject communities. In effect, certain subject populations may have been forcibly planted in communities in order to "outsource" tributary labor and thereby cut those communities out of reciprocated provisioning. From both the perspective of individual life change and of shifting relationships between elites and subjects, accurately tracking population movement in the Inca-controlled Andes and linking it to assigned social class is a critical avenue of inquiry.

The problem in researching population movement is that this phenomenon is difficult to unequivocally measure in ancient contexts. In fact, movement of individuals or groups in states that predate the sort of census records one finds nowadays is, as D'Altroy (2001) succinctly puts it, "archaeologically invisible." For example, the presence of material goods in graves could stem from immigration, but also from trade, while changes in settlement patterns could reflect colonization, admixture, or cultural influence. Therefore, recent decades have seen increased efforts on the part of bioarchaeologists, biological anthropologists who focus on analyses of human skeletal material, to reconstruct movement in ancient populations by directly analyzing the remains of their constituents.

Bioarchaeological techniques for identifying population movement center on identifying immigrants within skeletal populations through morphological, genetic and biochemical means, often comparing different populations in order to trace immigrants in a given population to their potential regions of origin. Metric and non-metric cranial traits are often used as genetic markers, but the degree to which these markers are buffered from developmental and environmental factors is not entirely clear. At present, there are no published studies that explicitly assess cranial trait frequencies against gene sequences from populations where both parameters are measurable. Also, while both metric and non-metric features are taken as proxies for genetic histories, studies of population admixture in the same regions of northern Chile have arrived at opposite conclusions (Sutter and Mertz, 2004; Varela and Cocilovo, 2002). Analyses of ancient DNA are relatively new to these contexts, but have shown promise in associated related versus non-related individuals in Andean contexts, notably among the "Children of Llullaillaco" discovered in 1999 in the Argentinean Andes (Grady, 2007). However, even if one does have data from ancient DNA or treats cranial features as accurate genetic proxies, genetic history does not equate directly to cultural or ethnic affiliation, given the latter's dynamic and complex nature, or to movement within an individual's lifetime. Studying patterns of intentional cranial vault modification is one way of estimating the presence of non-local ethnic groups in a given population, given that the practice is considered a particularly salient expression of ethnic identity (Torres-Rouff, 2003). However, the presence of a particular modification style could signify immigration by a foreign ethnic group, or equally the persistence of ethnic identity among locally-born descendants. Ultimately, measures of genetic heritage and cultural ethnicity lack the resolution to track migration within an individual's life, or to differentiate immigrants from their locally-born descendants.

The characterization of stable (non-radiogenic) isotopes in preserved skeletal and dental tissues provides an effective tool for approaching ancient population movement while avoiding some of these limitations, and forms the basis of this study. Stable isotope analyses have become widespread in bioarchaeological research, resulting in a steadily-growing literature that situates subsistence behavior and its impacts on health within immediate ecological contexts. The underlying assumption of this research paradigm as it applies to anthropology is that the isotopic composition of animal tissues, including those of humans, reflects the isotopic composition of consumed food and water (Price et al., 2002; Schwarcz et al., 1991; Schwarcz and Schoeninger, 1991). The isotopic composition of local foodwebs, as assemblages of organisms that consume and are consumed by other organisms, in turn reflect the isotopic composition of the local environment, with predictable fractionation (enrichment) effects in some isotopes due to their transference through different trophic levels. Isotopic studies used to estimate the nature of the diet can also be used to estimate the local environment from which a particular consumer fed (assuming that the diet was drawn primarily from local resources). Isotopic ratios of five commonly-occurring elements, carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), oxygen ($\delta^{18}O$), strontium ($^{87}Sr/^{86}Sr$) and lead ($^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and

^{208}Pb/^{204}Pb, referred to herein as ^{20n}Pb/^{204}Pb for brevity), have been studied in both human and faunal remains to address a wide variety of topics related to dietary reconstruction and patterns of migration, sometimes in combination.

Isotopic techniques are well-suited to assess individual mobility from one region to another, and thereby to identify population movement, for several reasons. First, isotopic analyses rely on direct, physiological measures using the individual as the unit of analysis and local ecology as the baseline, removing the ambiguities of associated artifacts, settlement patterns and other archaeological features. Second, isotopic analyses provide independent measures of geographic residence and dietary composition within the individual life span, independent of genetic history or archaeologically-determined ethnicity. Finally, isotopic ratios are found in all bodily tissues, which form at different points in life and vary widely in their rates of metabolic turnover. In the case of tooth enamel and (to a lesser extent) dentin, these tissues form at predictable rates during development and do not change once formed, thereby preserving isotopic ratios from specific, confined periods in an individual's life. Isotopic analyses of multiple tissues per individual, such as bone and enamel or dentin from several teeth, therefore permit the reconstruction of diet and local geography at various points in life, in essence revealing longitudinal trends.

When isotopic data are used in concert with other osteological, archaeological and, when available, ethnohistoric data, it becomes possible to more accurately interpret the effects that such movement had on diet, health and well-being. When that mobility is linked to social status, these techniques are especially useful in testing hypotheses regarding the composition and nature of social classes, as well as the functional nature of the imperial system that controlled them. This study generates multi-tissue isotopic and dental pathology data from a large segment of the well-preserved, well-contextualized skeletal population from Machu Picchu, Peru, utilizing published data on common skeletal pathological conditions, site archaeology and colonial ethnohistory to explore population movement and life change linked to assigned status.

Machu Picchu is located in the Urubamba province of the Department of Cusco in the southern highlands of Peru. The site itself sits along a ridge connecting Machu Picchu and Huayna Picchu mountains in a verdant region 2,430m above sea level. While early researchers interpreted the site as a sacred shrine populated by vestal virgins (Bingham, 1979 [1930]; Eaton, 1916), the modern consensus is that Machu Picchu was a royal Inca estate built ca. AD 1450-1470 during the reign of Pachacuti Yupanqui, one of the most famous and influential Inca emperors. The site was inhabited by a permanent population of servants until its eventual abandonment following the Spanish conquest of the 1530s, after which Machu Picchu fell into obscurity until its "discovery" by Yale archaeologist Hiram Bingham in 1911.

Bingham's excavations at Machu Picchu uncovered a skeletal population that to this day remains one of the largest, best-preserved and best-contexualized in the central Andes (Verano, 2003a), and which has been housed at the Peabody Museum of Natural History at Yale University. Based on mortuary and osteological analyses, Burger et al. (2003) and Salazar (2001) have suggested that the Machu Picchu servant population consisted of *yanacona* retainers. However, this hypothesis is tentative, and colonial documentary sources suggest that servants at Inca royal estates could also have included other classes such as *mitmacona* labor colonists and even local commoners known as *hatun runa* (Ortiz de Zuñiga, 1967; Rostworowski de Diez Canseco, 1999). Since the demographic composition and patterns of movement would have differed among these social classes, the distribution of isotopic data among the population would likely take different shapes depending on its particular social class. The Machu Picchu population presents a unique opportunity to use isotopic methods to directly answer several key questions:

1. How varied are isotopic parameters of diet and residence from early life in the Machu Picchu population? Are there immigrants among the Machu Picchu population, and if so, where might they have come from?
2. Do the respective distributions of each isotopic parameter match any of the expected distributions of *yanacona*, *mitmacona* and/or *hatun runa*?
3. Are there significant relationships between chronic pathological conditions (for example, anemia) and diet or residence during early life (represented by isotopic data)? I.e., are childhood pathological conditions due more to stressors in the local environment or to dietary inadequacy?

This thesis employs isotopic methods to better understand issues surrounding Andean life at a number of levels. At the level of the individual, results presented here provide insights into individual backgrounds, tracking continuity and change in residence and diet at various points in life and using it to create life history profiles for each member of the study population. At the level of the population, results characterize demographic variation that permits accurate estimation not only of the population's social class but of regions from which non-local immigrants may have originated. It also breaks new ground in assessing causal roles of local environmental versus dietary stress in the prevalence of pathological conditions in the population. Nonspecific pathological conditions have long been used as diagnostic criteria in assessing health and disease in ancient populations, but are often limiting in that they have a number of potential causes. This study provides innovate analytical techniques for better characterizing key stressors in skeletal remains, rounding out profiles of subsistence and mobility with additional insights into population health.

At the level of ancient Andean culture and Inca political economy, this study establishes a multifaceted methodological and analytical framework that will provide critical insights into the location and function of different social classes in the Inca Empire. Knowing *which* social classes were moved *where* in the empire will permit better understandings of elite-subject relations in different regions of the empire, especially during latter decades of Inca rule characterized by increasing political instability. This study therefore provides critical groundwork from which to establish comparative frameworks at other Inca sites in the future.

Overview of Chapters

The organization of this thesis generally follows this introduction, beginning with larger contextual questions and then focusing specifically on empirical components. Chapter 2 provides an overview of Pre-contact Andean culture, tracing the development of imperial states within the opportunities and constraints presented by the central Andean ecological and cultural landscape. The Inca was not the first imperial state in the Andes, and much of its political and economic structure appears to have drawn on earlier state forms; in turn, statecraft in general in the Andes appears to have drawn on ancient structures of household, community and regional economy. It is therefore essential to understand the Inca within this larger contextual framework.

Chapter 3 moves from this wider context into the specific research design of this study, using key questions raised in Chapter 2 to frame overarching hypotheses and elaborate on the Machu Picchu population as an ideal study sample for this inquiry. From there, Chapters 4 through 6 each serve as an independent report on the theoretical background, methods, results and interpretations of stable isotopic and osteological analyses. Chapter 4 centers on establishing population demography, migration and estimated regions of origin among identified immigrants at Machu Picchu based on strontium, lead and oxygen isotopic analysis of human and faunal tooth enamel. Chapter 5 centers on characterizing dietary composition among the population, estimating variation in early-life subsistence and dietary change during life based on carbon and nitrogen isotopic analysis of human tooth enamel and dentin, compared to a "menu" of common Inca food sources. Chapter 6 details the prevalence of various skeletal and dental pathological conditions, both from Verano's (2003a) earlier analysis of the Machu Picchu population and original data collected here. These data are statistically analyzed against isotopic parameters of residence and diet to identify the potential causal agents involved with different conditions. From there, the results of these three chapters and their larger interpretive significance are summarized in Chapter 7, which ends with concluding comments and projections for future research. Isotopic and osteological data and data analyses are summarized in Appendix A, listed in order by which they are referenced in the text.

This thesis provides significant insights into the Machu Picchu population, individuals who have long captured the interest of scholars and the public alike. These insights are particularly important given that, as of early 2008, Yale University and the Peruvian government arrived at an agreement following a protracted dispute, in which an unspecified part of the Machu Picchu collection will be returned to Peru. The artifacts and human remains are widely considered to be important cultural patrimony to the people of Peru and the central Andes as a whole. The findings from this research will therefore shed new light on the population as at least part of it is returned to its Andean homeland.

Moving beyond the Machu Picchu population itself, this thesis aims to better understand life under the Inca Empire, in terms of biological realities of diet and health related to culturally-mediated patterns of movement. The methodological and analytical frameworks established here will hopefully move forward comparative analyses of other populations living under ancient imperial states, both in the Andes and elsewhere in the world. While each state-level society is best understood on its own terms, much insight can be gained through reasonable comparative studies of ancient states through geographic space and time. This thesis, in its own small way, will hopefully contribute in advancing research and understanding in ancient lifeways.

Chapter 2. Inca Cultural and Ecological Context

Introduction

The Spanish invasion of Peru in 1532 brought about the abrupt end of the largest state to ever exist in the Western Hemisphere, that of *Tawantinsuyu* (the Land of the Four Quarters), the Inca state. Much of Inca life was so foreign to Spanish observers as to seem without Old World analogs, making it difficult to accurately portray the nuances of the empire. As such, important aspects of Inca statecraft were often overlooked. Two such features are the structure of Inca social classes and the political economy of population movement in the Inca Empire. State-mandated movement of thousands of subjects was a fundamental aspect of the Inca economy, permitting large-scale agricultural production, building projects and the suppression of hinterland dissent. In this imperial system, immigrant groups at a given Inca site would have varied in their demographic composition depending on social class, potentially varying in background as well. Further, as is elaborated below, these social classes likely had pre-Inca precursors as well. The distribution of different social classes throughout different sites and time periods in the central Andes could therefore be a potentially important node of comparison between Inca and earlier states. This avenue of inquiry is difficult to navigate using archaeological context or skeletal morphology; more direct measures of population movement, such as isotopic analysis, are still in their infancy (see Chapter 4). This study seeks to explore population movement and diversity in backgrounds related to social class through isotopic analyses of human skeletal remains hypothesized to be a particular type of Inca social class. In order to more clearly define the intersection between chemical method and less-tangible cultural constructs as social class, particularly in an Inca context, an overview of Andean culture history is warranted.

Early analyses of the Inca state relied on indigenous recounting of Inca oral history as recorded in Spanish chronicles. Tales of Inca origins varied between regions, but a pivotal historical moment is thought to have occurred when the state was still one of several small kingdoms in the central highland sierra of Peru. During their war with the rival Chanca polity, a cowardly Inca king and his heir are said to have fled the kingdom in fear of defeat. A younger son of the king took his father's place, and with divine aid led the Inca to victory. Having subdued the Chanca, this son took the name Pachacutec, which means "earthshaker" or "cataclysm" (McEwan, 2006: 74), created the institutions of government and administration central to the state, and led numerous campaigns to successfully annex prodigious swaths of the central Andes (Rowe, 1946: 204-205).

The portrayal of the Inca Empire as a pristine state whose establishment and expansion was driven by the works of a single messianic leader was frequent in Spanish chronicles of indigenous oral histories. Later analyses of Spanish sources created a theoretical rift in Andean research. Structuralist scholars, most notably R. Tom Zuidema (1964) and his students (Isbell, 1997; Urton, 1981; Urton, 1990) posit that very little of the oral history recorded in the chronicles represents actual historical events or processes; rather, indigenous accounts were mythical and symbolic accounts that reflect distinctly different notions of time and space, explaining the inconsistencies and contradictions found in different Spanish sources (Villarías Robles, 2004). Contrasting with this approach is the more mainstream stance of historicists, most notably John Rowe (1946), who agree that the linguistic and cultural barriers inherent to Spanish-indigenous interactions limit the insights to be gained from documentary analyses. However, advocates of the historicist approach maintain that these sources provide a wealth of information about Inca political economy, ideology and everyday life when examined with a critical eye. This is especially useful if one analyzes documentary sources in conjunction with archaeological data (Julien, 1983; Malpass, 1993) while paying attention to the seemingly mundane details underplayed or overlooked by the Spanish (Julien, 2000). Over time, researchers began to examine the Inca as a product of its Andean context, revealing through archaeological and ethnohistorical analyses that much of Inca statecraft followed, or sprang from, Andean patterns of cultural ecology and political economy originating thousands of years before the rise of the Inca state (Murra and Wachtel, 1986). To understand these Andean patterns requires examination of the ways that Andean cultural evolution operated within these ecological opportunities and constraints.

Paleoclimate data from the Quelccaya Ice cap of the Eastern Andean Cordillera suggests an overall long-term consistency and stability in the central Andes over the past 1500 years, punctuated by El Niño Southern Oscillation (ENSO) events and other episodes of climatic upheaval (Chepstow-Lusty et al., 1998; Shimada et al., 1991). During these disruptive events, the western Andean slopes are hit by flash floods and torrential rains, while the southern highland sierra and altiplano endure droughts. These periodic changes in regional climate have in part impacted the cultural development in the Andes. For example, climatic and archaeological data (Moseley, 1992; Shimada et al., 1991 and see below) point to periodic, often-severe droughts from AD 524 – 645 followed by torrential flooding from an El Niño, coinciding with the collapse of the

Moche polity in northern Peru, relocation of the Nazca polity of southern Peru, and shifts in power to the burgeoning Wari state. Seltzer and Hastorf (1990) point to a cooling in the central Peruvian highlands during the late thirteenth century, which they argue may have exacerbated political instabilities throughout the central Andes. Based on analyses of shellfish middens, Moore (1991) suggests an ENSO event circa 1300-1350 AD, coinciding with increased political instability between multiple competing states in the Late Intermediate Period . As we shall see, the geological, ecological and climatic contexts of the central Andes created critical constraints that have strongly shaped the cultural evolution of Andean civilizations.

Cultural Adaptation and Evolution in the Central Andes

The rough terrain, altitudinal extremes and climatic diversity of the Peruvian Andean landscape created substantial constraints on settlement, subsistence and mobility of indigenous Andean peoples over the nine millennia of habitation in the region (Verano, 1992). These constraints led to a number of political, economic and ideological systems that feature in Andean civilizations across geographic space and through time (Moseley, 1992; Murra, 1980) that has persisted in some areas into present day. At the center of this pattern is the notion of ecological complementarity, where groups effectively simultaneously utilize different aspects of the varying Andean landscape. The cold-current upwelling of the Peruvian, Chilean and Ecuadorian coasts have produced rich fisheries and salt deposits in coastal regions. In the highland sierra, the altitudinal gradients of the Andean cordillera results in horizontally-stratified ecological zones, each of which permit the cultivation of different resources. Coca and chili peppers are cultivated along lower altitudes, while corn, legumes, gourds and grains such as *kiwicha* and *quinoa* flourish in the temperate quechua zone (7,500-10,500 ft. abs). The many varieties of potato and other tubers indigenous to the Andes are cultivable in the *suni* zone (10,500-13,000 ft. abs) (National Research Council, 1989). The high elevation of the *puña* and *altiplano* (13,000-16,500 ft. abs) are too marginal for most food crops, but the abundant scrub grasses are used to pasture llamas and alpacas, the only large domesticates in the western hemisphere, as well as wild vicuñas. Andean groups have for millennia circumvented the limited horizontal space for agricultural fields by digging agricultural terraces into the slopes of mountains, opening up a substantial amount of arable land for agriculture and cultivating crops in multiple ecological zones. Intensive irrigation of highland rivers has created viable agricultural land in arid areas such as the coast and drier areas of the sierra (Moseley, 1992).

Murra (1980) has presented a highly influential highland economic model in which ethnic groups in the southern highland sierra maintained control over a larger and more diverse resource base by sending colonies of people to different altitudes and distributing the products from these various altitudes among the population as a whole, forming a "vertical archipelago." In this way, communities could effectively produce and utilize resources from multiple ecological zones, maintaining self-sufficiency without the need for markets or seasonal migration. Within this system, practices such as "energy averaging" (Isbell, 1978) in which surplus crops and meat from productive years was stored in processed, dried form as a patch for lean years, helped maintain community supplies.

Rostworowski de Diez Canseco (1999: 209-214; 1977) proposes an alternate "horizontal" economic model for the resource-rich coastal regions that emphasizes local maritime and agricultural specialization among and trade between different ethnic groups, especially along the coasts of northern Peru and Ecuador. Similarly, Moseley (1992: 146) suggests a "maritime-oasis" model for coastal regions of economic specialization in marine *or* coastal valley spheres. Communities would specialize in maritime or agrarian production and then engage in reciprocal exchange rather than market trade (see also McEwan, 2006: 85). These models provide useful frameworks for looking at the variation in economic organization of the different regions of Peru, and for understanding the similarities and differences in cultural practices among early complex societies and later with the Inca.

A key component of these Andean economies, especially the vertical archipelago of the Andean highlands, is the concept of the *ayllu* (Rowe, 1946: 252-256). *Ayllus* are kin collectives, made up of households who engaged in economic reciprocity and communal resource management. *Ayllus* still persist in modern Peru, but stem broadly from an ancient Andean institution comprised of distinct male and female lineages with endogamous marriage (Rowe, 1946: 255). Isbell (1997: 136-139) argues that the *ayllu*, grounded in veneration of a single, common ancestor mummy, first arose in response to the hegemony of early states and is not comparable to characterizations of modern *ayllus* as collections of households. However, Moseley (1999) strongly (and entertainingly) rejects this argument as unscientific and contradictory, while nonetheless noting the complex and dynamic nature of *ayllu* institutions over time.

Generally, ownership of lands and resources lay with the local *ayllu* rather than with individual households and access to *ayllu* lands were shaped by separate lines of inheritance among male and female moieties. *Ayllus* were governed by a pair of *curacas*, hereditary rulers from each moiety who claimed descent from the founders of the *ayllus*. *Curacas* could be either male or female, though they were generally male. Importantly, the *ayllu* operated on a system of *mit'a*, or obligatory labor. *Ayllu* members worked communal lands and pooled the surplus of their labor, which was then redistributed by *curacas* throughout the community as gifts at feasts and ritual celebrations. At a super-community level, groups obliged labor and labor products to regional centers, in exchange for finished goods and foodstuffs redistributed by local or regional *curacas* (Murra, 1980: 97, 121-134). This practice of tribute by labor rather than taxation facilitated large-scale storage of surplus at regional centers, the construction of impressive monumental architecture, and military campaigns (Moseley, 1978; Moseley, 1992; Rowe, 1946: 228).

In a vertical archipelago economy, the *ayllu* institution was particularly salient because a single *ayllu* could colonize land at different altitudes and distribute resources from different ecological zones. The non-mercantile nature of highland Andean economies suggest unique "fields of power" (Goodman et al., 1995), where power rested not in the ability to exact currency or resources, but rather to organize the labor efforts of constituent groups through labor reciprocity. The relatively greater labor specialization on the coast within a horizontal model of trade networks likely created power dynamics that were distinct from those in highlands, whereas the vertical archipelago system resulted in more extensive labor practices and less-developed trade networks (Stanish, 2001b).

These fundamental concepts underscore the cultural evolution of the Andes, providing common political and economic themes that are archaeologically and, in the early colonial period, ethnohistorically visible. The intensification of agropastoral subsistence practices in the highlands and presence of sedentary populations in the highlands and on the coast certainly have origins in the Initial Period (ca. 2085±35 – 1400±100 BC) (Moseley, 1992; Verano, 1992). It was during this period that intensive irrigation, terraced mountainside fields, heddle loom weaving, ceramics and other economic innovations first appear, coinciding with population growth and the progenitors of large-scale civilizations. Using Rowe's (1965: 194) chronological model, the cultural evolution of the central Andes is grouped into cultural horizons of integration punctuated with intermediate periods of fragmentation and relative instability.

The earliest evidence for the political, economic and social organization that characterizes later Andean statecraft lies with the Chavín of the Early Horizon (1400 ± 100 BC – 395 ± 25 BC). With the Chavín culture of northern Peru emerged widespread architectural, iconographic and ceramic styles that suggest a substantial integration of Peruvian groups under a similar cultural umbrella by 400 BC (Burger, 1992; Lumbreras, 1989). Later centuries saw the rise of the Moche of northern Peru and the Nasca and Paracas of southern Peru during the Early Intermediate Period (395 ± 25 BC – AD 540). The Tiwanaku of far southern Peru and Wari of south-central Peru followed during the Middle Horizon (AD 540 – 900); following their collapse, the resulting vacuums of power were filled by over one dozen polities, including the Chiribaya, Chimu, Lupaqa and Colla of the Late Intermediate Period (AD 930 – 1476) (Moseley, 1992). All of these civilizations can be broadly grouped into coastal or highland civilizations with maritime or intensive agricultural specializations, respectively (Parsons et al., 1997; Stanish, 2001b), but with substantial regional diversity within this broad dichotomy (D'Altroy, 1997; Moseley, 1992; Vreeland Jr., 1998). By the sixteenth century, the Andes had seen the rise and fall of several of the most complex indigenous states in the Western hemisphere, culminating with the Inca. There is some debate as to when the Inca established themselves as an expansionist imperial state; Rowe (1946: 200) and McEwan et al. (2002) argue that Inca imperialism began in the 1400s and was facilitated by remnants of earlier Wari and Tiwanaku state infrastructure, while Bauer and Covey (Bauer, 1992; Bauer and Covey, 2002) argue that Inca imperialism began earlier in the Late Intermediate Period (AD 930 – 1476) and expanded gradually before becoming fully realized during the Late Horizon (AD 1476 – 1532). One can generally state that the Inca civilization originated in the central Peruvian Andes during the Late Intermediate Period, circa AD 1200 (Rowe, 1946), and reached its zenith during the Late Horizon, in effect ending in 1532 with the arrival of Pizarro. At the time of European invasion, the Inca controlled perhaps one million square kilometers (Stanish, 2001b) connected by over fifteen thousand kilometers of roads and ruled by a royal elite in the capital of Cuzco in the southern Peruvian highlands (Rowe, 1946).

Continuity and Change: The Rise of the Inca State

At the turn of the fifteenth century AD, the Inca were merely one of several polities in the south central Andes. While Inca oral tradition recorded in Spanish colonial documents points to Sapa Inca Pachacuti as the originator of the political, economic and administrative features of the Inca state noted above (Rowe, 1946: 204-205), it is clear from the preceding discussion that state-level organization was present in the Peruvian Andes long before the Inca rose to power. Moreover, archaeological and ethnohistorical research shows that *Tawantinsuyu*, far from a pristine state, was firmly rooted in long-present aspects of Andean political economy.

All areas brought under Inca control were subject to state authority and labor taxation, the latter of which was a modification of the preexisting institution of *mit'a* labor on *ayllu* lands. Local lands in subjugated areas were immediately claimed by the state and divided into three parts: one belonging to the state, one belonging to the state religious institutions, and one belonging to the local community. Taxation was not framed as material tribute, but rather as labor; members of local communities worked state lands, the products of which were appropriated directly by the state, and sustained themselves on the products of their own lands (Cobo, 1890-1895 [1653], book 12, chapter 28). There was no Inca market economy and very little evidence of trade in the highlands (Murra, 1986); D'Altroy and Earle (1985) stress that the Inca state was one based on staple finance, i.e. agricultural products and utilitarian goods produced through the labor tax and moved through the empire by a vast network of roads and storehouses. In return for these goods, the state supplied *chicha* (maize beer) and gifts of textiles and other finished goods at large state-sponsored feasts, rituals festivals, echoing ancient Andean customs of the reciprocal obligation of local lords to their community. In fact, Morris (1986) argues that the impressive network of storehouses that so awed the Spanish upon their arrival in Peru were not used to provision the military or the state bureaucracy, but rather to supply these obligatory feasts and festivals. By modifying this large-scale system of reciprocal *mit'a* labor, the Inca kept subordinate groups economically independent from each other but dependent on the state, a strategy that fostered amicable relations between subject communities and the capital of Cuzco.

Other Andean cultural norms were maintained as well, chief among them the notion of duality, a system that Burger (1992) argues originated in Chavín and which was present in pre-Inca states such as the Chimu of the north coast (Netherly, 1990). The dual descent and inheritance along male and female lines that characterized *allyu* organization was maintained in Inca imperial structure, as Silverblatt (1978: 51-3) points to the presence of female *curacas* in Inca-controlled provinces and the function of the Inca queen, or Coya, as heading a separate chain of command over female concerns in Cuzco. The duality inherent to the upper hanan (political) versus lower hurin (religious) halves of Cuzco prompted structuralists (Duviols, 1979; Zuidema, 1964: 127) to argue for the existence of a diarchy involving both hanan and hurin Sapa Incas (literally, "unique Incas," used to describe the Inca kings). However, multiple rebuttals have effectively moved this hypothesis to the margins of Andean research; Gose (1996) points instead to complex manipulation of Inca elite authority via governors and "substitutes" within a strong monarchy.

With this continuation of ancient traditions, however, are aspects of Inca statecraft that dramatically altered pre-existing cultural norms. One such example is that of ancestor worship, where varied and sophisticated forms of mummification ensured that the remains of family members could remain part of the community; serving as intermediaries between the living and supernatural, the deceased often took part not only in their own mortuary rituals but in future rituals and festivals as well (Dillehay, 1995). While aspects of ancestor worship varied through time and by region, the institution of venerating ancestors as still-active members of communities was a central aspect of Andean life. Conrad and Demarest (1984) argue that the explosive expansion of the Inca state was catalyzed by a radically different form of ancestor worship. In *Tawantinsuyu*, each new Sapa Inca rose to power with only his title; the lands and assets of the previous king remained in his control until his death, when they were transferred to a special wing of the royal family called a *panaca*. Each Sapa Inca's *panaca* maintained his lands and estates for his mummy, which retained a position of power and prominence as if he was still alive. Conrad and Demarest argue that the meteoric expansion of the Inca state resulted from this practice, in which each succeeding Inca had to acquire his own material wealth, not only to support his household and fund political activities, but also as visible symbols of his prowess and power. The grand royal estates of the Sacred Valley in central Peru, including such architectural masterpieces as Machu Picchu and Ollantaytambo, were among the products of imperial expansion, as each new Sapa Inca sought to establish grand symbols of his rule. This impetus to amass land and material symbols of power also led to near-constant, far-flung military campaigns and growing instability in later decades of the empire. In their model, the authors argue that the Inca substantially reworked the Andean practice of ancestor worship in such a way as to forever alter the modes of expansion and necessitate effective strategies for governing the large populations brought under Inca control.

The early twentieth century saw avid debates about the nature of Inca political economy and administration, with competing portrayals of the Inca state as a Marxist regime (Patterson, 1991), benevolent dictatorship, socialist welfare state, and European-style empire (D'Altroy, 1992: 2). However, what has emerged from decades of research is a picture of the Inca state that while unique in several key aspects, followed a pattern not unlike other secondary empires. One fundamental aspect of Inca statecraft was its flexibility, a critical feature given the enormous size of *Tawantinsuyu* and diversity of the populations brought under its rule. Menzel (1959) argued that the nature of Inca conquest varied from region to region depending on the forms of local political organization that existed prior to the Incas' arrival. This was echoed by Dillehay (1977), who examined variation in Inca settlements in the coastal Chillon Valley of Peru and noted that the Inca strategically located administrative centers so as to control key resources and minimize local conflict. Heffernan further supports this in his analysis at Limatambo, 50 km outside of Cuzco, the landscape of which contained several large Inca structures, providing "visual symbols of Inca influence in the periphery of Cusco" (Heffernan, 1996: 159). Bauer (1992) and Bauer and Covey (2002) model the rise of the Inca state, through ceramic analyses of Cuzco's hinterlands, as a complex and flexible integration of regional ethnic groups that began well before Pachacuti's meteoric rise to power. While the timing of Inca establishment as an imperial state is debated (see above), an initial flexibility may have underscored political, economic and ideological strategies for integration into the burgeoning Inca state, and may have been drawn from earlier forms of statecraft. In an in-depth processual analysis of Inca statecraft through archaeological analyses of the Upper Mantaro Valley in Central Peru, D'Altroy (1992) emphasizes the flexibility of Inca conquest and occupation of various provinces of Peru. Employing a territorial-hegemonic continuum, D'Altroy argues that the Inca recognized the threat of force as more politically useful than exercised force, a notion echoed by Morris (1998). Provinces that willingly submitted to Inca rule were assimilated with minimal alteration of their political systems; their leaders were granted status in the Inca nobility or replaced with an Inca noble. In fact, Salomon (1986) argues that the Inca specifically maintained the authority and privileges of local lords in frontier areas so as to entwine their legitimacy with Inca state institutions. Subjugated groups that saw total overhaul of their political and economic systems were either those that lacked centralized political structures and had them installed by the Inca (Morris, 1998), such as the Chachapoyas in eastern Peru (Pease, 1982), and/or those that resisted Inca rule. The ways in which various regions were incorporated and controlled by the state was also dictated in part by their respective relationships with Cuzco (Julien, 1988). In comparing modes of Inca administration in different regions of Peru, Pease (1982) distinguished economic domination, where the state appropriated lands and superimposed their taxation system on an otherwise unchanged society, from more intrusive political domination. He emphasizes economic domination and only indirect rule among societies such as the *altiplano* Lupaqa, who actively consented to the Inca state. Aside from resource extraction by the Inca, the Lupaqa economic system and power structure were left largely unchanged and they maintained their influence over the Titicaca region. Conversely, the Chimu state of Chimor in north and central coastal Peru violently resisted an Inca presence, prompting decisive military action and a substantial Inca political domination in Chimu territories. Chimu populations were forbidden to carry arms, were not drafted into military service, and Chimu regions saw a marked depopulation as many residents were forcibly relocated to other regions of *Tawantinsuyu* as part of a disproportionately heavy labor tax. Other areas saw an overhaul not of their political systems, but their economic activities, as the state increased production of specific crops such as maize (Hastorf, 1990) and other goods for state purposes. Still others, such as northern Ecuador, maintained patron-client relations with the centralized administration in Cuzco but were not directly assimilated into the Inca state (D'Altroy, 1992: 133).

Other forms of direct control were more subtle, involving the manipulation of materials and symbolic forms. Jennings (2003) suggests, based on his analyses of ceramic iconography, that the Inca suppressed local cultural practices that ran contrary to imperial doctrine by altering the stylistic and symbolic forms present on local vessels and plates. In the Upper Mantaro Valley, D’Altroy and Bishop (1990: 133) posit clear distinctions between local Wanka and Inca corporate ceramics in materials, style and distribution, suggesting strict Inca control over production in the region. Ogburn (2004) argues that the transport of massive, finely-cut stones from Cuzco to urban centers in Ecuador for building projects represented a replication of Cuzco’s power and sanctity in a far-flung imperial province. Further, because there were no wheeled apparatuses or beasts of burden to accomplish this task, Ogburn emphasizes that moving these stones through human labor over such a long distance was an obvious display of Inca power and control over resources and labor. Inca manipulation of material culture was not universally intrusive, however; for example, Alden and Lynch (2006) point only to indirect influence over pottery styles in northern Chile. The Inca state therefore relied on a flexible mode of control during the early decades of the empire, using varying degrees of hegemonic and territorial control to effectively assimilate, subjugate, maintain compliance within and extract economic labor from politically and economically diverse groups throughout the central Andes.

This varied, adaptable mode of statecraft is not unique to the Inca. As described by D'Altroy (1992) in his comparison of the Inca and other states, Luttwak's (1976) nuanced analysis of Imperial Rome identifies distinct strategies employed in three separate periods from the 1st though 3rd centuries AD. During the early stage of the imperial era, Rome employed a distinctly hegemonic strategy of indirect rule, leaving subjugated client states mostly autonomous so long as tribute and military service were provided. It was only in the later periods of the empire that Rome became more directly territorial in exerting authority over its subjugated regions amid mounting instability. Luttwak emphasized Rome's effective use of force as a political tool and its reliance on implied threats rather than direct force as a key to its success. Further, Smith and Berden (1996) point to a pattern of indirect rule among the Triple Alliance, of which the Aztecs were the most powerful member, in Precolumbian Mexico; the authors posit that the imperial strategies employed by the Triple Alliance varied by locale, depending on available tributary resources, threat of revolt, and local systems of governance. Berden (1996) further explores this strategy of indirect rule, arguing that city states under Aztec control were typically allowed to retain their local power structures, but were tied to state authority through marriages and reciprocal gift exchange. The author stresses that the main purpose of Aztec domination of an area was to extract tribute in the form of goods and occasionally as labor or military service; as long as this was satisfied, conquered territories were mostly left alone.

While no written information exists for pre-Inca states, the presence of complex knotted cords used for administrative recordkeeping, called *quipu*, in both Inca and earlier states dating back to the Middle Horizon, point to administrative features of *Tawantinsuyu* that have earlier precursors. Rowe (1946), for example, suggests that features of the Inca administrative system were drawn directly from the Chimu. Moreover, a wealth of archaeological evidence suggests that similar forms of statecraft existed among earlier Peruvian states. The Wari state of the central Peruvian highlands is regarded as the first expansionist Peruvian empire and the smaller-scale antecedent to *Tawantinsuyu* (McEwan, 2005a). The Wari, like the Inca, boasted militaristic and economic expansion, complex administrative structures requiring enormous labor pools (McEwan, 2005b), and varied degrees of control among the different regions subsumed under Wari control (Schreiber, 1992). Its contemporaneous rival, the Tiwanaku state of the Lake Titicaca region, also employed varying degrees of control, cultural influence and colonization in subjugating Bolivia, southern Peru and northern Chile for resource extraction (Knudson, 2004; Moseley, 1992).

Population Movement and Political Economic Change

Also not unique to *Tawantinsuyu* was the large-scale movement of people for various state-related reasons. McEwan (2005b: 81-83) estimates a labor cost for building the site of Pikillacta near Cuzco that would have required many thousands of workers over several years, an endeavor made all the more impressive with the discovery of an equally large, contemporaneous Wari compound 15km away in the village of Huaro. Luttwak (1976) noted that the sheer size of the Roman army and its supply train meant that thousands of males moved throughout the empire through their employ as professional soldiers. Skinner (1977) and Mote (1977) both describe the movement of people, especially males, from rural to urban contexts in late imperial China to participate in the market economy. The importance of the Chinese market economy was such that while ethnic identity was technically tied to one's geographic residence, it was more strongly shaped by one's position in local and regional economies, providing major impetuses for individuals to migrate to other regions for trade and labor specialization (Leong, 1997). The market economy as a driving force in population movement is also seen in the pre-contact western hemisphere. Though its economy was based partly on tribute, Hassig (1985) emphasizes the equal importance of markets to the imperial structure of the Aztec Triple Alliance; markets were such an integral part of the Aztec economy that attendance at them was mandatory, spurring population movement for state-regulated economic purposes. In addition, thousands of individuals moved about the Aztec state as part of corvée labor, forced military service and merchant-spy networks for the elite, as well as to colonize hinterland territories (Hassig, 1985). In North America, owners of rice plantations in North Carolina specifically purchased slaves from particular regions of West Africa known for rice cultivation, harnessing not only the labor but the specialized knowledge and expertise of African rice farmers (Carney, 2002). Slightly later in US history was the dramatic, large-scale relocation of the Cherokee Nation by the US government; underneath its moral rhetoric of progress versus savagery, the Trail of Tears was primarily a tactic to free up arable lands and mineral mines for white settlers (Remini, 2001; Shadburn, 1989).

In the central Andes, population movement has a long history with pilgrimage to sacred or ritual centers and colonization of areas for economic production. The colonization of different ecological zones outlined in Murra's vertical archipelago model meant the long-term or permanent relocation of community members to diverse areas. Further, Von Hagen and Morris (1998) echo Burger (1992) in arguing that early urban structures in the Andes such as Chavin de Huantar functioned more as large-scale pilgrimage sites than fully-developed cities with permanent populations, underscoring the importance of spiritually-motivated long-distance travel.

With the rise of complex societies such as the Moche (Billman, 1997; Donnan, 1978; Donnan, 2004; Schaedel, 1951; Shimada, 1978; Shimada, 1994), Wari (Cook, 1987; Cook, 1994; Glowacki and Malpass, 2003; Glowacki and McEwan, 2001; Isbell and McEwan, 1991; Isbell and Schreiber, 1978; Schreiber, 1992) and Tiwanaku (Browman, 1978; Browman, 1980; Janusek, 2002; 2004; Kolata, 1993), one sees many aspects of population movement that are echoed in later periods, culminating with the policies of *Tawantinsuyu*. State cooptation of *mit'a* reciprocal labor would potentially have been present in order to carry out large-scale military campaigns and building projects. D'Altroy (2001: 455-9) cites archaeological evidence for the large-scale movement of laborers by the Moche for monumental building projects, as well as evidence for Wari and Tiwanaku colonies on the central and southern Peruvian coasts, respectively.

However, two features of Inca population movement make it so unique and significant to the political economy of *Tawantinsuyu*. First is its sheer scale. The Inca forcibly relocated hundreds if not thousands of households elsewhere in the empire to quash pockets of resistance (Pease, 1982), relocate labor specialists to areas where their skills were needed (Espinoza Soriano, 1973), and mobilize an enormous pool of labor for building projects and the production of staple goods that formed the basis of the state economy (Morris, 1998). This large-scale movement of people by the state reached its zenith under Inca Huayna Capac, who relocated an unprecedented fourteen thousand colonists to the depopulated Cochabamba Valley for tributary labor. More generally, Rowe (1982: 107) estimates that anywhere between ten and eighty percent of the population in a given area of Incaic Peru consisted of non-local colonists installed by the state.

The second feature of Inca population movement is its dynamic relationship to state social status. Social classes in *Tawantinsuyu* were typically but not strictly hereditary, and though class stratification was marked and rigid, to some extent social status could be achieved by merit or political maneuvering rather than exclusively by birthright (Cassman, 2000). Moreover, individuals could simultaneously belong to multiple social classes. For example, commoners were typically referred to as *hatun runa*, who worked state lands as part of *mit'a* obligations to the state and otherwise lived fairly independently. It was from this labor pool, however, that community members were drawn as *mitimaes*, colonists who were relocated temporarily or permanently to other parts of the state for agricultural work, military service, construction or other forms of labor tribute. *Mitimaes* were likely an ancient Andean institution as part of the larger *mit'a* labor system and highland strategy of vertical archipelagos, distinguished by their immigration to distant areas for labor service. However, under the Inca this institution was expanded exponentially, in terms of numbers and geographic distances. *Mitimaes* were obliged by the state to retain the dress, hair styles, and other visible signs of their cultural ethnicity and were provisioned by their *ayllus* for the first year or two of their service (Rowe, 1982), after which they were largely self-supporting on lands allocated to them by the state (Rostworowski de Diez Canseco, 1999).

Perhaps the least understood Incaic social class was the *yana* class (Rowe, 1982). *Yanacona* (plural) were individuals, mostly males (Silverblatt, 1978) selected from the *hatun runa* as well as the provincial elite to serve as retainers to the Inca nobility. The *yanacona* are portrayed in many Spanish chronicles as slaves and are dealt with by some researchers as a lowly, degraded class based on the fact that the Quechua term *yana* translates to “black” (Silverblatt, 1978). However, in an in-depth analysis of the term *yana* and the functions of *yanacona* in the Inca state, Villar Cordova (1966) argues that the *yanacona* were not slaves, but members of a special class whose exclusive functions were to serve Inca elites. The author recounts a passage in a chronicle by Sarmiento de Gamboa in which Inca Tupac Yupanqui led an army to the site of Yanayaco, which means Black Water, and violently put down a local rebellion. The Inca pardoned those surviving nobles who led the revolt, making them servants and branding them with the name *yanacona* as a mark of shame. Villar Cordova (1966) further argues that *yana* status evolved over the Inca period from a punitive label to an honored position bestowed on the leaders of conquered groups and exceptional commoners. *Yana* functions included agricultural work on royal estates, attending nobles on expeditions and military campaigns, carrying out administrative tasks, and even serving as local curacas in Inca provinces. More importantly, however, what distinguished that *yanacona* from almost all other nonelite social classes was (1) that they were relocated as individuals and (2) that they were totally removed from their *ayllu* networks. It should be noted that this pattern is also present among the *aclla*, or chosen women, an Inca social class that could be consider the female analog to the mostly-male *yana* class (Silverblatt, 1978). *Aclla* were women chosen by the Inca nobility for their beauty and talent, who were housed together in *acclawasis* in Cuzco and other Inca centers to weave cloth, brew *chicha* beer and serve as wives in marriages arranged by the nobility (Rostworowski de Diez Canseco, 1999; Silverblatt, 1987). Often, *yana* were given wives from among the *aclla* as rewards for their loyalty and service, and so when one discusses the *yanacona* as a group, it can be assumed that at least some *yana* households likely included *aclla* as well. *Yana* and *aclla* were selected as individuals by the Inca nobility and taken from their region of origin, unlike the *mitimaes*, who were moved about the state in large groups. This distinction is noted by Rowe (1982), who postulates that populations of *yanacona* households likely had wide variation in individual backgrounds. This isolation within one's population was further enforced by the detachment of *yana* and *aclla* from their *ayllus* and lineage networks. Unlike the *mitimaes*, these servant classes were wholly dependent on the resources of the state, and their labor did not factor into the reciprocal relations shared between the Inca nobility and their original kin groups (Rostworowski de Diez Canseco, 1999).

This severing of kin ties and dependence on the state came to play a significant role in the state political economy as *Tawantinsuyu* continued to expand and consolidate its rule in the Andes. Because *yana* and *aclla* labor was not counted in tallies of labor tribute for their native *ayllus*, it was also not counted in the reciprocity owed to those *ayllus* by the state as part of the *mit'a* system. The Inca nobility were thus able to in part circumvent their responsibilities to their subject provinces, in effect creating loopholes in an ancient labor contract. In later decades of *Tawantinsuyu*, even the *mitimaes* were effectively detached from their *ayllus*; as colonists often sent to regions far removed from their homes, *mitmacona* were less and less able to maintain kin ties with those who remained as well as those households sent as *mitimaes* elsewhere (Murra and Wachtel, 1986). Murra (1980; 1982; 1986) and later D'Altroy (1992; Earle et al., 1987) argue that later decades of *Tawantinsuyu* saw a shift from indirect, hegemonic rule to increasingly direct, territorial control over the various regions of the empire, based on ethnohistorical and archaeological analyses. Mechanisms by which the state could extricate itself from its reciprocal obligations to, and foster dependency among, the populace would have greatly facilitated a transition towards what D'Altroy and Earle (1985: 190) call increasingly "monetized" economic relationships. The rapid increase in the number of *yanacona*, *acllacona* and ultimately *mitmacona* late in the empire (Rostworowski de Diez Canseco, 1962: 133; Rostworowski de Diez Canseco, 1966: 32; Rowe, 1946: 268-70) as producers dependent on the state and removed from their kin networks, was likely a very effective strategy. This seems especially likely given the growing political instability of the latter decades of *Tawantinsuyu*: rapid expansion, far-flung military campaigns, and growing factionism among the Inca nobility undermined the stability of the state, culminating in a devastating civil war during the 1520s (Rowe, 1946: 208-9). *Yana* and *aclla* status was considered an honor, and service with the *mitmacona* was considered part of *mit'a* tribute. The state was able to co-opt ancient labor relationships and use them to completely alter their functions so as to benefit an increasingly unstable state at the commoner *hatun runas'* expense (Conrad and Demarest, 1984).

Tracing the movements of these servant classes in *Tawantinsuyu*, both geographically and over the course of the Late Horizon, would therefore help shed light on shifts in the state political economy, specifically the relationship between the state and its labor force. Further, Rowe (1948: 47), Murra (1972), Rostworowski de Diez Canseco (1999: 174) and Villar Cordova (1966) all recognize the possibility, even probability, that these Inca social classes had precedents in earlier states such as the Wari or Tiwanaku. Conversely, Topic (2003: 269) contrasts the dispersal of people throughout the Inca state with the Chimu practice of concentrating conquered artisans in the capital of Chan Chan, pointing to variation in the mechanisms of statecraft between the Inca and earlier polities. However, Rowe (1982: 97) laments the ambiguity in colonial documents regarding Inca social classes, noting "Rarely is a complete explanation [of these statuses and their overlap] called for or furnished [in Spanish colonial documents]." D'Altroy (2001: 461) also emphasizes the importance of mobile labor classes such as the *mitimaes* while acknowledging their near invisibility in the archaeological record. Cahill (1994) further emphasizes that the complexity of population movement under the Inca renders associations between ethnicity and social class ambiguous at best. This suggests that the genetic or morphological markers typically used to identify immigrants in archaeological populations would fall short of differentiating different social classes based on physical features (see Chapter 4).

This study aims to address this issue through isotopic and osteological analyses of the skeletal population from the Inca royal estate of Machu Picchu, in the Sacred Valley of the southern Peruvian highlands. While isotopic methods have been used effectively in other areas of the world and other time periods of Andean South America to address questions of population movement, these techniques have never been used to reconstruct status-related migration in Inca populations. The Machu Picchu population provides a unique opportunity to initiate this sort of research in the Inca archaeological record because (1) it is a large, well-preserved population and (2) it has abundant archaeological and ethnohistorical context. Based on their analyses of burial styles and associated artifacts, most of which were varied and utilitarian, Burger and Salazar (2003) postulate that the Machu Picchu population consists of *yanacona*. This is supported by ethnohistorical data (Villar Cordova, 1966) that lists service and agricultural work on royal estates as one function of the *yanacona*, though local *hatun runa* and *mitimaes* may have worked these estates as well (Ortiz de Zuñiga, 1967: 25-6). Therefore, independent lines of evidence suggest that this skeletal population is comprised of *yanacona* and *acllacona*, *mitimaes*, or some combination thereof. The analyses performed in this study (see chapters 3-5) therefore test these hypotheses using isotopic and osteological analyses of skeletal material that trace individual migratory and dietary histories. By firmly rooting individuals in their ecological and geographic contexts, this study analyzes the distribution of migratory data within individual life spans and across the population, working with the assumption that the shapes of these distributions will vary depending on the social class(es) of its constituents. By providing these independent measures, most of which are derived from no more than a few teeth per individual, this study opens the door to further research on less contextualized or poorly preserved remains. It provides an analytical template by which to build migratory data throughout Andean South America from which to better understand the origins, nature and political economic evolution of these ultimately pivotal social classes.

Chapter 3: Study Design

Introduction

This study is based on research conducted between 2004 and 2006 at the Yale University Peabody Museum of Natural History in New Haven, CT, as well as the Department of Cuzco, Peru, Emory University in Atlanta, GA and the University of Florida in Gainesville. It utilizes biochemical and osteological parameters to directly measure migratory history, dietary composition and physiological stress across individual life spans in a large, well-preserved skeletal population of non-elite residents from Inca Pachacuti's royal estate of Machu Picchu. The site is located in the Urubamba province of the Department of Cuzco in southern-central Peru, was constructed during Inca Pachacuti's reign and was inhabited approximately between 1450 and 1570. Archaeological and ethnohistorical data led Burger and Salazar (2003) to suggest that the Machu Picchu population consisted of *yanacona*, members of a cosmopolitan, non-elite social class. Since *acllacona* were often awarded as wives to *yanacona*, in this scenario it is likely that *aclla* would have been present as well. However, other classes, such as *mitmacona* colonists or local *hatun runa* taxpayers, may have been present as well (Ortiz de Zuñiga, 1967; Rostworowski de Diez Canseco, 1999: 230).

Since the Inca assembled and moved *yanacona* and *mitmacona* about *Tawantinsuyu* in very different ways and for different reasons, accurately characterizing the migratory history of the Machu Picchu population would help elucidate the social class of its constituents as well as the state system that brought them there. Isotopic reconstructions of diet have become common in Andean research; however, isotopic research concerning immigration and population movement in the Andes is in its infancy. This study is the first to attempt to distinguish and characterize multiple social classes using a variety of direct, measurable physiological features in a Precolumbian Andean population and reconstructing the life histories of its constituents. The size, preservation and rich context of the Machu Picchu burials makes it ideal for this form of analysis, because it permits a multifaceted, multilayered data set in which the shortcomings of one set of are compensated for by others; however, is not common to Andean skeletal populations. Complementary techniques would be necessary to make similar hypotheses regarding the class identity of skeletal populations with more ambiguous contexts. This study is therefore also intended to serve as an analytical template from which other skeletal populations can be analyzed, the geographic origins and subsistence patterns of their members assessed, and hypotheses as to their ethnic, cultural and/or class affiliations tested.

Andean South America is characterized as an area of high ecological diversity within geographically small areas (Moseley, 1992). The coasts, altiplano and montane valleys are characterized by markedly different altitudes, climatic conditions and available resources, resulting in a varying reliance on terrestrial and marine resources, the cultivation of different crops, variation in trade networks and differential exposure to a variety of environmental insults. Depending on where individual *yanacona* and *mitmacona* groups originated, a skeletal population consisting of one or both classes likely consisted of individuals having very diverse backgrounds and who may have experienced differing magnitudes of life change as a result of their relocation; *yana* would show isotopic, osteological and artifactual variation on an individual scale, while *mitmacona* would vary less among individuals and more between groups. Local *hatun runa* taxpayers would fall within "local" isotopic ranges and vary less in osteological features and burial contexts (See **H_1a** below).

Variation in multiple isotopic measures within and among the individuals from Machu Picchu will be assessed relative to markers of ethnicity, status and health. These markers include dental pathology and wear, cranial deformation and cranial pathology (Verano, 2003a). Archaeological markers include published analyses of burial context, i.e. location, style and material accompaniments (Eaton, 1916; Salazar, 2001). To more clearly interpret the absolute variation in isotopic measures at different developmental stages, isotopic reference data are presented from analyses of water collected from Machu Picchu, staple crops from just outside of Cuzco, Peru, and from archaeological faunal recovered from Machu Picchu in addition to published data from fish and terrestrial fauna. These data are used to frame (1) the Machu Picchu "menu" and (2) the "local" geology and climate of the Machu Picchu site.

Stable isotope research has been used to assess subsistence strategies and in-migration among archaeological populations worldwide, relating these measures to material culture and markers of poor health to substantially increase what is known of prehistoric societies. This study explores these issues more systematically and at much greater depth than currently exists in published literature, by characterizing multiple isotopic indicators of diet and migration in skeletal tissues formed at different periods during *in vivo* development. Results include individual, longitudinal profiles of dietary intake and local environmental context. These are used to interpret changes in diet or residence locale during early life (i.e. the span of permanent crown development, 0-13 years of age), whether groups of individuals pattern those changes similarly, and how such changes relate to overall health and artifact-based indicators of status. Further, it integrates isotopic and osteological data to create a powerful data set from which to infer relationships between diet, movement, physiological stress and social status. It tests ethnohistorical and archaeological hypotheses that the skeletal population from Machu Picchu is in fact *yanacona*, and whether other classes such as *mitmacona* or local *hatun runa* are represented, further elucidating the nature and functional consequences of non-elite statuses.

This study is among the first to simultaneously characterize isotopic signals of *both* dietary composition and migration in an Andean skeletal population, using an in-depth, life-history-oriented framework. Isotopic studies of geographic origin and immigration are very new to Andean South America (Knudson, 2004; Slovak, 2007b; Verano and DeNiro, 1993), which is exciting given the potential of these techniques in a region characterized by a long history of conscripted labor, military campaigns, pilgrimages and trade networks (Moseley, 1992). The aim of this study is to establish direct assessments of migration, dietary composition and health from which to better understand the complex nature of the Machu Picchu skeletal population. Given the possibly high degree of admixture across Andean South America, this study also aims to provide criteria for future research in Andean bioarchaeology.

The Machu Picchu Population

Machu Picchu is a well-known Inca site located forty-three miles northwest of Cuzco in the Urubamba valley of southern central Peru (Figure 3.1). The site itself occupies a ridge abutting Huayna Picchu Mountain at an elevation of 2,430m above sea level (abs), in the lower *quechua* zone (2300-3500m abs) near its border with the *yunga* zone (1000-2300m abs), and was constructed ca. AD 1460-1470 during the reign of Inca Pachacuti as one of his royal estates. Following the conquest of the Inca state by the Spanish, Machu Picchu faded into relative obscurity before being "discovered" in 1911 by Hiram Bingham as part of a Yale University expedition (Bingham, 1979 [1930]). Excavations at the site led by George Eaton revealed three main cemeteries consisting primarily of above-ground interments in caves or under rock shelters, some of which contained multiple individuals (Figure 3.2). The interment styles and degree of preservation varied substantially at the site, the latter due in part to rodent scavenging (Miller, 2003). The 1912 excavation at Machu Picchu was comprehensive for its time, and the overall assemblage includes adults, children, infants and associated artifacts, faunal remains and detailed descriptions of individual context (Eaton, 1916). These data provide a wealth of indirect evidence for cultural affiliation, social class and other salient features. Moreover, the Machu Picchu skeletal population (N_{TOTAL}=177) has been described as one of the largest and best preserved in the pre-contact Andes (Verano, 2003a).

The styles of ceramics at Machu Picchu, which were widely distributed among the graves and elsewhere around the site, suggest elevated status among the individuals at the site, though none indicate Inca nobility or royalty (Bingham, 1979 [1930]). The human skeletal population interred at the site also displays variation in cranial markers of genetic affiliation, styles of cranial modification, and the prevalence of pathological conditions (Verano, 2003a). Based on these findings and Salazar's (2001) analyses of the varied and non-elite nature of associated grave goods, Burger and Salazar (2003) hypothesize that the individuals in the Machu Picchu skeletal population were *yanacona*, members of the *yana* servant class. This is supported by numerous ethnohistorical analyses of colonial documents, which describe the *yana* as a special class of servants removed from tributary and kinship obligations. de Santillán (1879 [1534]) described the *yana* as individuals hand-selected by Inca nobles for their beauty, talent or other qualities, made *curacas* (officials) in their home provinces or else relocated to Inca centers and royal estates to serve as exclusive retainers of the Inca nobility (Murra, 1982; Pease, 1982; Rowe, 1982). The composition of *yanacona* populations therefore differed from those in other Inca classes such as the local *hatun runa* (commoners), *mitmacona* (labor colonies usually comprised of uprooted and transplanted communities of *hatun runa*) and the Inca nobility. However, analyses of ethnohistorical accounts have suggested that *mitmacona* and local *hatun runa* were also present at royal estates (Rostworowski de Diez Canseco, 1999: 230) (Chapter 2), meaning that the Machu Picchu population could consist of more than one distinct servant class, each with distinct demographic compositions.

Study Context

Studies of the Inca state and its effects on subjugated populations have depended heavily on the anthropological study of early colonial documentary sources, starting with the seminal works of Rowe (1946), Murra (1966; 1980) and Rostworkowski de Diez Canseco (1966; 1970; 1999) and more recently by Julien (2000), Niles (1993) and others. Additionally, much knowledge has been gained by contextualizing the Inca within a broad framework of Andean chiefdom and state formation through analyses of architectural and ceramic styles (reviewed in D'Altroy, 1997). Explicitly bioarchaeological studies (reviewed in Verano, 1997) have elucidated regional and temporal patterns of demography (Drusini, 1991; Drusini et al., 2001; Owen and Norconk, 1987), quality of life (Allison, 1984; Benfer, 1984; Norconk, 1987; Ubelaker, 1984), warfare (Tung, 2004; Verano, 2001), sacrifice (Verano, 1995; Verano, 2003b) and medical treatment (Verano et al., 2000). Greater efforts to explore regional variation in Inca influence directly juxtapose ethnohistorical accounts with analyses of material culture (Bauer and Covey, 2002; D'Altroy, 1992; Earle et al., 1987; Hiltunen and McEwan, 2004; Julien, 1993; Malpass, 1993; McEwan et al., 2002; Niles, 1993; reviewed in Stanish, 2001b).

These varied data provide information on settlement patterns, subsistence activities, warfare, health, and culture change, crucial information that is often absent or vague in colonial documents. Together, these techniques have contributed greatly to theories of the complex nature of Inca expansion and political economy. However, assessing the effects of these processes on population movement and admixture has been difficult; studies of migration and population affinity have been somewhat problematic in reconstructing ancient trends in movement and admixture. For example, craniometric (Rothhammer et al., 2002; Varela and Cocilovo, 2002) (Rothhammer et al., 2002; Varela and Cocilovo, 2002) and nonmetric analyses (Sutter and Mertz, 2004) of similar populations in the Azapa and Atacama valleys of northern Chile have come to opposite conclusions regarding the nature of Tiwanaku influence in the region, despite arguments by both that the parameters utilized represent heritable features. Moreover, while genetic affinities may provide insights into long-term population admixture (Kato et al., 1995), they do not equate to individual movement(s) within and between regions during life. The analytical precision of genetically-based parameters in tracing individual and group-level geographic migration, especially if multiple migrations occur, is therefore limited. This in turn limits interpretations of manipulation by states of the populations they control.

In the case of the Inca, where forced relocation is documented, an inability to accurately estimate the nature and magnitude of population movement hinders potentially significant advances in understanding the inner workings of the Inca state (see Chapter 2). For example, increasing the numbers of *yanacona* and *mitmacona* during the Late Horizon allowed the Inca nobility to extricate themselves from traditional obligations to the commoners under their control, thereby using these two institutions to effectively cut ties with many of their subjects (Murra, 1966; Murra, 1972). By divorcing these individuals and groups from the ties and obligations to their *allyu* ethnic communities (officially with the *yana*, de facto for many far-flung *mitima* colonists) and removing them from the state system of tributary labor, the nobility were no longer obligated to provide the degree of resource reciprocation that would otherwise be owed taxpayers (Rostworowski de Diez Canseco, 1999). This was a significant alteration of an ancient and enduring system by which *hatun runa* households paid tribute to their kinship groups through temporary labor on communal lands and were in turn granted resources by the leaders of those kinship groups (Murra and Wachtel, 1986), indeed the very system on which Murra (1980) argued Tawantinsuyu was based. This drastic alteration may have reflected larger issues of land scarcity and rising political tensions during the later decades of the Late Horizon (Conrad and Demarest, 1984). Understanding the composition of these two classes and where they were placed geographically within Tawantinsuyu is therefore particularly important to gaining a better understanding of the Inca state system.

Research Design

The goal of this study is to create an in-depth, life-history-oriented characterization of those members of the Machu Picchu population with sufficiently preserved dentition and for whom sex and/or age can be defined (N=74 of 177 total), involving multiple isotopic and osteological variables. It produces ecologically-based human (N=74), faunal (N=4) and environmental data from the Machu Picchu region of subsistence and migration throughout life, and relates these to published archaeological data from the site. It also presents longitudinal profiles of diet, health and regional movement for each individual studied, including estimates of where each individual originated. This study tests three major hypotheses (**H_{1-3}**) centering on longitudinal dietary and migratory trends and health dynamics within the population.

Hypothesis 1 (H_1): Residential, early-life isotopic variation will be wide and stochastic among the Machu Picchu study population.

Values of $\delta^{18}O$, $^{20n}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ are analyzed as indirect measures of the local environment, incorporated into living tissues through consumed food and water. Although these ratios differ in their sources and thus their implications for migratory history, the climatological indicators measured in $\delta^{18}O$ and geological indicators measured in $^{20n}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ produce powerful complementary residence and migration data when interpreted in combination. Significant variation in these isotopic values related to cultural and behavioral variables (burial context and cranial modification presence/style) permits the identification and characterization of non-local versus local individuals using both quantitative and qualitative methods.

Yana populations were assemblages of *individuals* each relocated by the Inca from different regions of ethnic origin; *mitima* populations were groups of individuals relocated *as collective groups* from a shared region of ethnic origin; local *hatun runa* would not necessarily have immigrated from elsewhere. Therefore, if any or all of these social classes are represented in the Machu Picchu population, individuals are expected to cluster differently in isotopic and osteological parameters according to status. As the available evidence points more to the Machu Picchu population as a group of *yanacona*, it is hypothesized that $\delta^{18}O$, $^{20n}Pb/^{204}Pb$, and $^{87}Sr/^{86}Sr$ data will all show wide variation, as would be expected among a group of individuals with wide, individually-based differences in background. Signficant grouping among a large number, or even all, of individuals will be interpreted representing a *mitmacona* population or even local hatun runa. However, it is also hypothesized that:

> **(H_1a)** <u>The majority of the individuals in the population will display $\delta^{18}O$, $^{20n}Pb/^{204}Pb$, and $^{87}Sr/^{86}Sr$ isotopic data that fall outside of the estimated "local" range at Machu Picchu</u>, suggesting that they immigrated to the site from elsewhere.

Isotopic ratios in human tooth enamel (representing early-life periods), faunal enamel and water (representing local isotopic ranges at the Machu Picchu site) will be analyzed to trace the presence, timing and nature of individual migration from non-local regions of residential origin to Machu Picchu. Enamel representing different developmental periods spanning birth through early adolescence will be sampled from each individual, producing individual time-series of isotopic results.

(**H_1b**) Cranial modification and/or burial context will significantly covary with enamel $\delta^{18}O$, $^{20n}Pb/^{204}Pb$, and/or $^{87}Sr/^{86}Sr$.

This hypothesis will test for variation both between individuals and between groups within the study population. A key assumption here is that *yanacona* will show individual-level variation in early-life isotopic values and cranial modification styles, while any *mitmacona* present at the site will significantly cluster according to isotopic and cranial modification data in distinct subgroups. Further, the fact that *mitmacona* were considered a lower status than *yanacona* (Rostworowski de Diez Canseco, 1999) suggests that burial location within the site might vary between isotopically-determined *yanacona* and/or *mitmacona*. Isotopic data will therefore be statistically analyzed against categorical scores representing the presence and type of cranial modification (Verano, 2003a), and burial location among the Machu Picchu cemeteries (Miller, 2003)

(**H_1c**) Individual $\delta^{18}O$, $^{20n}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ will significantly cluster together, corresponding to specific regions of the central Andes, represented by $\delta^{18}O$, $^{20n}Pb/^{204}Pb$, and $^{87}Sr/^{86}Sr$ data from analyzed faunal enamel and water as well as published geochemical data. This permits some estimation of where, geographically, the individuals from Machu Picchu originated and whether they cluster into isotopically-distinct subgroups. However, $\delta^{18}O$ is systematically enriched in first molars due to effects of breastfeeding (Wright and Schwarcz, 1998); therefore first molar $\delta^{18}O$ values are interpreted with this in mind.

Hypothesis 2 (H_2): Isotopic parameters of early–life diet will be wide and stochastic among the Machu Picchu population.

The variation in residential backgrounds suggested for the Machu Picchu population likely translates to variation in subsistence patterns and available food resources prior to arrival at Machu Picchu. The extent of this diversity, and change in its magnitude over the course of individual lives, is unclear. However, it is expected that a *yana* population (determined via the expectations discussed in **H_1**) would show wide, stochastic variation in dietary isotopic parameters from teeth, suggesting little commonality in early-life subsistence. A *mitmacona* or local *hatun runa* population would likely show little within-group variation, suggesting common subsistence patterns within the population or within subgroups of the population. Further,

(H_2a) Isotopic parameters of overall diet ($\delta^{13}C_{ap}$) and of dietary protein ($\delta^{13}C_{col}$, $\delta^{15}N$) will significantly covary, suggesting particular types of diets consumed in early life. These isotopic data will be compared to a reference set from foodstuffs collected near Cuzco, Peru and published data from marine and terrestrial resources from northern Chile. Assessing the dietary isotopic parameters from the Machu Picchu study population against this “menu” permits more accurate assessments of not only how varied the diets were among the population, but what those diets actually contained.

(H_2b) Isotopic parameters of diet ($\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, $\delta^{15}N$) will change throughout the life course among the individuals in the Machu Picchu study population, winnowing in variation from early- to later-life.

To test this hypothesis, dentin isotopic data will be compared to an earlier set of isotopic data (Burger et al., 2003) from bone collagen. Since bone remodels continuously throughout life, its isotopic signatures represent the last decade or so before death. Dentin is partly vascularized, and therefore might be subject to some degree of turnover during life, but far less than that which occurs in bone; isotopic signatures from dentin can therefore be taken as a general proxy of early-life (or at least earlier-life) diet compared to those from bone. These two sets of dietary isotopic data thus permit comparison of dietary trends between early and late life. Dietary variation would be expected to winnow between early and late life among a *yana* population, as individuals ate similar diets after they were grouped together as *yanacona*. *Mitmacona* might show a similarly small degree of dietary variation between early and late life, but a change in dietary composition following relocation, as a group, to Machu Picchu from elsewhere; local *hatun runa* might not show any change in dietary composition or variation across individual life spans.

(**H_2c**) Dietary isotopic parameters ($\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, $\delta^{15}N$) will significantly covary with residential isotopic parameters.

As discussed in Chapter 2, the ecology of the central Andes is complex, resulting in a diverse mosaic of environmental and climatic contexts within a relatively confined geographic area. Even with highland vertical archipelagos and coastal subsistence networks widening local subsistence bases, the regional ecological complexity of the Andes means that subsistence bases may still be tied to regional ecologies and climates.

Further, in estimating the actual dietary composition among the Machu Picchu residents, several confounding factors are taken into consideration (Katzenberg, 1992). These include overlapping δ^{13}C ranges in C_4 plants and marine protein and δ^{15}N enrichment among organisms in hyper-arid environments resulting from physiological mechanisms of water conservation (Ambrose, 1991). The measurement of offsets in δ^{13}C values (ΔC_{ap-col}) between enamel apatite and dentin collagen and between bone apatite and bone collagen, combined with δ^{15}N data, are used to distinguish between whole-diet and protein contributions to isotopic signatures as a way to control for these confounders. Further, δ^{15}N and δ^{18}O data are compared to see if both suggest the effects of aridity, as δ^{18}O is also predictably affected by rainfall and humidity. Since ΔC_{ap-col} measures the relative contribution of protein to the overall diet, it is employed as one proxy of dietary breadth. Additionally, the establishment of a local range of δ^{13}C and δ^{15}N through faunal and collected floral samples is used to further distinguish subsistence strategies in non-local ecological contexts, such as those from coastal, lacustrine or lowland contexts, following the methods of Tieszen and Chapman (1993).

Hypothesis (H_3) Individual pathological conditions will significantly covary according to dietary ($\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, $\delta^{15}N$) and/or residential ($\delta^{18}O$, $^{87}Sr/^{86}Sr$, $^{20n}Pb/^{204}Pb$) isotopic parameters.

The primary indicators of stress examined here are the frequency and prevalence of enamel hypoplasia, dental carious lesions, tooth abscesses, antemortem tooth loss, occlusal wear, porotic hyperostosis, and cribra orbitalia. The dataset pertaining to these conditions include data that were collected as part of this study as well as those previously reported by Verano (2003a). Such trends are useful in assessing the types and severity of stressors in an individual's life, but most of these pathological conditions are nonspecific or multifactorial in nature and it is therefore difficult to determine what exactly caused them. Therefore, it would be useful to assess their frequencies against independent measures of diet and locale to estimate which factors led to which conditions.

Although Verano (2003a) reported enamel hypoplasia in only three individuals in the population, he did not complete a full dental inventory (Verano, personal communication 2004). Dental analyses of the Machu Picchu population undertaken for this study at Yale in May – June of 2004 and January – March 2005 documented higher frequencies of linear enamel hypoplasia (LEH), as well as variation in dental wear patterns among inviduals estimated to be the same age. In this context, marked variation in dental wear is assumed to be an indicator of variation in diet-related abrasion rather than exclusively age-based attrition, and therefore related to dietary composition. During the course of dental analyses, slightly higher frequencies of healed cribra orbitalia were also found; these and higher rates of LEH suggest greater stress during early life than previously assumed. Dental pathology, cribra orbitalia or porotic hyperostosis, and other cranial porosities are assumed to reflect differential nutritional status or disease burden.

Univariate statistical analyses of stress indicators against local or non-local $^{87}Sr/^{86}Sr$, $^{20n}Pb/^{20n}Pb$ and/or $\delta^{18}O$ values across the study sample are used to infer differential vulnerability to some other stressor in the local environment, such as parasitic infection, as a factor in the etiology of pathological conditions. If these parameters are not significantly predicted by $^{87}Sr/^{86}Sr$, $^{20n}Pb/^{20n}Pb$ and/or $\delta^{18}O$ ranges, this would suggest an association between health status and other potential factors in early life or at Machu Picchu that are unrelated to geographic origin. Similarly, the same statistical analyses of stress indicators against $\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, $\delta^{15}N$ values across the study sample are used to infer differential subsistence, such as reliance on iron-poor cereals, as an etiological factor. Significant variation of a pathological condition with both residential and dietary isotopic parameters would suggest a synergistic relationship whereby both diet and local environment are factors in determining pathological conditions.

Interpretive Significance

This study joins several growing bodies of research that are able to accurately reconstruct individually based, longitudinal data sets in human skeletal remains, opening new avenues of investigation into the lifeways and dynamics of archaeological populations. These data have allowed researchers to overcome limitations and biases inherent to mortuary populations; in particular, examining trends in diet, residence and health from childhood among individuals who died as adults circumvents issues of representation and the possibility of mortality bias (Saunders and Hoppa, 1993). This study is distinct among this body of research in that it generates complex intra-individual data sets using multiple isotopic and osteological indicators from a substantial number and variety of preserved human, faunal and modern floral tissues; moreover, it makes a first attempt at identifying broad causal factors (diet versus locale) in nonspecific pathological conditions. The proposed depth and breadth of analysis, using a large and well-contextualized study sample, is as of yet uncommon in published Andean and wider anthropological literature. Given the significance of individual and population movement and admixture to reconstructions of ancient life and the need to better assess population heterogeneity, especially in the Andes, this study provides useful analytical criteria for further research in Andean bioarchaeology.

This study also provides definitive answers to questions regarding Inca state influence on non-elite subjects, focusing on three fundamental necessities of life: subsistence, residence, and health. The techniques central to this study provide direct, multifaceted and synthetic portrayals of dietary composition, migratory history and health that facilitate strong inference based on lifelong trends. They also provide valuable tools with which to assess documentary sources or address gaps in ethnohistorical and archaeological knowledge, particularly those associated with the everyday lives and lifelong experiences of less-visible members of ancient Andean societies. This research helps to better profile the identities and backgrounds of the Machu Picchu population and is a necessary first step in comparatively, isotopically characterizing Incaic social classes, as well as earlier, ambiguously affiliated or poorly-preserved Andean skeletal populations. The greater elucidation of dietary, demographic and health-related variation by class, the identification of causal stressors affecting aspects of health, and the tracking of population movement could revolutionize what is known of Late Horizon and earlier Andean civilizations.

Chapter 4: Population Dynamics at Machu Picchu

Introduction

Most bioarchaeologists assume that mobility existed in most archaeological populations, and that some individuals in a skeletal assemblage may not have been local to the site in which they were interred. This is especially true of populations from state-level societies, where forced and voluntary relocation was common practice. Understanding the nature and degree of population movement is therefore critical to understanding the political economic processes that prompted that movement. This assumption is potentially significant in interpreting paleodemographic characteristics, the distribution of skeletal pathologies, dietary variation, and even social class. However, empirically testing this assumption is difficult. Due to the indirect nature of much available data, the variation in backgrounds of individuals in skeletal populations is seldom explicitly characterized and the insights gained from bioarchaeological analyses are thereby limited.

One particular region that would greatly benefit from empirical studies of individual backgrounds and population dynamics is Precolumbian Andean South America. According to ethnohistorical sources, the Inca of southern highland Peru commonly and forcibly relocated individuals and even entire communities throughout *Tawantinsuyu* (Inca-controlled territory; in Quechua, the Land of the Four Quarters). This strategy served multiple purposes. In areas of dissent or resistance to Inca rule, forced emigration of residents and immigration of loyal colonists helped to prevent secession or outright revolt. More generally, the Inca tax system was based solely on labor performed on state-controlled lands, so large-scale mobilization of subject populations relocated far-flung communities of specialists to where their skills were most needed, and provided an enormous labor pool for state projects and military campaigns (Pease, 1982; Rowe, 1982; Wachtel, 1982).

State-mandated migration also occurred elsewhere, but neither to the degree nor in the same manner as occurred among the Inca. Of particular interest is that many of these migrations are linked to assigned social class. The relative representation of various social classes at a Late Horizon site provides potential insights into the nature of the site and its significance in the Inca state system, because members of different social classes were moved around *Tawantinsuyu* in distinct ways for different reasons. Some, such as the *yanacona* and their female counterparts, the *acllacona*, were moved as individuals and their presence a suggestion of prestige or Inca elite influence; others, such as the *mitmacona*, were relocated as groups of households or entire communities, and their presence represents a potential of increasing Inca control. Therefore, accurately reconstructing the movements of Andean populations dated to the Late Horizon (Inca) period ca. AD 1438-1532, is critical to understanding ways in which Inca imperialism was carried out: who was moved, from where, to where, and why. Moreover, it is also critical to understanding the evolution of Andean statecraft itself; decades of archaeological and ethnohistorical research support the view that *Tawantinsuyu*'s meteoric rise and complex administration drew substantially on pre-existing political Andean economic institutions and cultural characteristics (see Chapter 2). With documentary sources confined to the Late Horizon and subject to the myopia of the Spanish chroniclers, less tangible elements of Andean political economy, including mandated migration, are more difficult to assess (D'Altroy, 2001). Assessing patterns of immigration in various Andean sites can therefore hint at the origins and development of different social classes. More generally, identifying elements of immigration in skeletal populations, both Andean and elsewhere, can shed new light on factors influencing the health, diet and demographic structure of the population.

Assessing Migration in Prehistory

Recent decades have seen a rise in numerous methods to estimate the residential origins and movement of populations and the individuals within them, which could greatly aid in identifying and controlling for immigration in paleodemographic and osteological analyses. Studies of biodistance between populations have been used to estimate diachronic population movement or replacement on varying scales, using nonmetric cranial (Buikstra, 1980; Hanihara et al., 2003; Larsen, 1997) and/or dental (Coppa et al., 1998; Guatelli-Steinberg et al., 2001; Irish, 1998; Mayhall, 1992; Mayhall and Heikkinen, 1999) traits as proxies of genetic relationships with an assumed high heritability. The degree to which secular changes in tooth metrics and cranial robusticity (Harris et al., 2001; Van Gerven, 1982) affect these parameters is unclear. However, Fagundes et al. (2002) found sex differences in mtDNA haplogroups indicating greater female migration in four extant indigenous populations, suggesting a useful modern analog in genetically approaching prehistoric migration.

Cranial vault modification is perhaps the least ambiguous morphological feature used as a proxy of cultural affiliation, one which Torres-Rouff (2002: 163) describes as "a powerful, constant, and visually salient symbol of social identity," in that the modification must take place in infancy and becomes a permanent part of individual ethnicity. As such, the presence and style of cranial modification has become a useful marker in partitioning ethnic variation in Andean skeletal populations, where the practice has existed for at least 7,000 years (Gerszten, 1993). Ethnohistorical sources from the Late Horizon (AD 1400-1532) point to the diversity of cranial modification techniques and their importance as ethnic identifiers and status markers in the Inca state (Hoshower et al., 1995). Recently, notable attention has been directed at discerning the nature of interactions between the Tiwanaku state of northern Bolivia with populations in southern Peru and northern Chile during the Middle Horizon (AD 500-1000). Hoshower et al. (1995) analyzed individuals from multiple cemeteries in the Omo site group of Moquegua, Peru, identifying variation in cranial deformation patterns between cemeteries indicating changes in local ethnic composition or expression over time. Blom et al. (1998) argued against substantial Tiwanaku colonization in the Moquegua region based on consistent differences in cranial modification styles between populations in the Moquegua versus Tiwanaku Valleys, while Torres-Rouff (2002; 2003) argued in favor of moderate interaction with, rather than replacement by, the Tiwanaku in the Atacama desert of northern Chile.

Cultural indicators such as intentional cranial modification, dental modification (Buikstra and Ubelaker, 1994) or distinctive forms of dental wear (Irish and Turner, 1997) are certainly not heritable and may reflect more subtle expressions of identity besides or in addition to ethnic affiliation. Moreover, the permanence of these traits, given that they involve skeletal and dental alteration, are useful in identifying immigrants in numerous populations (Blom et al., 1998; Torres-Rouff, 2003) as well as ethnic admixture (Logan et al., 2003). However, identifying features of an individual's ethnic affiliation or genetic heritage do not necessarily reveal migratory patterns during life, and do not necessarily prove that an individual is a first-generation immigrant versus their locally-born descendants (Knudson, 2004).

A promising suite of methods of empirically assessing immigration and thereby population demographics are stable isotope analyses, which provide powerful analytical tools for reconstructing the diets (Ambrose, 1993; Katzenberg and Harrison, 1997; Schwarcz and Schoeninger, 1991) and migratory histories (Price et al., 2002; White et al., 1998) of ancient populations. The assumption underlying these analyses is that ratios of isotopes such as strontium, lead and oxygen reflect the ratios in consumed animals, plants and water, which in turn reflect local geology and climate; in essence, that one is what one eats and drinks, and thereby (assuming minimal food imports) where one lives. Building on these premises, preserved tissues such as bone, tooth enamel and dentin are analyzed to measure ratios of non-radioactive isotopes of oxygen, which vary by altitude, latitude, temperature and humidity, and strontium and lead, which vary by the composition and age of local bedrock. As direct measures of macronutrient intake and local environment, stable isotopes often complement other archaeological lines of evidence and yield novel and key insights into the residence and mobility of individuals in ancient populations. Because of their strong link to local environmental and geological conditions, these three isotopic ratios have been used to characterize residence and migration as reflected by the intake of local food resources (Fricke et al., 1995; Müller et al., 2003; Price et al., 1998; Price et al., 2000). These direct, ecologically-based measures have been utilized to identify immigrant populations and captured prisoners of war

(White et al., 2004; White et al., 2000; White et al., 2002; White et al., 1998), exogamous marriage (Bentley et al., 2004) and population movement during periods of transition (Bentley et al., 2003; Ezzo and Price, 2002; Grupe et al., 1997). Their utility and salience to bioarchaeology have made stable isotope analyses integral to research on skeletal populations in many different regions of the world.

Stable light isotopes and migration

Stable oxygen isotopes in the mineral apatite portion of bone and enamel reflect the isotopic composition of body water, which equilibrates the $^{16}O/^{18}O$ ($\delta^{18}O$) of skeletal tissues at a constant temperature of 37°C. Body water $\delta^{18}O$ is influenced by the oxygen isotopic composition of drinking water and, to a much lesser extent, water in air and food sources. The isotopic composition of imbibed water is in turn affected by latitude, altitude, and prevailing regional climatic patterns through the variable loss of ^{16}O via evaporation and enrichment of ^{18}O in local water sources (Dansgaard, 1964). These ecological and physiological processes make $\delta^{18}O$ a useful measure of local climatic variables such as overall climate, seasonal temperature change and fluctuating rainfall (White et al., 1998), and of an individual's movement to geographical areas characterized by $\delta^{18}O$ ranges distinct from those from which s/he originated (White et al., 2000; White et al., 2002).

Most stable isotope studies in anthropological literature utilize components of bone such as collagen or apatite to reconstruct dietary composition. However, these substrates undergo elemental turnover as part of normal bone remodeling throughout life, resulting in an isotopic signal that represents an isotopic average from the last ten or so years of life (Manolagas, 2000). Recently, several anthropological studies have analyzed tissues that preserve isotopic signatures from different periods of development in order to reconstruct longitudinal, intra-individual isotopic trends, following White's (1990) study of multiple preserved tissues in reconstructing diet among the Wadi Halfa population from Sudanese Nubia and Schwarcz et al.'s (1991) study of American soldiers interred in Canada. White (1993) further identified a seasonally-variable pattern of C_3 and C_4 consumption at Wadi Halfa population through incremental analyses of preserved hair, but found no such trend in a similar study from the Kharga Oasis (White et al., 1999). Balasse and colleagues successfully traced dietary trends associated with weaning and fattening in modern steers through analyses of intra-bone (1999) and dentin (2001) isotopic variability, illustrating the potential of such analyses for reconstructing dietary changes in vivo. Kohn et al. (1998) further demonstrate the utility of intra-individual isotopic analysis for reconstructing dietary and climatic trends by effectively discounting physiological processes as confounders in determining the isotopic composition of preserved faunal tissues.

The rarity of preserved hair in most archaeological contexts, however, and the susceptibility of bone and dentin to diagenetic alteration makes tooth enamel the most useful tissue for intra-individual isotopic analysis. Tooth enamel is composed of tightly-packed mineral prisms with almost no organic content, making it more likely to withstand diagenetic alteration. Moreover, tooth enamel forms at stable, incremental rates and does not remodel once formed, thereby preserving the biochemical composition and other features such as surface defects (Goodman and Rose, 1990) from specific points during development. Studying isotopic ratios of carbon and oxygen in tooth enamel is thus similar to studying enamel defects in that the parameters of interest form during specific periods during development and can be used to map trends during infancy, childhood and early adolescence regardless of the age at which the individual died. A number of studies have explicitly utilized $\delta^{18}O$ to trace residential origins, notably that by Müller et al. (2003) in estimating the region in Italy from which Ötzi the Iceman originated relative to where he died. Gadbury et al. (2000) analyzed isotopic signatures in microsampled bison enamel from Europe to track seasonal fluctuations in the $\delta^{18}O$ of consumed drinking water, positing a progressive decline in enamel $\delta^{18}O$ as indicative of a Holocene drying trend that caused catastrophic mortality among the population. Fricke et al. (1995) examined variation in enamel $\delta^{18}O$ from seven heterochronic Greenlandic populations and found both an overall decline in isotopic values suggestive of climatic cooling and within-population variation suggesting immigration and mobility. In Mesoamerica, White et al. (2000) estimated only a weak Teotihuacan colonizing presence at the site of Kaminaljuyu using enamel phosphate $\delta^{18}O$ to identify Teotihuacano immigrants, uncovering a previously-unknown degree of migration involving individuals from multiple regions. White et al. (2002) further identified a substantial number of immigrants, including among sacrificial victims, in a population from at the Feathered Serpent Pyramid through analyses of enamel phosphate $\delta^{18}O$, differentiating local residents, recent arrivals and more long-term immigrants through varying scales of isotopic equilibration. In the Andes, Verano and DeNiro (1993) performed a similar analysis of immigrants among sacrificial victims to interpret cultural significance.

Recently, several studies have successfully reconstructed weaning trends and early childhood diets among adult remains. Wright and Schwarcz (1998; 1999) estimated the timing and nature of the weaning process among a small population from Kaminaljuyu, Guatemala using analyses of $\delta^{18}O$ and $\delta^{13}C$ in tooth enamel carbonate, illustrating the utility of isotope analysis in uncovering rich biological patterns in poorly-preserved remains. These analyses not only permit an elucidation of *in vivo* changes in diet, but overcome the possible confounding effect of selective mortality bias in interpretation (Saunders and Hoppa, 1993; Wood et al., 1992) through the exclusive analysis of those who survived infancy and childhood (Wright and Schwarcz, 1999). Finally, reference $\delta^{18}O$ data from studies of modern precipitation (Bowen and Wilkinson, 2002) provide the necessary baselines from which individuals can be more accurately traced to specific environmental contexts.

Stable Heavy Isotopes and Migration

Unlike light isotopes such as oxygen, carbon and nitrogen, stable isotopes of strontium (Sr) and lead (Pb) vary very little in their respective atomic masses, and as such cycle through foodwebs without measurable fractionation. Isotopic ratios of strontium ($^{87}Sr/^{86}Sr$) and lead ($^{206/204}Pb$, $^{207/204}Pb$, and $^{208/204}Pb$) in bone apatite and enamel indirectly reflect those found in local bedrock, which leaches into groundwater, is taken up by plants, and thereby enters food webs (Price, 1989). Measuring these isotopic ratios in preserved animal and human tissues, assuming no contamination from burial soils or anthropogenic lead, provides indirect estimates of the local geological environment in which an animal lived (or at least of their dietary Sr and Pb sources). The strontium isotopic composition of different geological substrates varies by the geological age, mineral composition and weathering patterns of surrounding bedrock (Dasch, 1969).

Specifically, ^{87}Sr is the product of radioactive decay of rubidium-87 (^{87}Rb), which has a half-life of approximately 4.7 x 10^{10} years (Faure and Powell, 1972). Therefore, the amount of ^{87}Rb in the rock at the time of its formation and the age of the rock, i.e. the amount of time in which ^{87}Rb has undergone radioactive decay, is a key variable determining the amount of ^{87}Sr and therefore the ratio of ^{87}Sr/^{86}Sr (Faure and Powell, 1972; Fullagar et al., 1971). Generally, older rock types rich in initial levels of ^{87}Rb have higher ^{87}Sr/^{86}Sr ratios than younger, rubidium-poor rocks (Rogers and Hawkesworth, 1989). Proximity to marine environments can also be a factor, as ocean water shows a consistent ^{87}Sr/^{86}Sr value of 0.7092‰ (Veizer, 1989) and there are compositional differences in oceanic versus continental crust.

Lead isotope distributions vary depending on the composition of ore deposits, which are mixes of Pb incorporated into the Earth during its formation and Pb produced through radioactive decay of uranium and thorium (Faure, 1986; Gulson, 1986). Four lead isotopes are commonly studied in lead isotope geochemistry research (^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb). The latter three are each produced by radioactive decay of a different isotope of uranium or thorium that have respective half-lives of 4.5 billion years (^{238}Ur), 704 million years (^{235}Ur) and 14.0 billion years (^{232}Th) (Gulson, 1986; United States Geological Survey, 2001). Therefore, the lead isotope compositions of individual ore deposits are affected not only by the age of the ore, but also the degree of admixture of pristine and radiogenic lead. Plotting ratios of these three isotopes (^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb, referred to as ^{20n}Pb/^{204}Pb for brevity) against each other permits some characterization of a given ore deposit's lead isotope profile (Faure, 1986; Gulson, 1986). Lead, like strontium, transfers through foodwebs and substitutes for calcium in the mineral matrix of bones and teeth (Rabinowitz, 1991; Stack, 1990). Hence, variation in lead isotopic composition between different ore deposits permits some estimation of where, geologically, an individual lived during the developmental period of whatever mineralized tissue is being analyzed (Gale, 1989).

Characterization of $^{87}Sr/^{86}Sr$ abundance in the surrounding environment (Hodell et al., 2004) and biologically-available $^{87}Sr/^{86}Sr$ in faunal enamel (Price et al., 2002) have enabled researchers to estimate "local" baselines at archeological sites from which to distinguish non-local individuals and assess the degree and timing of immigration. These techniques are considered more ecologically relevant than those that equate statistical outliers in $^{87}Sr/^{86}Sr$ distributions with non-local immigrants (see discussions in Bentley et al., 2003; Knudson et al., 2005). Price et al. (1994) identified a significant number of immigrants among the population from Grasshopper Pueblo in Arizona, which Ezzo and Price (2002) attribute to dispersal linked to dietary stress. Price et al. (2000) identified numerous patterns of immigration among the different neighborhood complexes at the city of Teotihuacan in Mexico, especially in those with foreign architecture and artifacts. Knudson (2004; 2004b) identified varying patterns of Tiwanaku immigration, trade and influence in Chiribaya-affiliated sites in southern Peru. More recently, Knudson et al. (2005) used similar analyses to identify "local" individuals in southern Bolivia who were thought to have been outside the range of Tiwanaku influence but who were unexpectedly associated with high-quality, Tiwanaku-style accompaniments.

In Europe, Grupe et al. (1997) found a disproportionate number of females and several children with non-local $^{87}Sr/^{86}Sr$ values in a Neolithic Bell Beaker population in southern Bavaria, suggesting migration of small groups through exogamous marriage.

Among other Neolithic populations, Bentley et al. (2002) postulated that the agricultural *Linearbandkeramik* culture spread through Germany through initial colonization followed by indigenous adoption, while Montgomery et al. (2003) suggest that non-local immigrants among the Hebridean Norse of southwest Scotland were in fact captured slaves. In their analyses of populations in southern England, Evans et al. (2006b) suggest that isotopically local individuals associated with non-local artifacts are in fact locally-born descendents of earlier immigrant groups, retaining material forms of cultural and ethnic expression. Significantly, Evans et al. (2006a) describe a longitudinal isotopic record among three non-local individuals at Boscome Down based on analyses of tooth enamel, postulating a "systemic, reproducible migration pathway" among these individuals. Perhaps the most clear-cut heavy isotopic study of immigration is Price et al.'s (2006) identification of West African slaves in a multiethnic colonial Mexican cemetery based on their extremely high ^{87}Sr/^{86}Sr values.

Migration studies using lead isotopic ratios are less common, but rely on similar premises as those that rely on strontium. Carlson (1996) differentiated individuals grouped by burial context as Anglo-American fur traders and Native Americans through Pb isotopic analyses at a multiethnic cemetery in Alberta, Canada. In this study, the author further partitions an isotopic newcomer to the fur trading post associated with the cemetery, as well as potentially pathological lead exposure among one Native American individual attributed to cultural practice, rather than residence per se. Chiaradia et al. (2003) compared enamel and dentin Pb and Sr isotopes in remains from a Swiss necropolis, identifying in some individuals potential diagenetic contamination from anthropogenic lead in the Rhone River alluvial fan. Further, the authors point to the confounding effect of foodstuffs imported from geologically distinct but geographically close regions, suggesting that nonlocal isotopic signals in their population do not necessarily point to a nonlocal origin.

Of note among these isotopic studies is that many of their findings paint a more nuanced and complex picture of interaction, migration, conflict and exchange among a variety of ancient populations, linking particular features of archaeological context with heretofore unrecognized variation in backgrounds. Recently, a growing number of studies rely on multiple isotopic proxies to strengthen analyses and interpretations of ancient population movement. Knudson and Price (2007) and Evans et al. (2006a; 2006b), rely on both strontium and oxygen isotopic indicators; Montgomery et al. (2003) and Chiaradia et al. (2003) include both strontium and lead isotopic data in their analyses, and Bentley and Knipper (2005) rely on strontium, oxygen and carbon isotopic data, thereby adding multiple, independent isotopic parameters to their respective analyses. Interestingly, $^{87}Sr/^{86}Sr$ analyses are also being applied more directly to subsistence analysis; Reid et al. (2002) provide isotopic evidence for differential use of marine limestone or wood ash in maize processing between sites in the Solis Valley, Mexico, with other sites such as Teotihuacan and Monte Alban. Wright's (2005) suggestion that $^{87}Sr/^{86}Sr$ ratios among the local individuals at Tikal may be inflated compared to the local environmental range due to imported sea salt provides is echoed in coastal Peru by Slovak (2007a), and speaks to the need to better understand the variation in locally bioavailable strontium as well as the full breadth of subsistence in interpreting heavy isotopic data.

Study Objectives

Given the degree of state-mandated population movement in the Inca state described in ethnohistorical sources (see Chapter 3), and the variation in archaeological features among the Machu Picchu population (see Chapter 2), it is reasonable to hypothesize that at least some of the individuals interred in Machu Picchu's three cemeteries were not local to the Urubamba province. Based on suggestions that the Machu Picchu population may have been *yana* servants or perhaps a *mitmacona* labor colony, even a group of local *hatun runa*, one could reasonably hypothesize at least two potential distributions of oxygen, strontium and lead isotopic data (Figure 4.1). If the population consisted primarily of *yana* servants, the expected isotopic distribution for each tooth type would have a wide range and little modality or clustering, reflecting a group of individuals sharing no common background. On the other hand, if the population was primarily a *mitmacona* labor colony, the expected isotopic distribution would be more tightly clustered and show unimodality or some clear degree of bi- or multimodality, since *mitmacona* could sometimes be amalgamations of several groups (Wachtel, 1982). Both hypothetical distributions would be distinct not only from each other, but from that expected for local *hatun runa*, which could also include second or third-generation descendants of earlier immigrants (Figure 4.1)

The geological and ecological variation that characterizes the central Andes of the Inca heartland is substantial, resulting in a wide range of regional isotopic variation. However, individuals would only be distinguishable isotopically if they came from geologically and/or climatically distinct regions. Incorporating $\delta^{18}O$ as a proxy of local climate, and $^{87}Sr/^{86}Sr$, $^{206/204}Pb$, $^{207/206}Pb$, $^{208/206}Pb$, and $^{208/207}Pb$ in multiple tissues per individual permits a multifaceted analysis through which both climatic and geological signatures contribute to an overall, early-life isotopic “fingerprint” (Vogel et al., 1990). This analysis relies primarily on human tooth enamel, which does not remodel and therefore retains isotopic signatures from the period of each tooth’s development, for the duration of an individual’s life and, barring contamination, after death. Bone does not share tooth enamel’s general impermeability to diagenetic contaminants, and provides an isotopic average spanning ten or more years (Manolagas, 2000), and was therefore not included in this analysis. Further, the hypotheses in this study primarily concern place of birth, so early developing tissues such as tooth enamel, when compared to “local” reference data for each isotopic parameter, are best suited to test them. To provide a narrower temporal framework spanning several phases of development, enamel samples from multiple tooth types were analyzed, preferably permanent molars. The necessary reference data for this analysis is provided through archaeological faunal tooth enamel and geologic (spring-fed) water, both of which come directly from Machu Picchu, and published sources.

In his 1916 monograph of the Machu Picchu cemetery excavations, Eaton documented three cemeteries at Machu Picchu (see also Miller, 2003) where the vast majority of burials were found in a variety of mortuary contexts (Salazar, 2001). Moreover, in his osteological analysis of the Machu Picchu population, Verano (2003a) found variation in cranial modification styles and cranial morphology. This suggests potentially diverse ethnic or cultural backgrounds among the population; however, Verano (2003a) found no correlation between morphology or modification style and cemetery affiliation, meaning that this diversity in background may not be simple or unequivocal. Here, isotopic parameters are analyzed along with cranial modification style and cemetery affiliation to assess any relationships between early-life geographic residence and ethnic or cultural affiliation.

Methods

Sample Selection

Individuals from the overall skeletal assemblage were included in the study population based primarily on availability of identifiable permanent teeth, and secondarily by sufficient contextual data from Verano (2003a) on sex, age and any notable characteristics such as cranial modification or unusual burial context (see also Salazar, 2001), resulting in a study population of 67 adults, 6 subadults (10-16 yrs. at death) and one child (5-6 yrs. at death) from the three cemetery areas at the site. The ideal sampling design would consist of a first, second and third permanent molar from each individual, providing a developmental isotopic window spanning birth through thirteen years of age. However, ante- and postmortem tooth loss was common among the individuals studied, so it was not possible to consistently collect the same three teeth from each individual; moreover, any third molars present in the subadults and child were not erupted and thus inaccessible. Therefore, both anterior and posterior permanent tooth types were grouped into three broad developmental periods: first and second incisors and first molars comprised the “infancy/early childhood” (IEC) period, while canines, second premolars and second molars comprised “middle childhood” (MC), and third molars comprised “adolescence” (AD), summarized in Table 4.1. Using this sampling strategy, it was possible to standardize tooth types by developmental period while maximizing the different types of teeth available for sampling.

Each tooth was catalogued and cleaned with acetone, and the enamel surface abraded clean with a Dremel tool. For light isotope analysis, 10-30 mg of enamel was taken from each tooth using a hand-held Dremel tool and tungsten carbide diamond cutter saw attachment, spanning the cemento-enamel junction to the occlusal margin, or the area of maximum height in the case of worn teeth. Residual dentin was ground away when necessary. Because diagenetic alteration would most likely occur on the first several layers of enamel on the tooth surface (Nielsen-Marsh and Hedges, 2000), each tooth sample was cleaned of these layers via surface abrasion with the same Dremel saw attachment. First molar enamel sections were longitudinally divided into two equal portions, as separate procedures are necessary to prepare apatite samples for characterization of $^{87}Sr/^{86}Sr$ and $^{20n}Pb/^{204}Pb$ versus $\delta^{13}C_{ap}$ (i.e., $\delta^{13}C$ from mineral carbonate apatite) and $\delta^{18}O$; among individuals who lacked either sufficient M1 or I1 enamel or were missing those teeth entirely, portions of second or third molars were divided for both analyses instead. Otherwise, second and third molars were prepared singly for $\delta^{13}C_{ap}$ and $\delta^{18}O$ analyses ($\delta^{13}C_{ap}$ results are presented in Chapter 5).

Light Isotope Analysis

Enamel carbonate was isolated for $\delta^{13}C_{ap}$ and $\delta^{18}O$ characterization using methods adapted from van der Merwe et al. (1995), Ambrose (1993) and Schoeninger et al. (1989), as described in Turner et al. (2005). Enamel from each tooth was removed with crushed to a fine powder using an agate mortar and pestle and soaked for 24-72 hours in a

3:1 solution of ddH_2O and NaOCl (double-distilled water and bleach) in 15ml falcon tubes until any bubbling in the solution ceased, signifying that all organic material was removed. The samples were then centrifuged, rinsed to neutral with ddH_2O and soaked for 2-4 hours in a 0.2% acetic acid solution at 4°C, which removed exogenous carbonates and diagenetic contaminants while avoiding recrystallization of the enamel apatite (Garvie-Lok et al., 2004). The isolated carbonate samples were then centrifuged and rinsed to neutral pH with ddH_2O, freeze-dried under vacuum, and digested on an automated prep system at 50ºC in a VG prism mass spectrometer at the Center for Isotope Geoscience at University of Florida, Gainesville. Isotopic values are expressed as per mil (‰) relative to the international Pee Dee Belemite (PDB) standard for carbon and standard marine ocean water (SMOW) standard for oxygen. The analytical precision of the mass spectrometer used is ±0.05‰ for $\delta^{13}C$ and ±0.11‰ for $\delta^{18}O$.

The integrity of skeletal tissues and the potential confounding effects of diagenetic elemental exchange from interaction with burial soils are of concern when interpreting isotopic data. To avoid the possibility of analyzing diagenetically altered samples, human and faunal bone apatite was not included in this analysis because the mineral matrix of bone is more permeable to diagenetic contaminants. Tooth enamel, on the other hand, is composed almost exclusively of a mineral matrix that is tightly compacted and therefore highly impermeable to exchange in the burial environment. Moreover, empirical data and theoretical models indicate that enamel apatite retains its biogenic isotopic composition despite fossilization processes (Kohn et al., 1999; Lee-Thorp, 2000; Sponheimer and Lee-Thorp, 1999; Wang and Cerling, 1994). Finally, while White and colleagues (2004) suggest that enamel phosphate is less susceptible to diagenetic alteration than enamel carbonate, the two inorganic components appear to be comparable in their resistance to alteration and the integrity of biogenic signals.

Stable Heavy Isotope Analysis

Enamel from each available first molar was removed and abraded clean with a Dremel tool and diamond cutter attachment, then weighed. Sample processing for Sr and Pb isotope analysis was conducted in a class 1000 clean lab, equipped with class 10 laminar flow hoods, at the Department of Geological Sciences, University of Florida, under the supervision of Dr. George Kamenov. Human and faunal enamel samples were dissolved in pre-cleaned Teflon vials on a hot plate for 24 hours in 8N HNO_3 (optima). The vials were then opened and the solution evaporated to dryness in a laminar flow hood. Strontium and lead were sequentially separated by ion chromatography from single aliquots. The stems of 100µl columns were packed with Dowex 1X-8 (100-200 mesh) resin, which was rinsed with 2ml of 6N HCl (optima). Each enamel sample was dissolved in 100µl -200µl of 1N Seastar HBr and loaded onto the column resin, then washed three times with 1ml Seastar HBr. Lead was collected in a final wash of 1ml 20% HNO_3 (optima), and evaporated to dryness on a hot plate in a laminar flow hood.

During the lead elution step the wash was collected and evaporated on a hot plate for subsequent strontium separation, as strontium is not absorbed on the Dowex resin. The dried residues from the washes were dissolved in 3.5N HNO_3 and loaded on to cation exchange columns packed with strontium-selective crown ether resin (Sr-spec, Eichrom Technologies, Inc.) to separate Sr from other ions following procedure by Pin and Bassin (1992). Each 100µl column stem was packed with Sr-spec resin, which was then washed with 2ml 4xH_2O and equilibrated with 2ml 3.5N HNO_3 (optima). Dissolved samples were loaded onto the resin columns and washed four times with 100µl 3.5N HNO_3 (optima), then washed with 1ml 3.5N HNO_3. Strontium was collected in 1.5ml $4xH_2O$ and evaporated to dryness on a hot plate in a laminar flow hood.

Sr and Pb isotopic ratios were measured at the Department of Geological Sciences, University of Florida using a "Nu-Plasma" multiple-collector inductively-coupled-plasma mass spectrometer (MC-ICP-MS), using the time-resolved analysis method of Kamenov et al. (2006). For the Sr isotope analyses, on-peak zero was determined before each sample introduction in order to correct for isobaric interferences caused by impurities of Kr in the Ar carrier gas. $^{87}Sr/^{86}Sr$ was corrected for mass-bias using exponential law and $^{86}Sr/^{88}Sr = 0.1194$. ^{87}Sr was corrected for the presence of Rb by monitoring the intensity of ^{85}Rb and subtracting the intensity of ^{87}Rb from the intensity of ^{87}Sr, using $^{87}Rb/^{85}Rb = 0.386$ and mass-bias correction factor determined from $^{86}Sr/^{88}Sr$. The average value of the TRA-measured $^{87}Sr/^{86}Sr$ of NBS 987 is 0.710246 ($2\sigma = 0.000030$), which is indistinguishable from long-term TIMS NBS 987 results (0.710240; $2\sigma = 0.000023$) (Hodell et al., 2004). Pb isotopic analyses were conducted using Tl normalization technique on fresh mixtures to prevent the oxidation of thallium to Tl^{3+} (Kamenov et al., 2004). Analyses of NBS 981 conducted in wet plasma mode together with the sample analyses gave the following results: $^{206}Pb/^{204}Pb = 16.937$ (+/-0.004 2σ), $^{207}Pb/^{204}Pb = 15.490$ (+/-0.003 2σ), and $^{208}Pb/^{204}Pb = 36.695$ (+/-0.009 2σ).

Contextual Parameters

In order to assess any concordance between isotopic parameters and those of ethnicity and burial context, published data on cranial modification style (Verano, 2003a) and cemetery affiliation were included in this analysis. Individuals in the study population were assigned a cemetery affiliation score based on Eaton's (1916) categorization; those whose graves appeared isolated or whose cemetery affiliation was unclear were assigned a 'not in cemetery' score (Table 4.2).

Results

Results of all isotopic analyses are summarized in Tables 4.2 (humans) and 4.3 (fauna and water). Each isotopic parameter serves as a proxy of distinct geological or climatological contexts, thus data from each are discussed separately before analyzed in combination. Statistical analyses were performed using SPSS 14.0 for Microsoft Windows, SAS 9.1 (English) for Microsoft Windows, and Excel for Microsoft Office 2007, and included parametric and non-parametric analyses of variance and correlations, factor analysis and hierarchical cluster analysis.

$^{87}Sr/^{86}Sr$ Results and Discussion

The age of bedrock is the primary determinant of strontium isotopic ratios; ^{87}Sr is the product of radioactive decay of ^{87}Rubidium (Rb) (Faure and Powell, 1972). Thus, older rocks have higher ^{87}Sr/^{86}Sr ratios because more rubidium has decayed and produced more ^{87}Sr, while younger rocks have lower ratios.

Because the differences in atomic mass between strontium isotopes are miniscule, numerically small differences in isotopic ratios are considered interpretively meaningful. There is wide variation in early-life strontium isotopic composition among the Machu Picchu study population (Figure 4.2). ^{87}Sr/^{86}Sr values range from 0.703835‰ to

0.721183‰, with a mean of 0.710605‰ and standard deviation of 0.004819‰ (Table 4.4). The bedrock supplying each individual with their respective $^{87}Sr/^{86}Sr$ ratio during their first few years of life would have varied widely in age, and therefore the amount of ^{87}Rb decayed to ^{87}Sr. No significant variation was found in $^{87}Sr/^{86}Sr$ by sex, cemetery affiliation or cranial modification style (Tables 4.5-4.6), though there is significant variation by age ($p=0.051$); these results suggest little patterning in $^{87}Sr/^{86}Sr$ by cultural affiliation or ethnicity. The relationship with age suggests a possible pattern, though the lack of significance between age and any other isotopic parameter (see below and Chapter 5) makes the practical significance of this relationship unclear.

These results suggest that individuals in the Machu Picchu population grew up eating foods from distinct geological contexts. There are potential confounding effects of trade on these values, especially in strontium-rich foods such as salt or dried fish, as they are skewed in their $^{87}Sr/^{86}Sr$ ratios by seawater, which holds a constant ratio of 0.7092 (Veizer, 1989). Slovak (2007a) suggests that elevated $^{87}Sr/^{86}Sr$ ratios among the skeletal population at Ancón, Peru are the result of a dietary bias towards marine food resources among a local population rather than a substantial degree of immigration. Trade networks during the Late Horizon were extensive, meaning that consumption of marine foods by both coastal and highland individuals during early life could skew $^{87}Sr/^{86}Sr$ ratios among at least some of the individuals in the Machu Picchu population. Cobo (1964 [1653]: book 3, chapter 4, pg. 112) noted the importance of salt in most Late Horizon Andean diets, including salt collected from boiled-off spring water, mined salt, and sea salt. Indeed, there is no significant correlation between $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ among the Machu Picchu study population, suggesting that source of dietary strontium was not necessarily linked to local climate, i.e. that these results represent regional variation in early-life residence. Further, Wright et al. (1997) argue that the agricultural potential at Machu Picchu was insufficient to support the permanent population, and that imported foods likely made up at least part of the diet. In addition, Jones (2007) suggests based on pollen analyses of agricultural terraces at Machu Picchu that much of the arable land at the site was used to grow supplemental crops such as chili peppers, mate leaf and ornamental flowers. Thus, one could potentially argue that the Machu Picchu population was not comprised of immigrants who grew up elsewhere, but locals who had access to a wide variety of imported foods and seasonings. This is an unlikely scenario, for the following reasons.

First, to address this possibility, statistical analyses were conducted against diet-related pathological conditions and dietary isotopic parameters (results of these analyses are presented in Chapter 6). Using Kruskal-Wallis tests of non-parametric variance, no significant relationship was found between $^{87}Sr/^{86}Sr$ and oral conditions or porotic hyperostosis, although the relationships between $^{87}Sr/^{86}Sr$ and second molar dental wear, and $^{87}Sr/^{86}Sr$ and cribra orbitalia, approach significance ($p = 0.09$ and 0.089, respectively). Because the latter condition is not exclusively linked to diet, this does not suggest a dietary bias per se (see Chapter 6 for further interpretations of these relationships). There was also no significant correlation between $^{87}Sr/^{86}Sr$ and $\delta^{15}N$, suggesting no skewing effect on $^{87}Sr/^{86}Sr$ from the consumption of marine protein (Table 4.7). Moreover, many plant foods such as maize are low in calcium. As strontium substitutes for calcium in the formation of the mineral matrix of bones and teeth, as a low-calcium food, maize would contribute minimally to the body's calcium pool (Burton, 1996; Knudson, 2004).

More generally, to assume that strontium isotopic variation seen in the Machu Picchu population is due to dietary bias rather than differences in region of origin, is to assume *extreme*, consistently idiosyncratic and long-term variation in diet among all individuals in the population. There is no ethnohistoric or archaeological data to suggest such extreme within-population variation in subsistence; on the contrary, most models of ancient Andean economies suggest the pooling and redistribution of resources based on kinship and community ties (Murra, 1980; Rostworowski de Diez Canseco, 1970; Tomczak, 2003). Further, the variation in strontium isotopic data is mirrored by wide variation in lead and oxygen isotopic data (see below), the latter of which is not a proxy of consumed food. Finally, Kendall (1988) reports findings of extensive irrigated agricultural terraces at contemporaneous sites in the Vilcanota-Urubamba Valley drainage, all in close geographic proximity to Machu Picchu. Based on these results, Kendall points to the Urubamba Valley as a major source of maize and other crops for the capital of Cuzco, meaning that even foods distributed to Machu Picchu from imperial storehouses near the capital likely came from a local Urubamba source. Based on all of these factors, it is reasonable to suggest that strontium isotopic variation of this magnitude stems in large part from where individuals were born and grew up.

In assessing absolute variation and attempting to assign regions of origin to the Machu Picchu study population, one would generally expect higher $^{87}Sr/^{86}Sr$ ratios in the older geological contexts of the southern Peruvian highlands, with intermediary $^{87}Sr/^{86}Sr$ in the central Peruvian highland Cordillera and lower $^{87}Sr/^{86}Sr$ values in the north and central Peruvian coasts. These expectations are extremely general, however, given the geological complexity of the Andes. Moreover, if one recalls arguments by Price et al. (2002) that the geological range of $^{87}Sr/^{86}Sr$ is wider than the biologically available range that cycles through food webs, geological context may not be sufficient by itself for tracing individuals to various regions of the empire. A useful complement to estimating the local $^{87}Sr/^{86}Sr$ baseline at Machu Picchu, is published faunal (often guinea pig, or *cuy* in Quechua) $^{87}Sr/^{86}Sr$ data from recent bioarchaeological studies in the central Andes, much of which comes from Knudson et al. (2004; 2007; 2005), Andrushko et al. (in press) and four faunal specimens analyzed here. Estimated regions of origin for the Machu Picchu study population using these data are summarized in Figure 4.2.

Somewhat unexpectedly, there is also wide variation among the four specimens in the faunal group analyzed here, whose isotopic data were assumed useful as proxies of local isotopic ranges. One faunal sample (*L. trichodactylus*, a large-toothed vizcacha) was from a species not native to the Urubamba province (Eaton, 1916), and was therefore expected to diverge in its isotopic values. However, the other three specimens, all assumed local, also show notably wide variation. The integrity of the mineral matrix makes tooth enamel highly impermeable to diagenetic alteration; since all human and faunal Sr and Pb isotopic data were characterized from enamel, the likelihood of diagenetic alteration is slim. Moreover, diagenetic alteration would narrow, not widen, the isotopic ranges as all would be contaminated by the same local soils and $^{87}Sr/^{86}Sr$ values would converge. However, the degree of geological microvariation in the Machu Picchu region, indeed in the central Andes, is unknown. Andrushko et al. (in press) found similar variation in a broadly contemporaneous population from the sites of

Chokepukio and Tipón near Cuzco, including variation in geographically local faunal samples. Therefore, the variation seen in faunal data in their study as well as here could reflect some degree of isotopic microvariation, speaking to the need for further research. Alternatively, one or more of the three assumed-“local” faunal specimens at Machu Picchu could have been brought to the site from geologically distinct contexts for any number reasons, i.e. one or more of the “local” fauna were in fact immigrants themselves. Finally, one or more faunal specimens from Machu Picchu, and potentially from sites in other studies as well, had access to imported foods through trash middens. As noted above, imported food may well have been present at Machu Picchu, meaning that a geologically local isotopic signal could be skewed by dietary bias over the much shorter life spans of the faunal specimens. This potential confounder is not confined to archaeological fauna, either. Knudson et al. (2005) suggest a dietary bias from non-local foods in a modern faunal specimen with an outlier ^{87}Sr/^{86}Sr value. This underscores the importance of researchers monitoring food consumption, or even raising animals such as *cuy* themselves during lengthy field seasons, when using faunal enamel as proxies of local biologically available strontium isotope ratios.

^{20n}Pb/^{204}Pb Results and Discussion

Lead isotope distributions vary depending on the composition of ore deposits, which are mixes of lead incorporated into the Earth during its formation and lead produced through radioactive decay (Faure, 1986; Gulson, 1986). Since lead, like strontium, transfers through foodwebs and substitutes for calcium in the mineral matrix of bones and teeth, variation in lead isotopic composition between different ore deposits permits some estimation of individual residence (Gale, 1989).

Plots of the three lead isotope ratios characterized in the Machu Picchu population show high fidelity between the different isotopic ratios (R^2 values for linear plots are 0.87 and 0.60, respectively). Further, spearman correlation coefficients between the three lead isotope ratios are positive, strong and significant (Table 4.7), and factor analysis of strontium, lead and oxygen parameters (discussed further below) show a similarly strong relationship. This is expected since each individual's tissues would incorporate all three lead isotopes from the same dietary and environmental sources of lead, and confirms the analytic integrity of the lead isotopic data.

Wide variation is visible in all three of the different lead isotopic ratios (Figure 4.3). $^{206}Pb/^{204}Pb$ values range from 18.19 to 19.15‰ with a mean of 18.72‰ and standard deviation of 0.20‰; $^{207}Pb/^{204}Pb$ values range from 15.58 to 15.68‰ with a mean of 15.6‰ and standard deviation of 0.02‰; $^{208}Pb/^{204}Pb$ values range from 37.97 to 38.88‰ with a mean of 38.47‰ and standard deviation of 0.19‰ (Table 4.4). As is the case with $^{87}Sr/^{86}Sr$, the small differences in atomic weights among lead isotopes means that numerically small ranges of lead isotopic data are interpretively meaningful. These data suggest that individuals lived in regions with bedrock substrates widely varied in ore composition. As expected, there are significant, positive correlations between different lead species, but also wide variation within assumed-local fauna.

In looking beyond relative variation to absolute variation, as with the strontium data interpretations again are complicated but intriguing. Using MacFarlane et al.'s (1990) estimated lead provinces for the central Andes, we see three distinct lead isotope provinces in the regions of interest to this study. Stemming from variation in crustal composition and magmagenesis, these provinces correspond roughly to the coast, central and south central Peruvian Andes, with further division into subprovinces along the coast. Assigning regions of origin to individuals based on lead isotope data is therefore possible (Figure 4.3). This is made difficult, however, by the ranges in lead isotopic variation *within* the three provinces of interest, which result in substantial overlap in lead isotope values *between* provinces. As such, each individual received three estimates of their province of origin according to each of the three lead isotope ratios. Because of the overlap in isotopic ranges, each of the individual's three estimates could assign them to one, two, three or even all potential lead provinces. If a province was present in all three estimates for a given individual, that individual was assigned to that particular province based on consensus; if not, then the individual was labeled "unknown." There is no significant variation in $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, or $^{208}Pb/^{204}Pb$ by age, sex, cemetery affiliation or cranial modification style (Tables 4.5-4.6).

As noted earlier with strontium, the confounding effects of imported foods merit examination with lead isotopic values, as does the possibility of anthropogenic lead contamination. However, contamination from anthropogenic lead would skew the data towards the lead source, thereby narrowing rather than widening the range of variation. Moreover, the same assumptions of extreme, prolonged, and idiosyncratic dietary variation would apply to arguments that the wide distribution of lead isotopic values in the Machu Picchu population was due to imported food rather than immigration from elsewhere. Therefore, these data further suggest substantial immigration to Machu

Picchu from elsewhere, with ‘elsewhere’ representing any number of regions of Peru and the wider central Andes.

δ^{18}O Results and Discussion

As discussed above, oxygen isotopic ratios in preserved tooth enamel represent the isotopic ratios of imbibed water with some enrichment through metabolic processes during the time in which the tooth formed. Ratios in imbibed water are in turn influenced by temperature, humidity, altitude and other aspects of the local climate. Variation in δ^{18}O across a population therefore suggests variation in sources of drinking water and indirectly in local climate. As is shown in Figure 4.4, the individuals in the Machu Picchu study population show substantial between-individual variation in δ^{18}O at all three early life stages. Teeth that formed in infancy/early childhood (IEC) range in δ^{18}O from 18.34 to 27.7‰, with a mean of 22.9‰ and a standard deviation of 2.56‰; those that formed in middle childhood (MC) range from 16.24 to 26.7‰, with a mean of 22.1‰ and standard deviation of 2.6‰, and those that formed in adolescence (AD, i.e. third molars) range from 17.8 to 25.2‰, with a mean of 21.4‰ and standard deviation of 2.0‰ (Table 4.4). These are extremely wide ranges, suggesting marked differences in drinking water sources early in life among the Machu Picchu population. The following modified formula from Iacumin et al. (see also Dupras and Schwarcz, 2001; 1996) was used to convert enamel carbonate δ^{18}O to the estimated δ^{18}O of imbibed water:

$$\delta^{18}\mathrm{O}_{\mathrm{Carbonate}} = 0.78(\delta^{18}\mathrm{O}_{\mathrm{Water}}) + 31.2$$

$$\downarrow$$

$$\delta^{18}\mathrm{O}_{\mathrm{Carbonate}} - 31.2/0.78 = \boldsymbol{\delta^{18}\mathrm{O}_{\mathrm{Water}}}$$

The resulting in a set of $\delta^{18}O_{Water}$ values spans the entire range of $\delta^{18}O$ estimated for precipitation in the region (Figure 4.5). It must be noted that Machu Picchu, like other Inca sites including Tipon and Ollantaytambo, had canals and wells of spring-fed water that still function today, as well as cisterns for gathering and storing rainwater. Moreover, the branching Urubamba River runs along the base of Machu Picchu and Huayna Picchu Mountains. All of these water sources would be subject to different processes of evaporation, and would be expected to have different baseline $\delta^{18}O$ values. However, to assume that the variation in $\delta^{18}O$ among the Machu Picchu population is due to variation in consumption among the different local water sources at the site is to assume prolonged, idiosyncratic and extreme variation in water consumption at the site, which seems unlikely given the reasons discussed above for $^{87}Sr/^{86}Sr$ and $^{20n}Pb/^{204}Pb$. Moreover, the variety of potential water sources represented by the enamel carbonate $\delta^{18}O$ data far exceeds the number of water sources at Machu Picchu and suggests instead that individuals spent their early lives in a wide variety of climatic contexts.

The Machu Picchu study population also displays a good deal of *within*-individual $\delta^{18}O$ variation. Wright and Schwarcz (1998) postulate that isotopic differences exceeding 0.5‰ between teeth from the same individual may indicate enrichment or depletion associated with dietary changes such as weaning. Individual $\delta^{18}O$ values plotted across the three developmental periods of Infancy/Early Childhood (IEC), Middle Childhood (MC) and Adolescence (AD), show a consistent down-shifting between IEC and MC for most individuals regardless of their actual $\delta^{18}O$ values, suggesting enrichment in IEC teeth from breastfeeding. However, this downshift, while consistent, is not identical for all individuals. A plot of the magnitude of change in individual isotopic values between different developmental stages (Figure 4.6) underscores the variation in $\delta^{18}O$ change within individuals. These differences in magnitude suggest variation in the timing and nature of the weaning process, as some individuals show less depletion in $\delta^{18}O$ during MC, represented by teeth that develop between roughly one through seven years of age. Individuals who show less depletion may have consumed breastmilk for a longer duration during the development of MC teeth than those who show greater depletion between IEC and MC teeth.

However, not all within-individual differences are attributable to weaning-related trends. Changes in magnitude between IEC and AD teeth and especially MC and AD teeth, suggest possible mobility between climatically distinct areas during childhood, following weaning and prior to arrival at Machu Picchu. Constraints on sampling and funding prevented corroborating heavy isotopic analysis (i.e., Sr and Pb) of multiple teeth per individual. However, these within-individual differences in $\delta^{18}O$ raise intriguing possibilities of repeated mobility among several individuals in the population, similar to that suggested by Evans et al. (2006a) in their study of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ in southern England. As shown in Table 4.7, a Kruskal-Wallis test for IEC and one-way ANOVAs for MC and AD developmental periods revealed variation with sex in infancy/early childhood that approaches, but does not attain, 5% significance, with a mean $\delta^{18}O$ for females of 23.4‰ versus 22.1‰ for males. Variation in $\delta^{18}O$ by sex approaches significance in adolescence via a paired t-test (p=0.07). There is no significant variation in $\delta^{18}O$ by age, cemetery location or cranial modification style (Tables 4.7-4.8).

Synthesis of Sr, Pb and O Analyses

Spearman correlations show no significant relationships between $\delta^{18}O$, $^{87}Sr/^{86}Sr$ and $^{20n}Pb/^{204}Pb$, all of which show markedly wide variation in their respective distributions (Table 4.7). On the one hand, this is not surprising given that all are proxies of different aspects of residence, and the climate and geology of the central Andes is each complex. However, this does not necessarily preclude any groupings within the population that are not immediately apparent in these analyses, since individuals may share some subtle commonalities in background. Therefore, two additional analyses were run on the Machu Picchu study population: the first is factor analysis, conducted in order to examine any significant factors or characteristics that tend to shape the distribution of the population. The second, and more important to this study, is hierarchical cluster analysis, conducted in order to examine any significant grouping among individuals in the population by their values of *all* isotopic parameters. The three elements in this study tended to separate out as factors, with all three Pb isotopic ratios strongly grouped under one factor, and Sr and O isotopic ratios each listed under a second and third factor. This underscores the analytic integrity of the MC-ICP mass spectrometry, as the three Pb isotopic ratios would be drawn from the same Pb source in the local environment.

To perform hierarchical cluster analysis, Pb, Sr and O isotopic parameters were transformed into z-scores to control for variation in scales between each isotopic ratio. Individual values of $\delta^{18}O$ were collapsed into a single variable by selecting the developmental period (i.e., tooth type) that matched the tooth type sampled for strontium and lead isotopic characterization. For a few individuals, different teeth were used for light and heavy isotope analysis, therefore $\delta^{18}O$ from the closest developmental period was selected (for example, if an individual's M1 yielded only Sr and Pb isotopic data and their M2 and M3 both yielded δ^{18}O data, the M2 data was used to represent said individual's δ^{18}O in the cluster analysis). The analysis was run for models imposing three, four, five and six clusters, with a one-way ANOVA performed on each model to test for the highest degree of significant difference among the clusters. Ultimately, the goal of this analysis was to find the number of clusters that were most significantly different by *all* isotopic parameters used (δ^{18}O, ^{87}Sr/^{86}Sr, ^{20n}Pb/^{204}Pb). Results of the hierarchical cluster analysis show the most significance (p= 0.000) in a model with six clusters, with each cluster encompassing specific ranges of isotopic data (Figure 4.7b). This corresponds to the groupings shown in the dendrogram generated by the cluster analysis (Figure 4.7a); the dendrogram remained the same regardless of the number of clusters imposed in each test. It therefore appears that there are six potential groupings in the population, including two outlier individuals (PA 3219 G.61 and PA4761 G.99) each assigned their own cluster. PA 3219 G.61 is a female, aged 30-40 years at death, who has significantly depleted ratios of all three Pb isotopic parameters, but falls in the center of the ^{87}Sr/^{86}Sr range and high end of the δ^{18}O range. PA 4761 G.99 is an adult, possibly male, with relatively high Pb isotopic ratios, but also falls in the center of the ^{87}Sr/^{86}Sr range and the lower end of the δ^{18}O range. The six groupings into which the population fits can be generally characterized by the summary in Table 4.8, which is discussed in more detail below.

To assess whether these two outlier individuals and/or the three individuals in the fourth cluster had an artificial effect on the significance of the six clusters, both outliers and the three individuals comprising the fourth cluster were excluded. The cluster analysis was then rerun, imposing two, three and four clusters and testing each model for significant differences between clusters. The resulting dendrogram exhibits the same three clusters among the 39 individuals in the reduced group as is seen in the first three clusters of the six-cluster dendrogram for the full group; consistent with the dendrogram, one-way ANOVAs of the two, three and four cluster models indicate the most significance with a three-cluster model. Additionally, multivariate linear model comparisons were generated for the three-cluster model from the reduced group to check for significant pairwise differences between the three groups (i.e., is Cluster 1 different from Clusters 2 and 3, is Cluster 2 different from Clusters 1 and 3, etc.). While there were both significant and non-significant differences among clusters for each isotopic parameter, these non-significant differences showed no pattern across isotopic parameters. This suggests that while there is some overlap between clusters for each individual isotopic parameter, when all isotopic parameters are analyzed collectively, these areas of overlap are swamped by significant differences between clusters. These results all therefore indicate meaningful differences among the six clusters from the full group, and no skewing effect from the two outlier individuals or the 3-person fourth cluster.

The results of the full, six-cluster-model analysis suggest some potential patterning within the population by broad regional categories, discussed in more detail below. This may indicate subtle commonalities in background among the population, but perhaps not to the degree one would expect if *mitmacona* colonists made up a substantial part of the population. This assertion would benefit from assessment against reference data for the distribution of all of these isotopic parameters within and between regions; in the central Andes, reference data this comprehensive is at present largely unavailable. Future research in this area would be of enormous benefit to analyses of this sort.

Interestingly, there were no statistically significant relationships between δ^{18}O, ^{20n}Pb/^{204}Pb and ^{87}Sr/^{86}Sr and two contextual indicators, cranial modification and cemetery context. Cranial modification is a commonly-used indicator of ethnic affiliation initiated in early childhood during the growth and development of the skull, and could therefore be expected to vary significantly by regional locale. The lack of relationship between local climatic and geological context during early life suggests that residence and cultural affiliation are not necessarily linked, or at least that a given cultural affiliation or ethnicity likely spread on a scale that encompassed multiple ecozones. This would not be surprising in the late Pre-contact Andes, which witnessed the large-scale influence and expansion of a number of large societies, including the Wari, Tiwanaku and Inca imperial states. The intersection of residence and cultural affiliation through time is a fruitful area for future research, as evidenced by recent and ongoing research by Knudson and colleagues (above, and see Torres-Rouff and Knudson, n.d.) and projected research by Andrushko and Turner (n.d.). The lack of relationship between these isotopic parameters and cemetery location, and between cemetery location and cranial modification suggests that individual interments were not organized according to region of origin or ethnic background.

Discussion and Conclusions

One obvious feature emerges from these data. The variation in all isotopic parameters is wide and scattered, with no clear grouping in each distribution and ambiguous groupings by hierarchical clustering. This suggests (1) substantial immigration to the Machu Picchu site, and (2) marked variation in backgrounds among the population with uncertain degrees of commonality. The question then becomes, where might have the members of the population originated, and were any of these individuals local to the Machu Picchu region?

Even if we assume that all three assumed-local faunal specimens in fact reflect local geology, all but five individuals fall outside of the local $^{87}Sr/^{86}Sr$ range. Some general categorization is possible based on the geological context of the central Andes, the heartland of the Inca state. Using sources of $^{87}Sr/^{86}Sr$ data as reference criteria (Figure 4.2), four individuals fall within the Moquegua range, seven into the San Pedro de Atacama range, and six into the Cuzco range; however, the isotopic ranges of these three sites, which are not geographically close to each other, *all* fall within the isotopic range at the Ilo site. An additional 15 individuals fall within the Tiwanaku range, while two individuals fall within the local range at Potosí, in central Bolivia. Six individuals fall within the local Machu Picchu $^{87}Sr/^{86}Sr$ range, if all three assumed-local specimens are included. Interestingly, three of these individuals are affiliated to the same grave (G.50): PA 3207, a young adult, PA 3208, a juvenile aged 11-13 years of age, and PA 3209, a female exceeding 50 years of age. However, two of the six individuals also fall into the local range at Potosí, which is quite far from Machu Picchu. Moreover, if the outlier specimen among the three assumed-local fauna is removed, only one individual (PA 3207 G.50) from the entire skeletal assemblage displays an $^{87}Sr/^{86}Sr$ ratio local to Machu Picchu.

Examining all three $^{20n}Pb/^{204}Pb$ ratios paints a similar picture, shown in Figure 4.3; a substantial number of individuals are assigned to lead isotopic provinces on the coast and northern highlands. Those definitively assigned to Province 3b, where Machu Picchu is located, could come from anywhere in that large geographical swath of southeastern Peru. Further complicating things, a substantial number of individuals cannot be grouped into any of MacFarlane et al.'s (1990) provinces, suggesting residential origin in regions for which reference data is not currently available. The same trend holds for $\delta^{18}O$, shown in Figure 4.5, as only three individuals display values that fall within the range of local precipitation. Using Bowen and Wilkinson's (2002) $\delta^{18}O$ data from precipitation in South America, it would appear that the Machu Picchu population came from a wide variety of climatic contexts.

When analyzed synthetically, six significantly different clusters are produced. The range of values for each isotopic parameter among the members of each cluster were defined and then compared to the reference data that exists for each parameter in order to create an aggregate isotopic profile of the possible regions or origin for the individuals in each cluster. These aggregate profiles are extremely tentative, and there are areas of overlap among the ranges of individual isotopic parameters. Moreover, the admittedly small set of reference criteria available for the central Andes means that some of these profiles are more tentative than others. With these limitations in mind, however, it appears that the Machu Picchu population was comprised of individuals from the southern Peruvian coast, the Lake Titicaca region, the northern Peruvian highlands, (possibly) the coast of northern Peru and/or southern Ecuador, and (possibly) highland Bolivia beyond the Titicaca region (Table 4.9). This corresponds broadly to Salazar's

(2001) characterization of the Machu Picchu mortuary contexts and artifacts as mostly Lupaca, Chachapoya and Chimu. However, all three of these cultures were widespread in both territory and influence, so the analyses presented here provide not only support for Salazar's findings, but potentially a greater degree of specificity as well.

In short, all of the parameters examined here support the notion that this population was drawn from several parts of the central Andes, with little commonality in background among constituents. Returning to the question of which Inca servant class was present at Machu Picchu, these data overwhelmingly support the interpretation that the Machu Picchu residents were *yanacona* and/or mixed *yana* and *aclla* (Figure 4.1). Any *mitmac* colonists present were a relative minority. Tracing individuals to potential regions of origin can be difficult, given the relative infancy of these methods in the Andes and the still-small body of reference data. Nevertheless, some general placement of individuals to regions of origin is possible, as demonstrated here by the use of cluster analysis. Finally, the complexity of the data presented here and the lack of clear relationships with culturally-salient identifiers such as cranial modification or cemetery affiliation points to the importance of nuanced analyses of ancient population dynamics and population movement, especially in the Andean region.

Chapter 5: Dietary Patterns at Machu Picchu

Introduction

Dietary reconstruction is a critical aspect of archaeological analysis. To accurately estimate the diet of an archaeological population is to gain insights regarding subsistence practices, resource utilization and differential consumption. Not only is diet a fundamental aspect of everyday life, it is also a key area of intersection between ecology, political economy and physiological well-being. Therefore, mapping dietary characteristics in ancient populations, not only across cultures and time periods but also within single groups or even single life spans, opens an essential window to better understand their constituents.

As an area of extensive ecological and cultural diversity, the Precolumbian Andes is an area for which a better understanding of subsistence and diet provides particular political, economic and cultural insights. The ancient central Andean economy has long been characterized as a "vertical archipelago" in the highland sierra (Murra, 1980) in which single ethnic groups cultivated crops and pastured livestock at different altitudinal zones, pooling and redistributing resources in order to maximize production across several ecological systems. Conversely, the coastal regions of ancient Peru and northern Chile have been seen as areas of "horizontal" economic specialization, reliance on marine resources, trade and incipient monetization (Rostworowski, 1977). These regional economic differences were sustained under the Inca system of indirect control, meaning that different groups would have had varying access to different food resources depending on where in the state they lived. Moreover, in populations with a substantial degree of immigration and/or emigration, individuals or population subsets may have had widely varying dietary histories; given the synergistic relationship between nutrition and susceptibility to other stressors such as infection (Scrimshaw and SanGiovanni, 1997), especially early in life (Goldenberg, 2003), variation in dietary histories could have also translated to variation in health histories as well.

This study characterizes carbon and nitrogen isotopic ratios in a large sample of the skeletal population from the Inca royal estate of Machu Picchu in order to estimate dietary composition and the degree of dietary variation. Burger et al. (2003) hypothesize that the population from Machu Picchu consisted of *yanacona*, members of a cosmopolitan servant class who were individually selected by elites and moved about the empire for various services, including permanent residence as retainers at royal estates. As such, *yana* populations and/or mixed *yana*/*aclla* populations (see Chapters 2-3) would have been assemblages of individuals who had little to no commonality in background, differentiating them from *mitmacona* labor colonists or local *hatun runa* commoners. This hypothesis is supported by strontium, oxygen and lead isotopic results (Chapter 4). It would therefore be reasonable to assume that wide variation in background could also extend to diet, as the central Andes is characterized by a variety of ecozones and by varying modes of subsistence and goods exchange. An earlier isotopic dataset exists for the Machu Picchu population based on analyses of bone collagen (Burger et al., 2003), which remodels during life and represents averaged isotopic values for the last decade or so leading up to death (Manolagas, 2000). This study utilizes tooth enamel and dentin as the tissues of interest, providing a complementary isotopic dataset that represents isotopic values from specific developmental periods in early life. These two sets of data are therefore useful in interpreting individual dietary change over the lifespan and for characterizing diet from periods in constituents' lives prior to their relocation to Machu Picchu (Chapter 4).

Assessing Diet in Prehistory

The methods available for investigating questions of ancient subsistence, diet and nutritional status can be broadly separated into two categories: indirect, i.e. estimating or reconstructing resources that were available or utilized but not what or how much was actually eaten, and direct, i.e. estimating or characterizing the types and relative proportions of resources that were actually consumed. A suite of methods constitute each broad category, though in separating these methods one must note that some methods, including paleoethnobotanical and biochemical techniques, can measure direct and indirect dietary information depending on what exactly is analyzed.

Indirect Methods

The archaeological study of tools, site features and physical remains has a long history in paleodietary research and has recently developed a much higher degree of analytical precision and innovation in research design. Key innovations in this avenue of inquiry have included direct analyses of site materials to assess subsistence activities. For example, characterization of humic plant residues (Carbone and Keel, 1985), fatty acid residues (Ishige, 2001), trace elements (Knudson et al., 2004a) and stable isotopes (Webb et al., 2004) in soils have provided effective means of identifying specific subsistence activities including fish processing, maize cultivation and large-game hunting.

Other common techniques for estimating the available resource base have centered on various analyses of preserved botanical and faunal remains. Analyses of macrobotanical and faunal assemblages have permitted inferences regarding general resource consumption (Fritz, 1994), resource specialization (Gumerman IV, 1994), and change through time (Bokyoni, 1975). For example, Szuter (1994) emphasized the often unrecognized importance of rodents and other small fauna to the protein component of diets, while Crane and Carr (1994) traced increasing utilization of local animal sources through time among prehistoric lowland Maya populations. In an innovative study, Balasse and Tresset (2002) used stable carbon and nitrogen isotopic analyses of archaeological bovid dentition to suggest delayed slaughter of calves following weaning as a potential strategy to maximize the amount of milk available to a prehistoric pastoral population. Studies of highly durable microscopic plant residues, namely pollen grains and small durable structures found in the epidermal layers of herbaceous plants known as phytoliths, have permitted detailed estimations of food resources from sites where other botanical data is unavailable (Carbone and Keel, 1985; Smith Jr., 1985). Recent studies of starch and xylem cell microfossils from prehistoric New Zealand have provided the earliest evidence for the presence of specific cultigens that do not typically produce more commonly-analyzed pollen grains or phytoliths (Horrocks et al., 2004).

While these techniques have made significant contributions to advancing what is known of past resource bases and subsistence, all share inherent limitations. Most obvious among these are taphonomic biases, i.e. differential preservation by site, age, depositional environment, species and morphological element that affect the representativeness of any botanical or faunal assemblage (Parmalee, 1985; Wing, 1994). Of recent note are issues of recovery bias, including such mundane factors as screen-mesh size and whether or not flotation was used for small remains, to theoretical myopia skewing attention to larger or more-expected resources (Sutton, 1994). Finally, it is well-accepted that presence at a site does not equate to usage or degree of dependency, and thus even accurate reconstructions of resource *availability* often cannot be used alone to confidently predict the degree or frequency of resource *use* (Parmalee, 1985; Styles, 1994).

Complementing many of these approaches is bioarchaeological dietary reconstruction involving morphological and/or pathological studies of human remains. Chronic nutritional stress and/or dietary monotony often leads to skeletal and dental involvement through disrupted growth, oral disease, cranial lesions, and other such features (Goodman et al., 1984), while variation in patterns of tooth wear are often used to identify various food processing techniques (Irish and Turner, 1997). While significant inferences regarding diet can be made through single-pathology analysis, the vast majority of bioarchaeological studies focus on combined analyses of skeletal pathological conditions including tooth loss, carious lesions, occlusal wear and porotic or hypoplastic lesions. This multifactorial approach permits broad assessments of food intake among archaeological populations, often differentiating cultigen-, marine- and animal-based diets (Goodman et al., 1984; Kieser et al., 2001) and assessing the physiological and morphological effects of dietary shifts associated with culture change (Larsen, 2002; Van Gerven, 1982).

Among the limitations inherent to functional morphological and pathological analyses are preservational and recovery biases within and between archaeological populations (Guy et al., 1997; Saunders and Hoppa, 1993; Walker et al., 1988; Willey et al., 1997) and the nonspecificity of many skeletal and dental pathologies (Goodman et al., 1984). Also of concern is the difficulty of separating function from phylogeny in craniometric and dental allometric studies (Ungar, 1998; Van Gerven, 1982).

Direct Methods

The potential for directly estimating consumed food resources has become increasingly relevant to paleodietary studies. Indirect methods are essential to profiling what was available to a given population and the ways in which various resources may have been procured and used. The ability to extend this framework even further, to estimate what was actually consumed from the array of choices, using individuals as the units of analysis rather than whole populations, has revolutionized what is known regarding dietary intake and nutritional status through space and time.

Analyses of preserved gut contents and fecal material (coprolites) are especially useful for determining consumed foodstuffs in both human and faunal remains, providing important clues as to ancient subsistence, cuisines and nutrition. Fry (1985) noted the plethora of food material preserved in coprolites, which permits inferences regarding seasonal resource utilization, local climate and the specific resource components that were consumed. Holden (1991) provided direct evidence from Chilean mummies' gut contents and coprolites of tuber species thought only used for animal fodder, a decreasing reliance on domesticated plants though time and seasonal camelid pastoralism, while

Faulkner (1991) identified several plant processing techniques and an intermediate, mixed hunter-gathering and cultivating mode of subsistence among a transitional Early Woodland population in the United States. In an innovative study of faunal coprolites, Panagiotakopulu (1999) interpreted animal husbandry practices in Pharaonic Egypt through the identification of cereal types used for fodder. Even estimations of cuisines and processing techniques have been inferred from covarying plant types (Rhode, 2003) and the micromorphology of partially cooked starch grains (Horrocks et al., 2004) found in coprolites. All of these authors, however, independently note that coprolites provide little to no information on habitual dietary intake, and that their rarity in archaeological contexts limits their widespread use as a source of paleodietary information.

Isotopic reconstructions of diet in archaeological populations constitute an important area of bioarchaeological research, utilizing biochemical measures of the relative importance of constituent food types to individual diets. Isotopic ratios of carbon in bone apatite and enamel ($\delta^{13}C_{ap}$) represent the overall contribution to the diet of terrestrial or marine animals, and plants with C_3 versus C_4 photosynthetic pathways (less common are plants with crassulean-acid metabolism (CAM) photosynthetic pathways, whose $\delta^{13}C$ values are intermediate between C_3 and C_4). In bone and dentin protein, the majority of which is collagen, the same ratios ($\delta^{13}C_{col}$) represent the contribution found in dietary protein (Ambrose and Norr, 1993). Isotopic nitrogen ratios ($\delta^{15}N$) found in bone and dentin collagen reflect the types of protein (animal versus vegetable, leguminous, terrestrial versus marine) incorporated into the diet (DeNiro and Schoeninger, 1983), representing trophic-level effects in protein intake associated with organisms' positions in food webs (Ambrose et al., 1997; Ambrose and Norr, 1993; Lee-Thorp et al., 1989).

Calculated offsets between apatite and collagen $\delta^{13}C$ ($\delta^{13}C_{ap}$ - $\delta^{13}C_{col}$, i.e. $\Delta^{13}C_{ap\text{-}col}$) estimate the relative proportion of protein in an organism's overall diet (Lee-Thorp et al., 1989). Animal products have much higher protein content than do plant products. Therefore, calculated offsets between apatite and collagen $\delta^{13}C$ have generally been used to estimate the relative dependence on animal versus vegetable protein and the extent of carnivory in the diet, or changes in dietary macronutrients (Lee-Thorp et al., 1989). Early interpretations of these offsets suggested that values of 4% or less indicated diets in which the bulk of carbon was drawn from animal protein, indicating a more carnivorous subsistence pattern, while values of 6–7% indicated a more herbivorous diet, and values intermediate between the two indicated an omnivorous diet (Krueger and Sullivan, 1984). More recent interpretations, however, suggest that dietary differences only account for part of this herbivore–carnivore effect and must be considered along with processes such as methanogenesis and bone formation (Hedges, 2003), pointing to the need to consider metabolic variation across taxa when interpreting offset values and transposing these criteria onto humans.

Working from these basic premises, $\delta^{13}C_{ap}$ values from fossil and archaeological enamel and bone are used to directly characterize paleodiets (reviewed in Katzenberg and Harrison, 1997) and dietary resources (Kingston, 1999; Thackeray et al., 1996), while combined analyses of $\delta^{13}C_{col}$ and $\delta^{15}N$ have been used to further explore trophic-level effects between isotopic signatures in tissues of consumers and their prey (Sullivan and Krueger, 1983), the metabolic effects of water stress (Ambrose, 1991), and human subsistence variation in a wide variety of ecological contexts (Aufderheide and Santoro, 1999; Katzenberg and Weber, 1999; Larsen et al., 1992; Papathanasiou, 2003; Pate, 1997; Richards et al., 2003; White et al., 2001b; Yoneda et al., 2004). Such techniques provide insights into patterns of subsistence and resource utilization and measure inter- and intra-group variation in dietary composition, such as the relative abundance of different forms of protein and carbohydrate in the overall diet (reviewed in Katzenberg and Harrison, 1997).

Paleodietary analyses using stable isotopes have grown increasingly sophisticated with the refinement of analytical techniques, increased resolution and greater understanding of the complex and variable cycling of stable isotopes in biological systems. These include controlled feeding studies of laboratory animals (Ambrose and Norr, 1993; Tieszen and Fagre, 1993) and studies that include reference data from local floral and faunal food sources (Iacumin et al., 1998; Schoeninger and DeNiro, 1984; Tieszen and Chapman, 1993; White and Schwarcz, 1994).

Studies of $\delta^{13}C$ and $\delta^{15}N$ in prehistoric Americans have related dietary composition and food systems to cultural development (Larsen et al., 1992; White et al., 2001a; Wright, 1999; Wright and Schwarcz, 1998; Wright and White, 1996), sex-related dietary variation (Ambrose et al., 2003; Hastorf, 1996; Reinhard et al., 1994; White and Armelagos, 1997) and the stresses of European contact (Hutchinson and Norr, 1994; Larsen and Ruff, 1994). More recently, $\delta^{15}N$, $\delta^{18}O$ and $\delta^{13}C$ have been used to measure age-specific dietary trends such as those associated with weaning (Herring et al., 1998; Katzenberg et al., 1996; White and Schwarcz, 1994; Wright and Schwarcz, 1999) and subadult diet (Balasse et al., 2001; Katzenberg, 1992; Katzenberg et al., 1996; Schoeninger, 1995; Wright and Schwarcz, 1998; Wright and Schwarcz, 1999).

Many isotopic studies utilize single bone-tissue components that represent averaged isotopic characteristics over the course of life. However, isotopic markers of dietary composition from developmentally diachronic tissues, such as tooth enamel and dentin, have been used to elucidate dietary reconstruction at different stages of an individual's life. As discussed in Chapter 4, teeth form at predictable developmental rates (Hillson, 1996) and do not remodel once formed as do bones. Sampling enamel and dentin from multiple teeth per individual therefore permits the characterization of isotopic ratios representing diet at different stages of individual development. These isotopic data allow some discussion of early diet as it pertains to the process of supplementation and weaning as well as changes in diet during life.

Ancient Andean Diet: An Overview

Much of what is known about ancient Andean diet comes from colonial Spanish accounts, perhaps the most reliable of which come from accounts first published in 1653 by the Jesuit priest Bernabé Cobo (1890-1895 [1653]: 194; Rowe, 1946). Based on these sources, a handful of goods comprised the bulk of utilized food resources leading up to and during the Late Horizon, with broadly distinct but overlapping dietary patterns in the highland sierra versus the coast. Staple goods included maize; potatoes and other tubers; grains such as *quinoa*, *kañiwa* and *kiwicha*; *ají* peppers; salt; and legumes (Cobo, 1964 [1653]: Bks. 4, 11, 14). Importantly, *kiwicha* is the the only other known C_4 plant in the western hemisphere utilized by human populations besides maize. While enriched $\delta^{13}C$ values in most prehistoric North American populations (for example, Larsen et al., 2001) indicate consumption of maize, C_4-grazing animals or marine foods, in southwestern

North America and Andean South America the same enriched values could indicate consumption of *kiwicha* as well. *Kiwicha* is the Quechua name for amaranth (*Amaranthus caudatis*), a nutrient-rich C_4 grain that high in protein and fiber (National Research Council, 1989: 143), and is therefore a plant product with distinctly different effects on oral health and risk of iron-deficiency anemia than maize (discussed in more detail below). Coastal populations included a substantial degree of crayfish and fresh and dried fish such as sardines and anchovies, though there is little to suggest that pelagic (deep-sea) fish contributed to the diet (Marcus et al., 1999: 6568). These products were also dried and traded for dried llama meat to the highlands, where they were kept in storehouses (Marcus et al., 1999; Rostworowski, 1977). Similarly, communities in proximity to rivers may have also consumed fish, though evidence for this is not unequivocal (Davis, personal communication 2007). Hunting was strictly regulated by the Inca, while *cuy* (guinea pig) and llama were consumed primarily in ceremonial or celebratory contexts (Rowe, 1946: 217); therefore consumption of meat was likely limited. Llama and alpaca were not utilized for their milk, and dairy appears to have played no part in the diet. Baker (1963) notes the widespread consumption of lime and ash with chewed coca leaves in modern contexts and suggests that this practice has long provided an important source of dietary calcium to Andean populations.

Recently, isotopic studies of Andean populations have provided critical insights into prehistoric Andean subsistence variation (Aufderheide et al., 1994; Aufderheide and Santoro, 1999; Benfer, 1990; Sandness, 1992; Tomczak, 2003; Ubelaker et al., 1995; Williams, 2004). Several studies have focused on regional and temporal variation in subsistence patterns related to social complexity, including those related to social or gendered inequality. Hastorf (1990), for example, found differences in isotopic parameters of diet among Xauxa versus Inca populations in the Upper Mantaro region, suggesting changes in subsistence due to imperial influence on crop production and resource access. Hastorf (1996) further found sex differences in maize consumption based on isotopic and archaeological site data, suggesting that males in the Xauxa culture enjoyed more gifts of maize and *chicha* (maize beer) at elite-sponsored feasts than did women under Inca domination.

In her review of colonial accounts of Inca-period Andean diet, Bray (2003: 9) notes that the diets of high-status versus low-status groups in the Inca state primarily differed not in their basic components, but in the quantity and quality of resources, the style of preparation and in the variety of accoutrements. Thus, the nobility consumed more meat and a greater variety of maize-based dishes, while commoner and servant classes consumed proportionately more tubers and greens (Bray, 2003: 9-10). The distinction of these models is supported by Tomczak's (2003) isotopic study of populations from the coastal Osmore drainage of southern Peru. In addition, there is a long tradition in the central Andes of community self-sufficiency, meaning that within both models of change, there would likely be less emphasis on long-distance or interregional trade (Murra, 1972). Within this overall context, it would therefore be reasonable to assume diversity in diet related to subsistence context, varying by climate, altitude, aridity and proximity to rivers, lakes and the Pacific Ocean. Data suggesting that the Machu Picchu population was drawn from a number of areas of the central Andes (Chapter 4) could therefore also be used to suggest that members of the population grew up consuming different diets. This could have important implications for interpreting nutritional status and health among the population (Chapter 6), and for understanding non-elite subsistence practices during the Inca period. To explore this suggestion, isotopic data directly related to dietary resources are characterized for the Machu Picchu population and used to interpret both within-individual and between individual dietary trends.

Study Objectives

The generation of cross-sectional and longitudinal isotopic data sets permits detailed, multilevel reconstruction of culturally- and ecologically-mediated dietary trends at different points of life. Given the degree of state-mandated population movement in the Inca state described in ethnohistorical sources (Chapter 3), variation in archaeological features among the Machu Picchu population (Chapter 2), and wide variation in oxygen, strontium and lead isotopic data (Chapter 4), it is hypothesized here that at least some of the individuals in Machu Picchu were not local to Urubamba province. The variation in backgrounds suggested for the Machu Picchu population likely translates to variation in subsistence patterns and available food resources prior to arrival at Machu Picchu. The extent of this diversity, and change in its magnitude over the course of individual lives, is unclear. Therefore, it is further hypothesized that (**H_2**) the Machu Picchu population varies significantly in isotopic parameters of diet from early in life (i.e., birth through early adolescence), and that (**H_2a**) diet early in life differs from diet later in life.

As shown in simplified models in Figure 5.1, the distribution of each isotopic parameter is expected to vary widely and with no discernable modality, as would be the case among *yanacona* where potentially every member came from a different geographic and/or cultural background. Moreover, variation of dietary isotopic parameters in a *yana* population would be expected to winnow between early- and late-life, as dietary patterns converged following arrival at Machu Picchu. Bi- or multimodality in the distribution of isotopic data would indicate dietary similarities among subsets of the population, as would be expected if the Machu Picchu population was wholly or partly comprised of *mitmacona* colonists who would likely share similar backgrounds. In a *mitmacona* population, early-life diet would also be expected to differ from early-life diet, marking subsistence change with relocation to Machu Picchu; however, within-population variation would be consistently low. A population of local *hatun runa*, including locally-born descendants of earlier immigrants, would be expected to show consistency in diet, varying little in dietary isotopic parameters both early and late in life.

This study characterizes early-life dietary patterns in the Machu Picchu population that likely predate relocation to the site, and compares a subset of these early-life parameters to published results from previous isotopic analysis of bone collagen from the population by Burger et al. (2003). Since the latter are from analyses of bone collagen, they represent the *last* decade or so in the life of the individuals examined. The data produced here are drawn from an adult population, but represent dietary composition during the *first* decade or so of life. They therefore complement the existing isotopic data and provide a window into a different developmental period for individuals in the Machu Picchu population. The comparison of these two sets of isotopic data will permit assessment of both within-individual variation across the life span and between-individual variation among the population. However, the 1987 study sample is based on different sampling criteria of accessible and analyzable bone in the earlier study, versus available tooth dentin here. There is therefore overlap in these study samples in that thirteen individuals have been analyzed for both early- and late-life isotopic data, but there are also individuals studied here who do not have isotopic data from bone collagen as a result.

Methods

Sample Selection

Individuals from the overall skeletal assemblage were included in the study population based primarily on availability of identifiable permanent teeth, but also by sufficient preservation to estimate sex and age or by notable characteristics such as cranial modification or unusual burial context, resulting in a study population (N=74) from the three cemetery areas at the site. The same procedure used to isolate and characterize δ^{18}O in enamel carbonate also characterizes $\delta^{13}C_{ap}$; therefore, tooth enamel sampling criteria for apatite carbon isotope ($\delta^{13}C_{ap}$) analysis is summarized in Chapter 4.

The ideal sampling design for collagen carbon isotope ($\delta^{13}C_{col}$) analysis would be similar to that for $\delta^{13}C_{ap}$, consisting of a first, second and third permanent molar from each individual, providing a developmental isotopic window spanning birth through roughly fifteen years of age. However, concerns with minimizing intrusion to *in situ* teeth among Peabody Museum staff led to a modified sampling design centered on collecting minimal material to generate viable purified collagen samples. One needs only 20-30mg or so of tooth enamel in total to characterize carbon, oxygen, strontium and lead isotope ratios (see Chapter 4), because enamel is made up almost entirely of the mineral carbonate or phosphate hydroxyapatite needed for analysis. However, only approximately 20-30% of dentin is the organic matrix (most of it Type I collagen) needed for organic carbon and nitrogen isotope analysis (Becker et al., 1986; Butler, 1992); one therefore needs a larger dentin sample to start with in order to produce isotopic data. With this and museum sampling concerns in mind, 25-40mg of dentin was collected from those individuals with adequately exposed and accessible dentin in M1, M2 and/or M3 teeth, in order to characterize $\delta^{15}N$ and $\delta^{13}C_{col}$ from purified dentin collagen. M1 dentin represents “infancy/early childhood,” while individuals’ M2 and M3 dentin were pooled when both were present, to maximize collagen yield and represent “middle childhood/adolescence” (Table 5.1). Individuals who only yielded M2 or M3 dentin were still grouped in middle childhood/adolescence, as both are subsumed in that category. As detailed in Chapter 4, tooth enamel was sampled from M1, M2 and M3 from each individual when present, resulting in $\delta^{13}C_{ap}$ data representing three distinct time periods for each individual, “infancy/early childhood,” “middle childhood,” and “adolescence” (Table 5.1). Incisors and second premolars were used, respectively, as substitutes for first and second molars in the event of their absence. $\Delta^{13}C_{ap\text{-}col}$ offsets were established for infancy/early childhood by taking the difference between first molar enamel and dentin $\delta^{13}C$, and for middle childhood/adolescence by taking the difference between pooled dentin and averaged enamel values for $\delta^{13}C$ in second and third molars.

Isotopic Analysis

Recent assessments of isolation protocols for archaeological bone collagen (Liden et al., 1995) suggests that methods of extraction using only sodium hydroxide (NaOH) to remove lipids can decrease collagen yields and fail to completely remove lipid contaminants. The dentin samples analyzed here were quite small, the majority weighing less than 30 grams, therefore maximizing collagen yield while ensuring collagen purity was of central concern. Thus, a collagen purification protocol designed to minimize contaminants in very small samples was adapted from previously-validated methods (Turner et al., 2007; Turner et al., 2005) modified from those detailed by Stafford (personal communication 2002), Liden *et al.* (1995) and Ambrose (1993). Samples were crushed with an agate mortar and pestle and continually flushed for four hours with a 10:5:1 solution of methanol, chloroform and water in a Soxhlet distillation apparatus to remove lipids, then air-dried for forty-eight hours at room temperature. Samples were then transferred to annealed 15ml glass tubes with Teflon caps and demineralized in 0.5 M HCl at 4ºC until translucent in appearance, with periodic replacement of HCl using annealed glass pipettes. Samples were then treated with a 0.2% potassium hydroxide (KOH) solution for 48-72 hours, depending on sample integrity, to remove humic contaminants, soaked in 0.5 HCl for 48 hours at 4ºC, and then solubized in a 0.05M HCl solution at 95ºC for approximately 8 hours. The gelatinized samples were filtered through .045μm millipore syringe tips into 5ml borosilicate tubes and freeze dried under vacuum for 36 hours. The data generated here are distinct, both in terms of the developmental period they represent and in terms of the method used to characterize them, from the earlier set produced in 1987 by Burger et al. (2003) for the Machu Picchu population. These earlier bone collagen data were generated using methods that have undergone some alteration in the ensuing seventeen years with increased attention to lipid removal and reducing initial tissue sample sizes.

Baseline isotopic data exists for a number of Andean food resources, particularly marine animals, based on research by Tieszen and Chapman (1993). Since $\delta^{13}C$ in marine trophic webs is enriched by as much as 7‰ compared to their terrestrial counterparts (Schoeninger and DeNiro, 1984) due to difference in atmospheric versus oceanic carbon pools (Smith and Epstein, 1971), these provide important dietary contextual data. However, Tieszen and Chapman utilized food resources from northern coastal Chile, one of the most hyper-arid regions of the world. Ambrose (1991) points to enrichment in $\delta^{15}N$ values with water stress and Kingston (2003) notes substantial differences in $\delta^{13}C$ from the same species of plant based on different growing conditions. Therefore, modern plant samples from Inca-period staple crops and archaeological llama bone were collected from farms in the village of Huacarpay, outside of Cuzco, Peru and analyzed isotopically in order to characterize a terrestrial "menu" based in the southern Peruvian highlands. Care was taken to ensure that plant samples were from farms that do not utilize chemical fertilizers so as to avoid any potential enriching effect on $\delta^{15}N$ due to high-nitrogen inputs (Commisso and Nelson, 2007).

In a review of colonial literature on traditional Andean culinary practices, Bray (2003: 9-10) describes the most common methods for preparing food as boiling, roasting, toasting, grinding and fermenting (i.e., for *chicha*). Most of the staple goods collected here are inedible and indigestible in their raw form. Therefore, food samples were rinsed with ddH_2O and subjected to boiling, roasting and toasting in the laboratory, then freeze-dried and ground prior to characterization of $\delta^{13}C$ and $\delta^{15}N$. This permitted comparison of isotopic values based on differences in preparation.

Carbon and nitrogen stable isotope composition of purified collagen and food samples were analyzed on a Carlo Erba CNS analyzer interfaced with a Micromass Prism Series II stable isotope ratio mass spectrometer at the Center for Isotope Geoscience at the University of Florida, Gainesville. The analytical precision of the mass spectrometer was ±0.20‰ for $\delta^{15}N$ and ±0.14‰ for collagen $\delta^{13}C$. Samples of tooth enamel carbonate apatite were also purified for inorganic carbon and oxygen isotope analyses; enamel sampling criteria, purification methods, mass spectrometry analysis and enamel $\delta^{18}O$ results have been presented and discussed in Chapter 4, while $\delta^{13}C_{ap}$ results are presented below. Statistical analyses were performed using SAS 9.1 (English) and MS Excel for Microsoft Office 2007.

Results

The isotopic results for the Machu Picchu human dentin and bone samples are summarized in Table 5.2. Results for analyzed food samples are summarized in Table 5.3, which also includes reference data from Tieszen and Chapman (1993) for fish and other faunal resources. No systematic difference was found in $\delta^{13}C$ or $\delta^{15}N$ of food samples based on cooking/preparation technique; this bolsters the integrity of this reference set. Two features are immediately obvious in the Machu Picchu study population's isotopic data set: (1) pronounced variation in the distribution of carbon and nitrogen isotopic values for dentin and enamel, and (2) an absence of C/N ratios. I will address each of these features in reverse.

Ratios of carbon to nitrogen (C/N) are a common, if not ubiquitous, measure of sample integrity in organic isotope analyses, and collagen samples from preserved bone or dentin are considered unaltered if their C/N ratios fall within a range found in living bone, i.e. 2.9 to 3.6 (Ambrose, 1993). The absence of C/N ratios among the dentin samples in this study is due entirely to the minute amounts of collagenous material purified from each individual, discussed above; there was simply not enough collagen to produce isotopic data and the %C and %N necessary to calculate C/N ratios using the mass spectrometer described above. However, the majority of these samples can be considered unaltered by diagenetic processes for several reasons. First, the majority of the graves at Machu Picchu were above-ground cave interments, meaning that many of the individuals had no contact with burial soils. The possibilities of elemental exchange through the grave environment were therefore minimal. Additionally, a second commonly-used measure of collagen integrity is the percent yield of collagen relative to the initial bulk tissue sample, as the Type I collagen that represents the vast bulk of skeletal protein is considered to comprise 20-30% of the overall skeletal mass (Becker et al., 1986).

As summarized in Table 5.2, percent yields by and large fall into within the range expected in living tissue, which bolsters sample integrity; however, the presence of outliers among percent yields presents an additional issue. Several individuals displayed collagen yields in excess of 35% or even 50%, which would not be expected in living tissue and therefore can be directly interpreted as inadequately purified or contaminated. Therefore, the eight samples above the 25% high-end threshold of living skeletal tissue were excluded from reported results and analyses. To assess the potential of systemic methodological error skewing collagenous isotopic ratios, percent yields were plotted with $\delta^{15}N$, $\delta^{13}C$ and calculated offsets ($\Delta^{13}C_{ap-col}$) between enamel apatite $\delta^{13}C$ and dentin collagen $\delta^{13}C$ (Figures 5.2, 5.3 and 5.4, respectively). All three plots indicate no significant linear or modal relationship between percent yields and any isotopic measures, with Pearson and Spearman correlations non-significant for all (Table 5.5).

As summarized in Table 5.4, individual $\delta^{13}C_{ap}$ at all three developmental periods ranges over 10‰, with standard deviations of 3.2 – 3.3‰. If we assume a diet – apatite spacing of ~11‰ (Tomczak, 2003), which is intermediate between the 9‰ spacing of small-bodied omnivores and the 13-14‰ spacing of large-bodied ruminants, the diets of the individuals in the Machu Picchu population ranged in $\delta^{13}C$ from -12.0‰ to -24.5‰, which encompasses much of the range between C_4 and C_3 plants and their consumers (Ambrose, 1993). It can therefore be inferred from these data that individuals at either end of the $\delta^{13}C_{ap}$ continuum were consuming quite different diets, with some relying primarily on C_3 resources such as C_3 plants, freshwater fish and terrestrial browsers, and others on C_4 resources such as maize, amaranth, or terrestrial grazers. Individual $\delta^{13}C_{col}$ at in infancy/early childhood and middle childhood/adolescence ranges upwards of 5‰ and with standard deviations exceeding 2.5‰ (Table 5.4, Figure 5.5). These ranges also indicate marked difference in diet among those individuals analyzed, in this case specifically in dietary protein; assuming a 5‰ difference between $\delta^{13}C_{col}$ and $\delta^{13}C_{diet}$, along the $\delta^{13}C_{col}$ continuum some individuals appear to have consumed freshwater fish, terrestrial C_4 grazers, and/or *kiwicha* while others relied more on C_3 browsers and C_3 plants, and others likely consumed mixed diets. In addition, magnitudes of change within individuals across developmental periods shows marked variation in both $\delta^{13}C_{ap}$ (Figure 5.6), suggesting diversity in dietary change during early life as well.

As discussed earlier, $\delta^{13}C_{ap}$ data serve as proxies of whole diet, including carbohydrates, proteins and fats, while $\delta^{13}C_{col}$ data serve primarily as proxies of the contribution and source of dietary protein (Ambrose and Norr, 1993; Jim et al., 2004). Therefore, studying offset values between apatite and collagenous carbon ($\delta^{13}C_{ap}$ –

$\delta^{13}C_{col}$, i.e. $\Delta^{13}C_{ap\text{-}col}$) gives some indication of the relative contribution of protein to the overall diet. As shown in Table 5.4, $\Delta^{13}C_{ap\text{-}col}$ values are similarly varied in their distribution, ranging from 5.7-9.3‰ and with a standard deviation of 1.1‰. This suggests that individuals varied widely in the relative contribution of protein to their diets, with some individuals consuming more substantial proportions of protein in their diets, and others consuming very little. While one could interpret this to mean that the former were relying on a relatively larger amount of animal protein, such as llama or *cuy* meat or marine foods, lower $\Delta^{13}C_{ap\text{-}col}$ values could also reflect substantial incorporation of amaranth, or *kiwicha*, in the diet. Amaranth has a protein content of 13-18%, higher than many other grains (National Research Council, 1989: 143) and substantially higher than Andean leguminous sources such as lima beans (5.3%). This is admittedly lower than the protein content found in forms of animal protein such as llama *charqui* (dried llama meat, which has as much as 80% protein (Garcia et al., 2001). It is also lower than the 16-23% protein content of quinoa, a native C_3 grain. Nonetheless, *kiwicha* could have contributed a significant amount of protein to the diet that is isotopically intermediate between marine animals and C_4 terrestrial grazers (Figure 5.7), as its protein is of high nutritional quality (National Research Council, 1989). Those with high $\Delta^{13}C_{ap\text{-}col}$ values, i.e. lower contributions of protein in the diet, were likely consuming proportionately higher quantities of low-protein plant materials.

An additional parameter of estimating the nature of dietary protein is collagenous $\delta^{15}N$, which serves as a proxy of dietary protein composition. Nitrogen isotopes also enrich in a stepwise manner of 3-5‰ through trophic webs, thereby reflecting trophic-level effects in protein intake associated with the position of organisms in food webs

(Ambrose et al., 1997; Ambrose and Norr, 1993; Hedges and Reynard, 2007; Lee-Thorp et al., 1989). As shown in Table 5.4 and Figure 5.5, $\delta^{15}N$ values vary widely throughout early and middle childhood; standard deviations exceed 2‰ and, in middle childhood reach 4.8‰. While mean $\delta^{15}N$ values for these two periods are each 11.8‰, ranges of both early and middle childhood $\delta^{15}N$ exceed 8‰, from 8.3‰ to 16.5‰ and 7.4‰ to 24.4‰, respectively.

Interestingly, only one individual exhibits $\delta^{13}C_{col}$ and $\delta^{15}N$ in the range one would expect from a diet that includes substantial marine fish, with a $\delta^{15}N$ value of 24.4‰ during middle childhood/ adolescence. This outlier individual (PA 3227 G71) is a male, aged 19-24 years at death, who displays a percent yield within the normal range, and is not an outlier in their $\delta^{13}C_{col}$ value (-12.0‰). He is therefore not excluded from analyses; it is possible that this extreme degree of enrichment in $\delta^{15}N$ could be due to prolonged breastfeeding, especially from a mother whose own diet was rich in marine fish, to consumption of marine fish himself, to metabolic abnormalities, or some combination of these factors. However, if his $\delta^{15}N$ outlier is excluded from the middle childhood/adolescent cohort, the $\delta^{15}N$ range for the study population reduces from 17.0‰ to 6.3‰, which is still a substantial degree of variation.

Assuming a roughly 3‰ enrichment between food source and consumer, this suggests that (with the exception of the aforementioned outlier) the $\delta^{15}N$ of the various protein sources consumed by most of the individuals in the study group during early and middle childhood ranged between 4.4‰ and 13.5‰. These values span the range of most, but not all, of the available protein sources (Figure 5.7), discussed in more detail below. A possible confounder of these estimates is that $\delta^{15}N$ has been found to enrich in animals living in arid environments, due to physiological mechanisms of water concentration that result in excretion of a concentrated, ^{14}N-rich urea. Since areas of the central Andes, especially the coastal desert, are characterized by moderate to extremely high aridity, this could be of potential concern. However, there is no correlation between δ^{15}N and δ^{18}O from dentin and enamel from corresponding teeth (among an admittedly small sample size). Since δ^{18}O in teeth reflects the δ^{18}O of consumed water, which in turn is affected by climatic measures such as aridity, this lack of correlation suggests that enrichment through physiological means of water conservation is less likely a major influence on δ^{15}N values.

The presence of both δ^{15}N and $\Delta^{13}C_{ap\text{-}col}$ allows for some further exploration of early-life protein consumption among the Machu Picchu population. A Pearson's correlation shows a negative, but non-significant association between δ^{15}N and $\Delta^{13}C_{ap\text{-}col}$ during infancy/early childhood. However, a Spearman's correlation shows a strong, negative and significant association during middle childhood/adolescence ($r = -0.64$, $p=0.05$), indicating that higher δ^{15}N (indicating protein intake from animal sources or *kiwicha*) correlates to lower $\Delta^{13}C_{ap\text{-}col}$ (i.e., more of the carbon in the overall diet is drawn from protein) during this period (Table 5.5). The fact that this relationship is not significant during infancy/early childhood, when breastfeeding would play at least a partial role in overall subsistence, is unexpected, but may indicate variation in the duration of breastfeeding and the nature of supplementary foods. These results suggest an intriguing, but unclear relationship between the *proportion* and the *type* (terrestrial animal, freshwater animal, high-protein plant) of protein in the diet. They also further underscore the complexity of the isotopic results, and thereby the nature of the dietary composition early in life, among the individuals at Machu Picchu.

Discussion

Carbon and nitrogen isotopic results for the Machu Picchu population are highly variable and suggest marked diversity in dietary composition in early-life developmental periods. Interpreting this variation in terms of reconstructing what people were eating during these periods is complex, and requires consideration of a number of influences, potential confounders, and subsistence scenarios.

For example, values of $\delta^{15}N$ are likely enriched relative to available food resources in the environment during dentin formed in infancy/early childhood, because individuals were likely breastfeeding during part if not all of the first 3.5 years of their life. As discussed above, exclusively breast-fed infants are feeding from their mothers, so the $\delta^{15}N$ of infant tissues is typically enriched by 3‰ relative to older children and adults as they represent additional trophic-level fractionation (Fogel et al., 1989). This would imply that early childhood $\delta^{15}N$ would be enriched by as much as 6‰ relative to consumed dietary protein, i.e. $\delta^{15}N_{\text{diet}}$ + 3‰ = $\delta^{15}N_{\text{maternal tissue}}$, + 3‰ = $\delta^{15}N_{\text{infant tissue}}$. However, the resolution of the sampling here is insufficient to estimate the age at which individuals received supplementary foods or ceased breastfeeding, since almost all individuals are represented by a single dentin sample.

It is perhaps most conservative to assume some additional enrichment in the early childhood sample cohort relative to maternal tissues, indicating at least some breastfeeding during the development of M1 dentin, but not 3‰, which would imply breastfeeding for the entirety of M1 development. As such, an overall enrichment of 4.5‰ relative to food resources is assumed for early childhood $\delta^{15}N$, suggesting a dietary protein base for the Machu Picchu population during childhood of 3.7-12.0‰. These revised early-childhood estimates still suggest that individuals (or rather, they and their mothers) consumed dietary protein from a wide variety of sources, but suggests some inclusion of ^{15}N-depleted foods, such as beans and other leguminous sources, and very little reliance on ^{15}N-enriched foods such as marine fish (Figure 5.7). Overall combined $\delta^{13}C$ and $\delta^{15}N$ results suggest that none of the individuals in the population obtained their dietary protein exclusively from leguminous sources such as lima beans. Several individuals are enriched in $\delta^{15}N$ while relatively depleted in $\delta^{13}C_{col}$, suggesting at least partial reliance on freshwater fish or C_3 browser meat for dietary protein, and similar to findings by Falabella et al. (2007) among populations in central Chile. Some appear to have consumed a substantial proportion of *kiwicha*, while others consumed mixed diets of C_3 and C_4 plants and terrestrial animal and plant proteins.

Comparison with Previous Isotopic Results

A pre-existing isotopic dataset for part of the Machu Picchu population from Burger et al. (2003) permits comparison among a subset of this study population who have both dentin and bone collagen results (Table 5.2). For this subset, $\delta^{13}C_{col}$ and $\delta^{15}N$ values are summarized in Table 5.4; mean $\delta^{13}C_{col}$ shows an increase of 1‰ between dentin and bone results, but similar standards of deviation throughout. Mean $\delta^{15}N$ declines by roughly 2‰ and shows a much smaller standard deviation in bone versus dentin results, especially between bone and dentin representing middle childhood/adolescence. This suggests wider variation in sources of dietary protein earlier in life versus the years leading up to death; taken in conjunction with the data presented in Chapter 4, this points to a greater diversity in dietary protein sources prior to migration to Machu Picchu.

It should also be noted that bone collagen isotopic data represent averaged values over the last decade or so of life (Manolagas, 2000). Since almost half (N=10) of the dentin samples in the study population represent a developmental period extending to as late as fifteen years, it is possible that some lingering isotopic values from early-life were incorporated into bone collagen averages, especially for individuals who died in their twenties or even early thirties. While this would not extend to the entire study sample, it is worth noting that the dentin and bone collagen datasets could have areas of overlap, and that variation in the former may contribute to some of the variation in the latter.

As shown in Figure 5.8, individuals vary in the magnitude of change between early- and late-life in both $\delta^{13}C_{col}$ and $\delta^{15}N$. However, most individuals exhibit an increase in $\delta^{13}C_{col}$ and depletion in $\delta^{15}N$. This suggests a decrease in the proportion of ^{15}N-enriched dietary protein and an increase in the proportion of C_4 food resources. The depletion in $\delta^{15}N$ would be expected at least in part from individuals whose dentin was sampled from first molars and therefore represents values from infancy/early childhood due to supplementation and weaning, though a shift in protein sources independent of this process could also play a role, especially among those whose dentin was sampled from later-developing molars. One could interpret the slight enrichment in $\delta^{13}C_{col}$ as suggesting that there was little change in sources of carbon from dietary protein, but this does not necessarily mean little change in dietary protein sources, given the overlap in $\delta^{13}C$ values between *kiwicha*, C_4 grazers, and maize on the one hand, and between freshwater fish, C_3 browsers and C_3 plants on the other. Unfortunately, $\Delta^{13}C_{ap\text{-}col}$ offsets from dentin and enamel samples are not useful in comparisons between early- and late-life $\delta^{13}C$ data since no bone apatite was characterized in Burger et al.'s (2003) study. However, teasing apart possible shifts in dietary protein sources given this overlap in $\delta^{13}C_{col}$ is facilitated by examining carbon isotopic values in conjunction with $\delta^{15}N$. Slight enrichment of $\delta^{13}C$ in conjunction with depletion in $\delta^{15}N$, tentatively points to increased maize consumption as a potential explanation for both trends. Several individuals appear to have slightly depleted or shown little to no change in their $\delta^{13}C$, but it is argued here that the direction of change may actually be towards enrichment that is masked by differences in sample purification methods between the bone collagen and dentin collagen datasets.

The collagen purification methods used by van der Merwe and Lee-Thorpe in their 1987 characterization of the Machu Picchu bone collagen for Burger et al. (2003) reflected prevailing methodologies at that time. However, subsequent studies by Liden et al. (1995) suggest that aspects of those common purification techniques, specifically the use of NaOH, may be insufficient in removing humic contaminants and lipids from tissue samples. Hence, the methods used here for dentin collagen purification take this into account and incorporate more meticulous with lipid removal through Soxhlet distillation with methanol/chloroform solutions and KOH for removal of humic contaminants. This is a critical point since lipids are depleted in $\delta^{13}C$ relative to proteins, including collagen (DeNiro and Epstein, 1977; Tieszen et al., 1983). Therefore, even if we assume a very slight depletion in all of the resulting bone collagen data due to residual lipids (for example, 0.5‰), this would shift the magnitudes of change in $\delta^{13}C$ seen in Figure 5.8

such that all but a few individuals show zero change, slight enrichment, or moderate enrichment between dentin and bone collagen values. This hypothetical shift accounting for methodological differences would have no effect on $\delta^{15}N$. This supports the interpretation that more than a few individuals show some enrichment in $\delta^{13}C$, possibly due to increased maize consumption between early and late life and corresponds with interpretations of maize consumption at Machu Picchu by Burger et al. (2003).

Conclusion

In sum, the population from Machu Picchu appears to have consumed a wide variety of foods early in life, spanning the range of subsistence contexts attributed to Inca-period Andean populations. The population also appears to have varied widely in the proportion of protein contributing to individuals' overall diets. This variation in diet extends to a lesser degree into adulthood, though the degree to which adult variation could be inflated by residual isotopic values from earlier in life is unclear. However, there is a decline in $\delta^{15}N$ and slight enrichment in $\delta^{13}C_{col}$ between early-life (dentin) and later-life (bone). These results suggest that maize became a more important dietary component, and that ^{15}N-enriched protein sources such as meat, fish or *kiwicha* became less important, following relocation to Machu Picchu, a notion echoed by Burger et al. (2003). However, the magnitude of this potential dietary shift is itself widely variable, meaning that dietary composition for some individuals remained (isotopically speaking) largely unchanged while others experienced marked change. This study illustrates the potential of using multiple organic and inorganic tissues per individual in examining both between-and within-individual isotopic variation, mapping variation and life-course change in diet linked to status-mediated movement in the Precolumbian Andes.

Chapter 6: Possible Etiologies of Pathological Conditions at Machu Picchu

Introduction

The analysis of pathological conditions in preserved skeletal remains has a long tradition in biological anthropology, revealing key patterns of malnutrition, stress and disease in a wide variety of geographical and temporal contexts (Armelagos, 1969; Cohen and Armelagos, 1984; Goodman and Rose, 1991; Kelley et al., 1991; Kellner, 2002; Larsen and Milner, 1994; Lingstrom and Borrman, 1999; Peckmann, 2003; Reinhard et al., 1994; Rose et al., 1985; Ubelaker, 1994; Verano, 1997; Walker, 1985; Walker, 1986; Wright and White, 1996). However, the majority of pathological conditions are limited in their interpretive significance because they are nonspecific in their etiological nature. Many are indicative of chronic conditions with some specificity, such as anemia or microbial infection; yet these and many other such conditions have multiple causal factors. Does cribra orbitalia in a given individual signify anemia due to dietary iron deficiency or to iron loss through parasitic infection? What sort of infectious agent(s) cause a given individual's periosteal reaction? Conditions of the dentition, such as carious lesions and tooth wear, elucidate stressors specifically related to diet, but do not provide concrete information regarding the types of foods actually consumed. Dental pathologies such as enamel hypoplasia are highly sensitive records of episodes of stress at definable points in development, but are nonspecific in that they do not indicate the type(s) of stressor involved (Goodman and Rose, 1990). In terms of their distribution within and between populations, uncertainties in delineating the causal factors of commonly-examined pathological conditions in turn limit interpretation and comparison. One strategy to overcome this is to analyze multiple conditions to identify stressors acting on individuals. This study presents an additional avenue of inquiry, the use of multifaceted stable isotope analysis to elucidate potential causal factors in several pathological conditions. While numerous studies have examined dietary stress through osteological and stable isotope analyses, this study explicitly seeks to differentiate dietary and environmental causal factors, through isotopic and osteological analyses of the large and well-preserved population from the site of Machu Picchu in central Peru.

In this study, dental and cranial pathology data are analyzed statistically against carbon, nitrogen, strontium, oxygen and lead isotopic parameters for two key purposes. The first is to examine relationships between ambiguous indicators such as porotic hyperostosis, cribra orbitalia and enamel hypoplasia against isotopic parameters of geographic origin and/or early-life dietary composition to assess the potential causes of each. The second is to analyze relationships between features tied directly to diet, such as dental wear, carious lesions, and abscesses, against isotopic parameters to assess degree to which subsistence and its resulting health effects are rooted in geographic context. The goal of this analysis is to identify and better understand the relationship between prevalence and distribution of pathological conditions, and their potential causes, prior to relocation to Machu Picchu.

Pathological Conditions at Machu Picchu

Recently, Verano (2003a) completed a survey of the Machu Picchu human skeletal population, updating an earlier osteological study by George Eaton (1916) and reinterpreting the demography, ethnicity and likely function of the population. Verano's analysis did not include a full dental inventory (Verano, personal communication 2004), thus one was completed here as part of enamel and dentin sampling for isotopic analysis. As detailed in earlier chapters, individuals from the overall skeletal assemblage were included in the study population based primarily on availability of identifiable permanent teeth for isotopic analysis, and secondarily by sufficient contextual data from Verano (2003a) on sex, age and any notable characteristics such as cranial modification or unusual burial context (see also Salazar, 2001), resulting in a study population of 67 adults, 6 subadults (10-16 yrs. at death) and one child (5-6 yrs. at death) from the three cemetery areas at the site. Data for pathological conditions are drawn from Verano's (2003a) published data and from data collected at the Yale University Peabody Museum from 2004-2006.

Dental & Cranial Pathological Conditions – Context and Analysis

Each individual in the study sample was examined for pathological features in their dentition as potential indicators of local environmental or nutritional stress. Following established standards for data collection (Buikstra and Ubelaker, 1994), the following conditions were scored, recorded and photographed: incidence, severity and location of enamel hypoplasia, occlusal tooth wear, carious lesions of the dentition and abscesses. During the collection of these data, it was noticed that a number of individuals displayed a fine porosity of the brow and temporal bone; while the etiology and significance of these porous areas is uncertain, they were scored as mild or moderate when present (Figures 6.1a-b, 6.2a-b) in order to investigate them further. Additionally, during the course of dental data collection, eight individuals in the study population were identified as having very slight, healed cribra orbitalia in addition to the four identified by Verano (2003a: 110-111). Estimates of age, sex and porotic hyperostosis and were taken directly from Verano (2003a).

Porotic hyperostosis & cribra orbitalia. The etiologies of porotic hyperostosis (PH) and cribra orbitalia (CO) have long been debated in osteological literature. While there is consensus that both types of lesions are symptoms of anemia, the opposite is true regarding the nature of the anemia and its ultimate causes. Both are attributed to hypertrophy of the bone marrow during childhood in response to hemolytic (Rosthschild, 2002), parasitic (Hapiot, 2003; Stuart-Macadam, 1998) or iron-deficiency (Buckley, 2000; Mittler and Van Gerven, 1994) anemia. Wright and Chew (1998) suggest that cribra orbitalia represents an earlier manifestation of childhood anemia, which can lead to cranial porotic hyperostosis if the anemia persists into adulthood, a notion echoed by Blom et al. (2005). Some have suggested, however, that the lesions are due to other causes such as infectious osteitis or diagenetic alteration (Wapler et al., 2004), lead poisoning (Glen-Haduch et al., 1997) and smallpox (Peckmann, 2003). Kent and colleagues (1994) have suggested that both types of porotic lesions should be interpreted as adaptive responses to parasitic infection through the sequestering of circulating iron necessary for pathogenic growth and reproduction. The presence of the lesions is thus similar to fevers in that it ultimately benefits the host, who in this case is not actually *suffering* from iron deficiency. Holland and O'Brien (1997) dispute this interpretation, arguing that this model of cribra orbitalia and porotic hyperostosis ignores the high rates of dietary anemia among agriculturalists consuming iron-poor cereals with high levels of phytate, an antagonist to iron absorption. They further argue that a synergistic effect of malnutrition and infection is the more plausible cause of anemic lesions, echoing the interpretations of others (Salvadei et al., 2001). However, Blom et al. (2005) argue that latitudinal patterning of porotic hyperostosis in Peru may be due more to differential exposure to parasites in coastal environments rather than dietary iron deficiency. Also germane to Andean paleopathology is Rothschild's (2000) suggestion that porotic hyperostosis and cribra orbitalia could be due to hypoxic anemia caused by migration from low to high altitudes.

In interpreting the significance of these healed lesions in the Machu Picchu material, one must take into account these numerous possibilities for causation. However, if one assumes that the stressors, whether infectious or altitudinal in nature, are in some way linked to local environmental context during early life, it would be possible to examine the role of local environment (via isotopic data) in shaping PH and CO frequencies. It would also possible to analyze PH and CO frequencies against independent (isotopic) parameters of dietary composition to assess the degree to which these lesions are due to an iron-deficient diet (Chapter 5). A similar interpretive framework is useful in analyzing the frequency and distribution of linear enamel hypoplasia (LEH) among the Machu Picchu population (see below). In their comprehensive review, Goodman and Rose (1990) emphasize the interpretive significance of LEH because these lesions serve as highly sensitive, non-specific indicators of metabolic stress experienced by the individual during the period in which the affected tooth crown developed. Therefore, as it pertains to the Machu Picchu population, LEH frequencies analyzed in conjunction with isotopic indicators of residence (Chapter 4) and those of diet (Chapter 5) may help clarify nutritional vs. local environmental insults as causal agents.

Porosity of the brow and temporal bone. An interesting feature observed on a number of individuals was a fine to moderate porosity lacking defined margins of the cortical bone surrounding the external auditory meatus and the supraorbital margin (Figures 6.1a-b, 6.2a-b). The etiology and therefore significance of these porous areas are unclear, however they could reflect some degree of hypervascularization around the ears and/or face due to hypoxia. Yoder (2005) reports similar porosity in a skeletal population from Denmark and suggests vitamin D deficiency as a causal factor. Van Gilse (1938) attributed generalized hyperostosis of the ear canal to infection, though it is unclear how this would lead to corresponding porosity of the supraorbital margin.

Oral pathological conditions. A commonly-employed indicator of general, episodic stress is a type of developmental enamel defect termed enamel hypoplasia (Goodman and Rose, 1990; Rose, 1979), due to the superior preservation of teeth in archaeological contexts and the sensitivity and time-specificity of the defects themselves. Enamel hypoplasias are thought to be sensitive but non-specific indicators of the body's response metabolic insult; the brain secretes corticosteroids and alters the incremental secretion of enamel during tooth crown formation (Goodman and Rose, 1990; 1985). The fact that teeth do not remodel once formed as do bones means that stressors occurring during periods of tooth development are "fossilized," providing critical records of childhood stress in both juvenile and adult remains (Goodman and Rose, 1990).

However, their low specificity means that any number of stressors could lead to hypoplastic lines, including poor nutrition (Brasili et al., 2000; Goodman and Rose, 1991; Jontell and Linde, 1986), diarrheal disease and other stresses of weaning (Goodman, 1988; Goodman et al., 1987), and prolonged infection (Kreshover, 1944; Suckling et al., 1986).

Tooth carious lesions are easily recognized pathological features that are directly related to the consumption of a cariogenic diet, i.e. one that is high in sticky and sugary starches such as maize. Bacterial colonies ferment these carbohydrate residues on tooth surfaces, secreting acidic compounds that demineralize tooth enamel, dentin and roots, resulting in large cavities of continued infection (Hardie, 1982; Holloway, 1983). Chronic, severe carious lesions often lead to oral infections and the appearance of bony abscesses in the maxillary and mandibular alveolae, and thus abscesses also indirectly reflect a poor and often monotonous cereal diet. Carious lesions and subsequent alveolar abscesses are much more common among populations that consume diets heavily dependent on starchy, sugary foods with less fiber and which are generally soft due to cooking and processing (Bonfiglioli et al., 2003; Hillson, 1996; Lingstrom and Borrman, 1999). While occlusal tooth wear is often used as an aging criterion (Lovejoy et al., 1985), such a technique relies on the assumption of uniform attrition and a stable, consistent diet. This is not assumed for the Machu Picchu population, and in fact is a central hypothesis under examination in this study, so for current purposes, variation in occlusal tooth wear among individuals assigned similar ages (ages taken from Verano, 2003a) is taken to represent variation in diet.

In South America, studies of the prevalence of oral and skeletal pathologies across diachronic populations have been pivotal in understanding such diet-related trends as the consequences of agricultural transition. For example, Verano (1992) interpreted general increases in porotic hyperostosis and/or cribra orbitalia as indicative of increased nutritional or infectious burdens due to the stresses of increasing sedentism, population density and growing differentials in status over time. Ubelaker (1984) used increased frequencies of carious lesions as one of several lines of evidence pointing to reduced quality of life in Ecuador following the intensification of agriculture, while Benfer (1984) found no change over time in a similar analysis of coastal Peru and attributed this to the maintenance of a wide subsistence base following domestication. Drusini (1991; Drusini et al., 2001) reported paleodemographic and paleopathological evidence of decreasing quality of life in southern Peru from the Nasca culture of the Early Intermediate Period to the Wari culture of the Middle Horizon, manifested as decreases in stature, increased infant mortality and probability of death at all ages, decreased tooth wear but increased tooth loss, carious lesions and porotic hyperostosis among the Wari, suggesting a shift in diet and increase in overall stress. Kelley and colleagues (1991) compared patterns of dental decay in several populations from northern Chile to correlate frequencies and severity of pathological conditions by subsistence pattern.

Regarding later Andean periods, Ubelaker (1994) also examined multiple indicators of stress and demographic transition in several skeletal populations from Ecuador in order to examine the effects of European contact on population health. Based on decreases in male stature (despite marked consistency in pre-contact periods), dramatic decreases in life expectancy at birth, increases in infectious lesions and traumatic fracture, and increases in the frequency of dental carious lesions and tooth decay, Ubelaker (1994) postulated an overall decline in health during early and late historic periods as a result of new diseases and European influence. However, Ubelaker previously notes variation in estimated population size before and following European contact and the rates and magnitudes of population decline, and suggests that extrapolating the trends observed in Ecuador or any other single region to the rest of Andean South America would be tenuous at best (Ubelaker, 1992). In Georgia and Florida, Larsen et al. (1998; 2001) describe dramatic increases in carious lesions, enamel hypoplasia and other stress indicators between Precolumbian and early Spanish colonial Native American populations. These trends are attributed to the cariogenic effects of an intensified production and consumption of maize. Lingstrom and Borrman (1999) found rates of carious lesions among a seventeenth century Swedish population that strongly suggest a much more cariogenic diet than is traditionally interpreted for that time period. In comparing early versus later Neolithic Chinese farmers, Pechenkina et al. (2002) found significantly higher frequencies of carious lesions related to an increased reliance on soft, processed cereals such as millet, pointing to a reduction in dietary breadth and quality over time.

These studies point to the utility of oral and cranial pathologies in providing insights into dietary variation and change through time among ancient populations. When combined with chemically-based parameters such as stable isotopes or trace elements, osteological analyses of diet are strengthened and interpretations regarding subsistence more refined (Larsen et al., 1998; Larsen and Milner, 1994; Pechenkina et al., 2005; Sandford et al., 1983; White and Armelagos, 1997). Moreover, combining analyses of dietary isotopic data, residential isotopic data, and pathological conditions could be especially useful in assessing the relative contributions of diet and locale on various conditions.

Statistical Methods and Results

Pathological conditions were recorded and coded using established data collection standards (Buikstra and Ubelaker, 1994), or coded from Verano's (2003a) findings. Pathological conditions included in this analysis are summarized by individual in Table 6.1 and by percentage of the study population in Table 6.2. Percentages of the study population measurable for each condition were included to account for differences in preservation among the individuals in the population. As elaborated in Chapters 4 and 5, the distributions of dietary ($\delta^{13}C_{ap}$, $\delta^{13}C_{col}$, $\delta^{15}N$) and residential ($\delta^{18}O$, $^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) isotopic parameters exhibit wide, stochastic variation. Because these parameters were characterized in tooth enamel and dentin representing developmental periods between birth and 13 years of age, this variation is consistent with marked differences in diet and local residence during infancy, childhood and early adolescence. Multivariable analyses were performed on continuous isotopic and discrete pathological parameters using SAS 9.1 statistical software for Windows.

The majority of the study population had at least one enamel hypoplasia on at least one of their anterior teeth, while a smaller percentage had at least one on one or more molars (Table 6.2). Carious lesions, abscesses and antemortem tooth loss were all prevalent, suggesting a substantial degree of poor oral health. Occlusal tooth wear was mild to moderate but was widely varied among the study population, suggesting differences in diet-related abrasion. One individual (PA 3202 G47A) displayed lingual surface attrition of the maxillary teeth, or LSAMAT (Irish and Turner, 1997); interestingly, this individual was the only child included in the study population, but does not fall within the local strontium or oxygen isotopic range at Machu Picchu (see Chapter 4).

Chi-square tests for association were performed to assess significant association between discrete paleopathological variables (Table 6.3). These tests revealed highly significant relationships between the number of carious lesions, abscesses and teeth lost antemortem (AMTL), which is not surprising given that these conditions are often related, sequential stages of oral infection. Carious lesions and AMTL also significantly vary by the number of enamel hypoplasia on the anterior teeth, and the relationship between number of abscesses and number of molar hypoplasia approaches significance (p=0.074). Occlusal wear scores are also significantly related to each other, and to other dental pathological conditions. Average anterior wear scores significantly vary by AMTL, while the relationship between second molar wear scores and AMTL approaches significance (p=0.09). Second molar wear scores also vary significantly by number of abscesses, and approach significant variation by number of carious lesions (p=0.081). Variation in second molar wear scores is highly significant with first, but not third, molar wear scores. This would be expected, as wear patterns between first and second molars are often caused by the same abrasive forces, with second molars less affected due to their later eruption. However, first molar and third molar wear scores do vary significantly, and the practical significance of this relationship is unclear.

The relationship between the prevalence of porotic hyperostosis and cribra is highly significant, which one might expect given that both are attributable to childhood anemia. Interestingly, neither condition shows any significant relationship with any oral pathological conditions, though the association between porotic hyperostosis and number of carious lesions approaches significance (p=0.076). This could suggest divergence in the stressors leading to these oral and cranial conditions.

A combination of one-way ANOVAs and Kruskal-Wallis with Wilcoxon Rank Sum tests were employed to assess significant associations between isotopic proxies of residence or diet and paleopathological data. The results of these tests are summarized in Tables 6.4 and 6.5. Kruskal-Wallis tests found a significant relationship between ^{87}Sr/^{86}Sr, which is a proxy of local geology, and age category but no relationship between ^{87}Sr/^{86}Sr and sex. The relationship between cribra orbitalia prevalence and ^{87}Sr/^{86}Sr approaches 5% significance (p= 0.089); the mean ^{87}Sr/^{86}Sr for those with cribra orbitalia was 0.7084‰ versus 0.711‰ for those without. Also, the relationship between severity of molar wear and ^{87}Sr/^{86}Sr approaches significance (p=0.09, w/M2 wear score). No significant association was found with any other pathological conditions.

One-way ANOVAs found no significant relationship between ^{20n}Pb/^{204}Pb, three related proxies of local geology, and age category or sex, though the relationship between ^{206}Pb/^{204}Pb and sex approaches 5% significance (p=0.095). Also, ^{207}Pb/^{204}Pb was found to significantly vary by severity of third molar dental wear (p= 0.03, R^2=0.25) and the number of anterior enamel hypoplasia (p=0.032, R^2=0.57), but not by any other pathological conditions; the practical significance of these relationships is unclear. ^{208}Pb/^{204}Pb showed no significant variation by any pathological conditions.

Interestingly, some patterning was present between $\delta^{18}O$, a proxy of local water and thus local climate, and the presence of porous conditions of the skull and enamel defects. A one-way ANOVA revealed highly significant variation in adolescent $\delta^{18}O$ with the severity of porosity of the external auditory meatus ($p=0.015$, $R^2=0.37$). Also, highly significant variation in $\delta^{18}O$ was found in infancy/early childhood and in middle childhood by presence of cribra orbitalia; mean $\delta^{18}O$ during infancy/early childhood is 25.1‰ among those with the condition versus 22.4‰ for those without, and the respective means in middle childhood are 24.4‰ versus 21.4‰. Significant variation in $\delta^{18}O$ was similarly found in infancy/early childhood and middle childhood by presence of porotic hyperostosis; again, individuals with the condition show a higher infancy/early childhood mean $\delta^{18}O$ of 25.6‰ versus 22.7‰ for those without, while the respective means for middle-childhood are 24.7‰ versus 21.7‰. Relationships between $\delta^{18}O$ and the number of molar enamel hypoplasia approach significance in infancy/early childhood and adolescence ($p=0.067$ and 0.082, respectively), and are significant in middle childhood ($p=0.015$, $R^2=0.34$). However, no significant variation in $\delta^{18}O$ was found in any of the three developmental periods by age category, dental wear score, cemetery location, cranial modification or other pathological conditions, including porotic hyperostosis and enamel hypoplasia of the anterior dentition.

Relationships between pathological conditions and $\delta^{13}C$ in both enamel apatite ($\delta^{13}C_{ap}$), which reflects an individual's whole diet, and dentin collagen ($\delta^{13}C_{col}$), which reflects an individual's source of dietary protein, were similarly complex and intriguing across tooth development periods. Kruskal-Wallis tests show significant variation in $\delta^{13}C_{ap}$ in infancy/early childhood with severity of first molar dental wear ($p=0.04$);

variation by severity of second molar wear approaches significance (p=0.07), as does variation by prevalence of cribra orbitalia (p=0.08). Kruskal-Wallis tests found no significant variation in $\delta^{13}C_{ap}$ during middle childhood by any pathological conditions; adolescent $\delta^{13}C_{ap}$ varies significantly by sex (p=0.028), and approaches significance with the prevalence of cribra orbitalia (p=0.08) and the severity of porosity of the external auditory meatus (p=0.087). Dentin collagen $\delta^{13}C_{col}$ shows little significant variation by pathological conditions, with highly significant variation in infancy/early childhood by the number of molar enamel hypoplasia (p=0.012, R^2=0.87), significant variation in middle childhood/adolescence by the number of teeth lost antemortem (p=0.05, R^2=0.70) and variation approaching significance in middle childhood/adolescence and third molar wear severity (p=0.06, R^2=0.64). Dentin collagen $\delta^{15}N$, which reflects sources of dietary protein, also has no significant variation by any pathological condition except molar LEH, which is highly significant (p=0.023, R^2=0.83).

Discussion

Several interesting trends emerge from these results. First is a significant relationship between the presence and severity of porosity in the external auditory meatus and adolescent $\delta^{18}O$; only a weak relationship exists with any dietary isotopic parameter, namely adolescent $\delta^{13}C_{ap}$. While these results could suggest both diet and especially local climate as factors in the prevalence of these porous areas of the temporal bone, this interpretation is severely limited by the lack of significant variation of any other isotopic ratio, including $\delta^{18}O$ and $\delta^{13}C_{ap}$ during other developmental periods. It is also fundamentally limited by the porous areas themselves and the uncertain nature of their practical significance as pathological conditions.

A second trend is the lack of significance between signs of oral disease, i.e. carious lesions and abscesses, and diet, conditions that are commonly associated with a diet heavy in soft, sugary starches such as maize (Bonfiglioli et al., 2003; Hillson, 1996; Lingstrom and Borrman, 1999; Ubelaker, 1984). The only exception is a significant relationship between third molar wear and $\delta^{13}C$ in middle childhood/adolescence, though the lack of significance with first or second molar wear makes this result difficult to interpret. However, these mostly non-significant relationships are not surprising given that all isotopic indicators of concern here represent diet and residence early in life. Because the vast majority of individuals at Machu Picchu died as adults after immigrating to the site from a variety of contexts, one would not necessarily expect significant variation in adulthood conditions by isotopic values.

A third trend is the potential relationship between linear enamel hypoplasia on molar, but not anterior, teeth and both dietary ($\delta^{13}C_{col}$ and $\delta^{15}N$) and residential ($\delta^{18}O$, $^{87}Sr/^{86}Sr$, $^{20n}Pb/^{204}Pb$) isotopic parameters. These findings suggest that local climate, and especially diet, played roles in their prevalence. These and the fact that molars are considered less hypoplastic than anterior teeth such as canines and incisors suggest two complementary interpretations. The first is that these LEH frequencies indicate early-life stressors stemming from diet and local climate that were sufficient in their intensity to disrupt enamel formation in less-hypoplastic molar teeth. One could easily dismiss this interpretation by noting that if molar teeth were involved, certainly more hypoplastic teeth would display LEH as well. However, there was a considerable degree of post-mortem tooth loss and post-mortem enamel breakage among the Machu Picchu population, much more so among the incisors and canines than the premolars and molars. While the absence of these teeth precludes firm interpretation either way, one could speculate that there could have been substantially more hypoplasia in anterior teeth among the population than these results suggest.

Another trend that emerged in the analyses of $\delta^{18}O$ relative to pathological conditions is highly significant variation in mean isotopic values by the presence or absence of healed cribra orbitalia and porotic hyperostosis, porous lesions attributed to chronic childhood anemia of uncertain etiology. The mean $\delta^{18}O$ for individuals with at least one of these conditions was 2-3‰ higher in infancy/early childhood than the mean $\delta^{18}O$ for those without it, and 3‰ higher in middle childhood. This suggests a potential link between the prevalence of the condition and local environmental conditions related to climate during childhood. The significance of these relationships contrast with weak or insignificant relationships between dietary isotopic parameters and oral pathological conditions generally attributed to certain types of diet. This suggests an etiology of childhood anemia owing more to environmental stressors than to dietary iron deficiency. More specifically, those with cribra orbitalia and/or porotic hyperostosis display higher $\delta^{18}O$ than those without; since $\delta^{18}O$ tends to be enriched at lower altitudes and regions with increased aridity, this suggests the possibility that those with the healed lesions may have lived in arid coastal regions. The possibility that individuals were exposed to environmental stressors such as water-borne parasites in these regions is tentatively supported by these data. This relationship is further supported by the albeit-weak relationship between $^{87}Sr/^{86}Sr$ and cribra orbitalia, as reference data tentatively point to lower $^{87}Sr/^{86}Sr$ values towards lower altitudes and coastal areas versus higher values in regions such as the Lake Titicaca basin.

The relationship between early-life isotopic parameters of and molar, but not anterior, enamel hypoplasia is weakly significant regarding residence and strongly significant regarding diet. These results tentatively suggest a relationship between the prevalence of molar LEH and substantial stressors due to primarily to nutritional stress, but also to stressors related to local climatic context. Further, the relationship between isotopic parameters of residence during early life and the presence of cribra orbitalia and/or porotic hyperostosis represents perhaps the first isotopically-measured indication of local environmental context rather than diet as a causal factor in chronic childhood anemia.

While diet appears to be the primary factor associated with molar LEH, considered an indicator of extreme stress since molars are less hypoplastic teeth, local climate appears to have played some role as well. It is possible that both of these relationships stem from the same stressor: for example, individuals with molar LEH could have consumed a diet deficient in key nutrients *and* contaminated by microbial pathogens in the local environment, such as one incorporating marine foods or prepared using contaminated water. In this example, diet and climate interact synergistically to increase the risk of infectious disease and malnutrition during early life, leading to symptoms including molar hypoplasia. While this example is employed hypothetically, relationships between diet, local climate, and poor health such as this could have impacted segments of the Machu Picchu population during early life, prior to immigration to the site.

It is important to note that there is a substantial difference in the respective sample sizes between residential and dietary isotopic parameters, shown in Tables 6.4 and 6.5. Moreover, there was considerable post-mortem tooth loss among the Machu Picchu population, especially of anterior teeth. This difference in the number of cases with both observable pathological conditions *and* the dietary versus residential isotopic parameters of interest could mask or skew significant relationships with diet. However, in the cases of cribra orbitalia and porotic hyperostosis, both oxygen and strontium show some degree of significant association despite representing different proxies of residence and neither representing proxies of diet. $^{87}Sr/^{86}Sr$ is indeed taken into the body through consumed foods, but it is absorbed into plants and animals without fractionation and therefore is used as a proxy of local geology; any local food source that contains strontium is therefore a direct source of local bioavailable strontium, regardless of what that food source is. As is discussed in greater detail in Chapter 4, there is little reason to suspect a skewing effect of imported food at Machu Picchu on the order of magnitude observed in the distribution of the $^{87}Sr/^{86}Sr$ data. This supports the interpretation that if nothing else, the locales and therefore local environmental conditions in which individuals were born and lived as children were *at least* as important as diet in the prevalence of cribra orbitalia and porotic hyperostosis. Moreover, anemia is a condition of multiple causal factors; therefore these findings should not indicate anything definitive about the causes of anemia across populations, as is often the center of ongoing debate in published literature discussed above. Rather, they point to an analytical framework for investigating causal factors of this and other non-specific conditions in skeletal populations that can provide some insight into differential stressors and risks in different contexts.

The lack of significance with isotopic parameters shown by several pathological conditions, and significance with both dietary and residential isotopic parameters among conditions such as linear enamel hypoplasia, illustrates that the relationship between likely stressors and the prevalence of conditions is not clear-cut. However, the results presented here suggest that some insights into stressors acting on individuals are possible. This permits a greater understanding of the dynamics of stress and well-being in ancient populations.

Conclusions

The population from Machu Picchu was clearly a diverse and complex assemblage of individuals, and their remains have proven invaluable in providing insights into life in the Inca Empire. The wide variation in isotopic proxies of early-life diet and residence, coupled with variation in the frequencies and severities of common pathological conditions, speak to variation in background and health. The purpose of this study was to attempt an empirical assessment of potential causal factors in the prevalence of these pathological conditions using independent measures of diet and residence early in life. Results tentatively, but intriguingly, point differentially to local environment, diet or some combination thereof as possible sources of stress acting on individual bodies. The findings presented here, while not unequivocal or universally applicable, shed light on possible stressors differentially affecting the Machu Picchu population long before death. More generally, they suggest a new avenue of inquiry for interpreting the significance of nonspecific pathological conditions in skeletal populations.

Chapter 7: Summary of Findings, Conclusions and Future Directions

The aim of this study has been to elucidate variation in individual backgrounds among the skeletal population from Machu Picchu, Peru through stable isotope and osteological analyses. The purpose of doing so is twofold: Firstly, to isotopically estimate the specific social class of this Inca servant population based on different expected distributions of isotopic data for different social classes; Secondly, to characterize various aspects of individuals' backgrounds, including how different those backgrounds were, where individuals may have originated, what their diets comprised, how their diets and residences may have changed during their lives, and potential sources of chronic stress early in their lives. In doing so, this study has sought to create a framework for exploring where and when different Inca social classes were located and/or moved around the empire as a way to, eventually, better understand their role in late imperial instability. It has also sought to create sophisticated individual profiles within an Inca servant population in order to better understand the magnitudes of life change that individuals experienced as a result of mandated, class-based movement.

The parameters on which this investigation has been based are each proxies of different aspects of life, with varying degrees of specificity, drawn from tissues reflecting different developmental windows. The preceding three chapters explored these parameters and the techniques involved in generating and analyzing them in detail. This chapter synthesizes and summarizes the key findings of this study in a larger interpretive context, and identifies compelling avenues of inquiry stemming from these findings that are ripe for future research.

Finding #1: The Machu Picchu population was most likely a mix of **yanacona & acllacona.**

The Machu Picchu population exhibits notable diversity in a number of osteological characteristics. In an earlier study, Verano (2003a)found variation in cranial morphology, the presence, style and severity of cranial modification, and pathological conditions, while this study describes variation in the severity of occlusal tooth wear and oral pathological conditions. All of these suggest variation in ethnic background, sources of chronic stress, and diet among the population. However, as these are nonspecific markers, they provide no *definitive* indications that this was a cosmopolitan group of people from different backgrounds, as the *yanacona* and *acllacona* are described in the Chronicles, as opposed to a *mitmacona* labor colony or even a local population with a history of immigration and admixture. Oxygen, strontium and lead isotopic ratios were characterized in human tooth enamel from Machu Picchu in order to identify immigrants among the population, using faunal enamel isotopic data as a local baseline. These isotopic data were then analyzed statistically and compared to published isotopic data in order to estimate possible regions of origin. In addition, these data were statistically analyzed against published data on cranial modification styles and cemetery affiliation (Burger and Salazar, 2003) to assess any patterning of variation by ethnicity or possible cultural affiliation.

As shown in Chapter 4, the variation in all isotopic parameters of early-life residence were widely distributed, and each parameter was notably stochastic in its distribution, i.e. no clear bi- or multi-modality suggesting subpopulations. This very clearly suggests substantial variation in early-life residence among the population.

Moreover, the majority of the population fell outside of the local Machu Picchu baseline for each parameter, which suggests that most of the population immigrated to Machu Picchu from elsewhere at some point following childhood. Since *mitmacona* labor colonies are described in the Chronicles as groups of people uprooted from their homes and moved elsewhere, one would expect a substantial degree of immigrants in the Machu Picchu population if it had indeed consisted of *mitmacona*, but little variation within the population itself; instead, findings from strontium, oxygen and lead isotopic analyses all match the expected distribution for a population of *yanacona* and *acllacona*. Moreover, several individuals appear to have moved between isotopically distinct regions during their childhood, *before* immigrating to Machu Picchu.

Interestingly, no significant relationships were found between any of the strontium, lead and oxygen isotopic parameters and either cranial modification style or cemetery location, which suggests that ethnic identity is not tied to geographic context. This is not surprising, and points to isotopic and cranial modification data as complementary, but not interchangeable, demographic measures (see also Torres-Rouff and Knudson, n.d.). This also supports Salazar's (2001) suggestion that non-Inca mortuary practices were suppressed at Machu Picchu, as the distribution of burials does not indicate grouping according to any similarities in background.

To take the analysis a step further and examine any subtle commonalities in background not immediately apparent in each individual isotopic parameter, a hierarchical cluster analysis was performed on all those individuals whose tissues yielded strontium, lead *and* oxygen isotopic data, effectively layering all of these parameters on each other and looking for significant patterns in a synthetic analysis. What emerged from this analysis was a set of six, significantly different clusters within the population. Five of these six clusters displayed strontium, lead and oxygen isotopic ranges that matched baseline ranges for specific regions of the central Andes; this is the first such study to use a multivariate statistical framework with multiple sets of isotopic parameters to trace individuals to their regions of origin. An important caveat to this finding is that this was successful in five of the six established clusters; the remaining cluster spanned the entire range of values represented in published reference data and also included the largest number of individuals. This technique, while intriguing and highly effective, is therefore not perfect. This is also not surprising given that there is geographic overlap in strontium, lead, and oxygen reference data, such that a number of individuals fell into more than one possible region according to each parameter.

Finding #2: Individuals varied widely in their dietary history, and in the degree of dietary change over the course of their lives.

One of the assumptions of this study was that variation in region of origin among the Machu Picchu population might also translate into variation in subsistence patterns, given the degree of ecological diversity in the Inca realm. As such, carbon isotopic ratios were characterized in tooth enamel carbonate, and both carbon and nitrogen isotopic ratios were characterized in tooth dentin collagen, in order to estimate individual dietary composition in infancy and periods of juvenility. These data were then compared to reference isotopic data from foods identified in the Chronicles as common components of Andean diets; these data were drawn both from published sources and generated as part of this study. This analysis and its results are discussed in detail in Chapter 5.

As was the case with isotopic parameters for region of origin, those for diet were also widely distributed, with no significant grouping in the population. They also spanned the isotopic ranges of much of the reference "menu," suggesting marked dietary variation early in life among the population. Notably, very few individuals displayed isotopic data suggesting a substantial reliance on marine fish or on legumes as the primary source of protein; most individuals' data suggested mixed diets incorporating varying degrees of terrestrial and freshwater protein, vegetables and grains.

Using an earlier set of isotopic carbon and nitrogen data for the population generated from analyses of bone collagen, a comparison was possible, for a small subset of the study population, between isotopic data from early-life (dentin) and late-life (bone) tissues. What emerged from this comparison was a trend among the majority of the subsample of depletion in nitrogen isotopic values and enrichment in carbon isotopic values over the lifespan. An examination of this trend against the corpus of reference data from food sources strongly suggests an increased reliance on maize in adulthood. The size of this subset limits the degree to which one could generalize these findings to the rest of the population; however, these data are nonetheless intriguing, because a dietary shift towards increased maize consumption in this context could have been a double-edged sword. Maize was considered a symbolically important food source, brewed into *chicha* for feasts and celebrations as gifts from elites. Maize is also deficient in lysine and has a relatively low amino acid complement, making it a poor source of protein unless it is complemented by other foods such as legumes. Further, maize is high in sugar, which can lead to oral decay, and high in phytate, which inhibits iron uptake and thus contributes to dietary iron deficiency. An increased reliance on maize in adulthood, presumably following relocation as *yana/aclla* to Machu Picchu, may therefore have meant shifting to a culturally-elevated, nutrient-depressed mode of subsistence, with divergent symbolic and nutritional outcomes.

Finding #3: Chronic, nonspecific pathological conditions in the population stemmed from different sources of stress.

As is common in many skeletal populations, the Machu Picchu population exhibited varying degrees of pathological conditions suggesting chronic childhood anemia, periodic stress during infancy and ongoing oral decay. Many of these pathological conditions, such as porotic hyperostosis, cribra orbitalia and linear enamel hypoplasia, are considered sensitive but nonspecific indicators with multiple possible causes. The anemia that leads to cribra orbitalia and porotic hyperostosis could arise through dietary deficiency or through iron loss from parasitic infection. The periodic stress episodes that lead to enamel hypoplasia, such as weanling diarrhea, include malnutrition, infection, and often a synergistic combination of the two. Assessing the etiologies of these conditions, and their variation within and between populations, therefore necessitates independent data on the potential causal factors themselves.

To achieve this, these pathological conditions in the Machu Picchu population were statistically analyzed against isotopic parameters of the local environment in which individuals were born and grew up, as well as isotopic parameters of the diets that individuals consumed during these same early-life periods. These analyses are described in detail in Chapter 6. The goal of these statistical tests was to assess if there were any significant relationships between pathological conditions and diet on the one hand, and between pathological conditions and local environment on the other. Intriguingly, a number of significant relationships emerged. Cribra orbitalia and porotic hyperostosis, both indicators of anemia, were significantly related to *where* affected individuals were born and grew up than *what* they ate. This suggests that their anemia was etiologically related to their local environment, specifically coastal environments. While these data cannot identify specific aspects of coastal environments, such as water-borne parasites, that would have directly caused anemia, they do point to stressors in the environment and not dietary iron deficiency as significantly associated with anemia in this population. Enamel hypoplasia, an indicator of periodic stress during dental development, was significantly related to both where affected individuals grew us *and* what they ate. This fits in well to what is known of enamel hypoplasia formation in extant populations, namely a synergistic relationship between dietary inadequacy and environmental factors (such as contaminated water) leading to diarrheal disease and other sources of episodic stress. Interestingly, a number of indicators showed no significant relationship with diet, including common forms of oral pathology such as carious lesions and abscesses. This does not necessarily indicate that diet was not a factor in oral decay; rather, it suggests that no one dietary pattern stands out as particularly strong in leading to poor oral health.

These findings are not meant to conclusively demonstrate single-etiology relationships for the conditions studies here in any general sense. These conditions remain multifactorial in their etiologies, and the causal factors involved in each likely vary from population to population. Rather, these findings demonstrate possible etiologies for these conditions in the Machu Picchu population, and provide an independent method of assessing these conditions in other populations from other contexts. In essence, these findings help address the nonspecificity of these conditions, allowing some interpretation of what caused particular conditions in the population under study. Future use of this analytical strategy could help shed light on the distribution of sources of stress acting on ancient populations in different places and at different times.

Case in Point: PA 3227 G71

It is clear from the previous three chapters, and the summary of findings above, that interpreting individual backgrounds among the Machu Picchu population requires a reasoned, conservative assessment of isotopic and osteological parameters with an understanding of the inherent limitations of each. Keeping these limitations in mind, the suite of techniques utilized in this study nonetheless present a highly effective way to directly characterize the backgrounds of individuals in skeletal populations. A particularly good illustration of this is PA 3227 G71, a male aged 18-24 years at death. This individual presented no notable pathological conditions, but exhibited pronounced annular modification of his cranial vault, a style traditionally associated with the Aymara of the far southern Peruvian, northern Chilean and Bolivian highlands. His strontium, lead and oxygen isotopic results all very clearly fall into published isotopic ranges for southern Peru and northern Chile, near to but not directly on the coast. Moreover, his carbonate carbon, collagenous carbon and nitrogen isotopic results all clearly indicate a prominent role of marine fish in his diet. It is therefore possible to make very firm assessments about PA 3227 G71's early life that would otherwise have been invisible. His style of cranial modification suggested Aymara ethnic affiliation, but he could very well have been born and raised at Machu Picchu, his modification a continuation of a cultural tradition stemming from a very different homeland. Instead, this combined isotopic and osteological data set clearly identifies him as an immigrant to Machu Picchu, and suggests a marked change in diet and locale following his arrival.

This individual serves as a prime example of the efficacy of the methods used in this study in opening a window into the lives of individuals living under the direct influence of the Inca. Analyses of this sort elucidate lifelong patterns that would otherwise be invisible or, at best, equivocal in ancient populations, providing new interpretive insights into the etiologies of pathological conditions, subsistence variation and change and geographic movement. In this particular context of Inca imperial control, these analyses provide a first attempt to estimate social class based on demographic characteristics, with the intent to use these same frameworks to further explore Inca social classes in the future.

Future Directions

The findings presented here speak as powerfully to the need for future research as they do to the insights gained thus far. Thus, this study will be used as a springboard for future investigations in a number of areas:

1. *Isotopic and osteological analyses of other Inca populations.* Specifically, the heuristic models of isotopic distributions presented here concern local *hatun runa*, *mitmacona* labor colonists, and mixed *yanacona/acllacona* populations. Having associated the Machu Picchu population with the latter, attention will be turned to other populations that are suggested *mitmacona* or assumed local communities. Investigation into accessing such populations is currently ongoing. The eventual

goal of this would be to establish a comparative database of well-contextualized populations, yielding a combination of archaeological, ethnohistorical and osteological/isotopic data that can then serve as the analytical templates for investigating skeletal populations with less clearly-defined contexts. In this way, the distribution of different social classes during the Inca imperial period might become better understood, and may be used to strengthen analyses of instability, movement and political economy during this short but eventful period in Andean history.

2. *Diachronic analyses of Andean populations.* In order to better understand the patterns of movement described immediately above, movement in the Inca period must be placed into a larger temporal context. The Inca were not the first Andean state, and may well have based much of their statecraft on pre-existing forms. Tracing patterns of population movement in earlier time periods such as the Middle Horizon, when the Wari and Tiwanaku states flourished in the central Andes, is critical to understanding both commonalities and divergence in these patterns under the Inca.
3. *Continued development of robust isotopic reference data.* Bioarchaeologists involved in isotopic analysis are intimately familiar with the vital importance of reference data ranging in scale from individual sites to major regions. Isotopic research is relatively recent to Andean contexts, especially those studies concerned with systematic identification of population movement. Consequently, much less is known about the environmental distributions of strontium, lead and oxygen isotopes in different areas, and the degree of microvariation in isotopic

ratios in geographically local areas. Moreover, much is still uncertain about the exact mechanisms of elemental uptake by organisms, i.e. the pathways by which strontium is differentially bioavailable. Reference data for food resources is similarly underdeveloped; an expansive database exists for northern Chile, but given that region's pronounced aridity, isotopic values from plants and terrestrial mammals may be skewed by adaptive mechanisms of water conservation. Elsewhere in the central Andes, reference data is relatively patchy, especially when one considers the documented importance of less-frequently characterized foods, such as *kiwicha*, *quinoa* and lacustrine fish in regional subsistence patterns. Therefore, continued isotopic research in the Andes must focus on expanding reference datasets for all isotopic parameters in a variety of materials, including wild and domesticated plants, animals, water sources and soils. Ongoing isotopic studies by researchers in the Andes (Turner et al., 2008) present promising contributions to expanding current reference data. However, large-scale, systematic studies explicitly focused on gathering isotopic data to serve as bioarchaeological reference criteria would contribute substantially to the development of this promising area of research.

Conclusions

This study centered on isotopic and osteological analyses of the Machu Picchu population, elucidating variation in individual backgrounds in order to estimate assigned social class and better understand patterns of health, diet and movement across the lifespan. The findings generated here provide a potential framework for directly characterizing Inca social classes and tracking their distribution throughout the Inca empire during a period leading up to large-scale instability and eventual conquest. Moreover, these findings provide a window into the lives of Inca subjects and the ways in which those lives changed as a result of Inca imperatives. Continued research using these frameworks will place the Machu Picchu population in their proper context as one of many populations affected by the Inca, and will further our understanding of life in this expansive, short-lived and highly influential state.

Appendix: Tables and Figures (in order of reference in text)

Figure 3.1 *Location of Machu Picchu, Peru (Burger and Salazar 2003; image reproduced with permission of authors)*

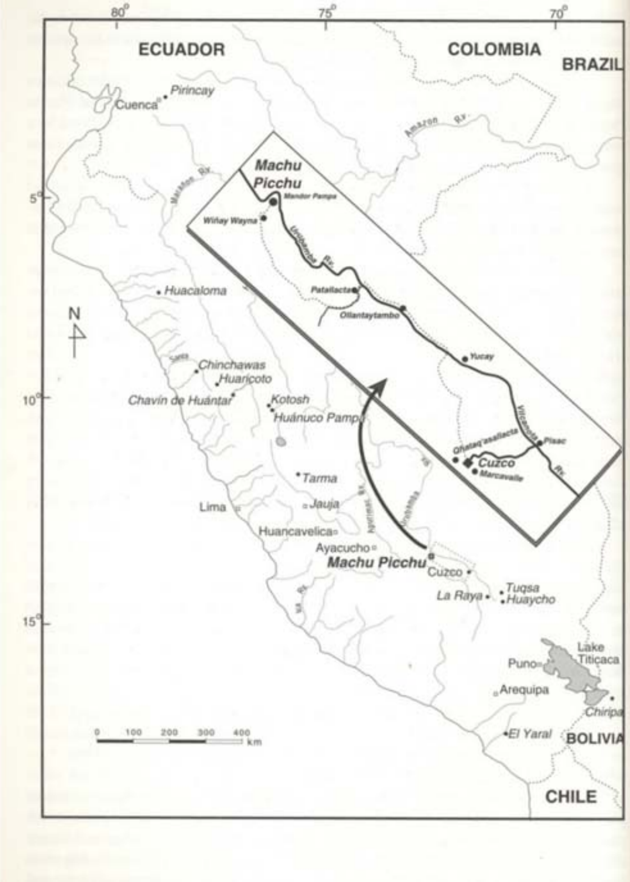


FIGURE 1.10. The location of Machu Picchu in relation to other place names mentioned in the text.

Figure 3.2 *Image of cave interment at Machu Picchu (Burger and Salazar 2003; image reproduced with permission of authors)*

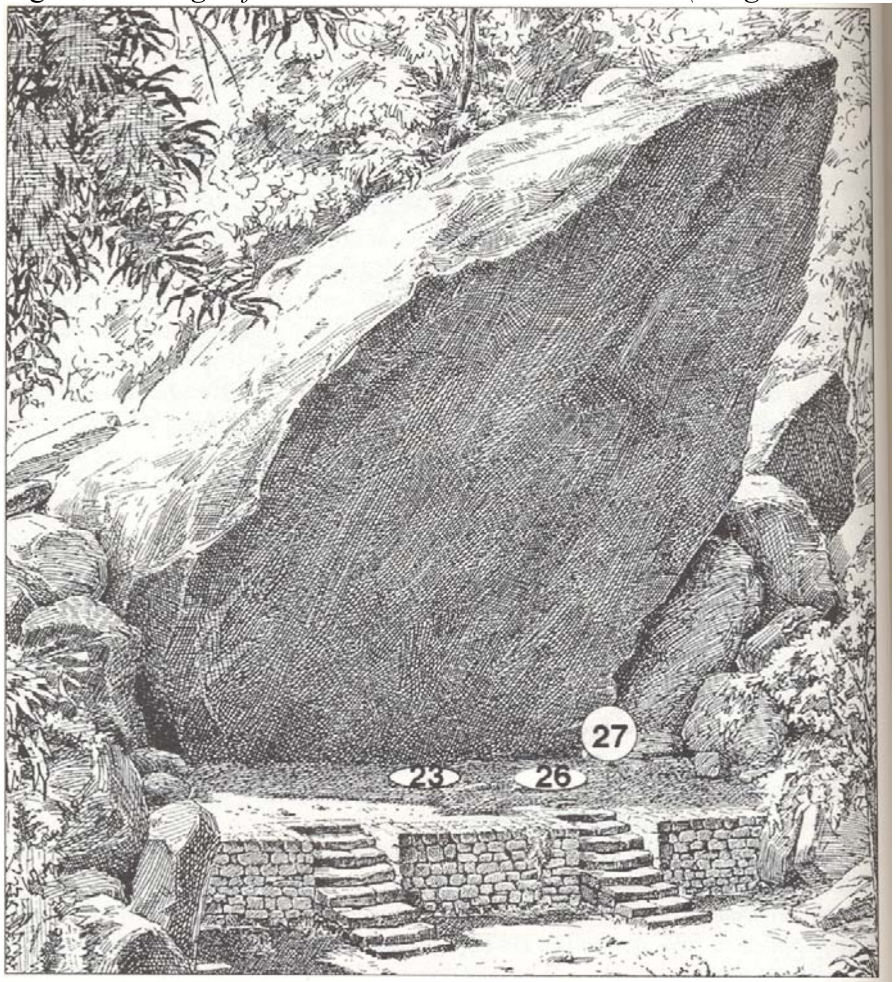


FIGURE 1.11. Locations of Graves 23, 26 and 27 on the Rock-sheltered Terrace. Modified from Eaton 1916:22, fig. 18.

Table 4.1. *Categorization of Tooth Type by Developmental Period*

Tooth Type	Years of Development[1]	Assigned Period
I1	0.0-5.0	Infancy/Early Childhood (IEC)
I2	0.8-5.5	Infancy/Early Childhood (IEC)
C1	0.3-7.0	Middle Childhood (MC)
PM1	1.0-7.5	N/A (none present)
PM2	2.0-8.5	Middle Childhood (MC)
M1	0.0-3.5	Infancy/Early Childhood (IEC)
M2	2.5-8.0	Middle Childhood (MC)
M3	8.0-15.0	Adolescence (AD)

[1] From Hillson (1996) and White and Folkens (2000)

Table 4.2 *Summary of Residential Isotopic Parameters by Individual*

Burial Number	Age @ Death (yrs.)	Sex	EC $\delta^{18}O$	MC $\delta^{18}O$	AD $\delta^{18}O$	EC-MC $\delta^{18}O$	MC-AD $\delta^{18}O$	EC-AD $\delta^{18}O$	$^{87}Sr/^{86}Sr$	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
PA3195 G41	40-50	F	21.6	20.6		-1.0			0.720692	18.815	15.648	38.615
PA0531 G70			21.2		20.7			-0.5	0.709424	18.590	15.631	38.426
PA4747 G3B				25.6					0.708036	18.814	15.648	38.517
PA3192 G40	30-40	F	20.4	19.1	17.8	-1.3	-1.3	-2.6	0.714593	18.747	15.648	38.442
PA3163 G9	20-25	M	20.4		20.1			-0.3	0.707485	18.527	15.626	38.384
PA4761 G99	Adult	M	21.6	21.3	21.0	-0.3	-0.3	-0.6	0.713423	18.924	15.667	38.882
PA3232 G77	40-50	F	22.6	21.6		-1.0			0.707711	18.710	15.641	38.474
PA3168 G16	25-30	M	22.3		23.4			1.1	0.706308	18.780	15.636	38.709
PA3246 G102			19.7		18.1			-1.6	0.707490			
PA3211 G52A	30-40	M		20.5	20.2		-0.3		0.706786	18.746	15.640	38.457
PA3186 G37	20-30	F	24.7	23.0	23.1	-1.7	0.1	-1.6	0.705646			
PA3179 G31	30-40	F	24.4	23.6	23.7	-0.8	0.1	-0.7	0.703835	18.531	15.623	38.273
PA3191 G40	30-45	F	23.7	23.2	20.4	-0.5	-2.8	-3.3	0.705427	18.703	15.637	38.478
PA3248 G107	Young Adult	M	24.6	23.8		-0.8			0.718239	18.719	15.650	38.460
PA3202 G47A	5 to 6		21.7	21.0		-0.7			0.707521	18.678	15.644	38.504
PA0524 G46	17-20	F		20.0					0.707442	18.557	15.624	38.380

PA0522 G8	Adult	F	27.7								
PA3194 G41	30-35	M	23.0	22.0		-1.0			0.721183	18.608	15.636	38.336
PA3158 G4G				26.0					0.716557			
PACoMd G37	Adult	F		25.4								
PA0525 G55									0.720183	18.579	15.620	38.168
PA3206 G49	18-22	F							0.708077	18.630	15.631	38.331
PA3187 G37	30-40	F	26.0						0.713409	18.830	15.653	38.569
PA3160 G5	25-35	M		25.1					0.710723	18.631	15.632	38.372
PA3221 G63	25-35	F	26.9						0.705280	19.015	15.679	38.884
PA3209 G50	50+	F	23.0		22.2			-0.8	0.713978			
PA3222 G65	8 to 9		20.9						0.711433	18.579	15.620	38.168
PA3158 G4F			27.4						0.709010	18.743	15.639	38.445
PA3159 G4B	Young Adult	M	25.6						0.720525	18.808	15.654	38.514
PA3158 G4C	Adult	M		21.2					0.714648	18.695	15.637	38.461
PA3188 G37	50+	F		20.3								
PA3158 G4A	Young Adult	M	20.9						0.709130	18.792	15.653	38.538
PA3158 G4B									0.719907	18.720	15.646	38.415
PA3165 G11	50-60	F		22.3								
PA3196 G42	40-50	M	18.3	18.6		0.2			0.719170			
PA3157 G3A	30-40	F	25.1	25.1	24.9	0.0	-0.1	-0.1	0.710980	18.778	15.652	38.538
PA3208 G50	11 to 13		22.0	21.6		-0.4			0.712832			
PA3164 G9B	20-25	M		24.6					0.704382			
PA3243 G93	30-45	F	24.5	25.3	22.6	0.8	-2.8	-1.9	0.704769	18.977	15.661	38.416
PA3228 G72	10 to 11		27.4	26.6		-0.9			0.706096	19.013	15.669	38.729
PA3238 G84	17-20	M	21.9	16.3	19.7	-5.6	3.5	-2.1	0.707643			
PA3227 G71	19-24	M		21.9	19.1		-2.8		0.707559	18.252	15.603	38.298
PA3173 G23	16-18	M	21.5	19.7		-1.9			0.711764			
PA3220 G62A	20-30	M	20.0	19.4	21.7	-0.7	2.3	1.6	0.708021			
PA3197 G42	55-65	F	26.3						0.709581			
PA3156 G1	19-23	F	24.8	24.1		-0.8						
PA4746 G2A	Adult	M	25.7	24.4		-1.3						
PA4746 G2B	Adult		24.6	24.7		0.0						

PA3161 G5B	Middle Adult	F	20.8									
PA0521 G7	15-17		27.5	26.7		-0.8			0.70702	18.916	15.652	38.725
PA4749 G12	Adult	F							0.707287	19.074	15.656	38.467
PA3166 G13	45-55	F	19.9	16.2		-3.6						
PA0523 G14A	18-21	F							0.710032	19.151	15.681	38.681
PA3182 G32	30-35	M	24.5	24.2		-0.3						
PA3183 G33	25-35	M							0.707125	18.715	15.628	38.421
PA3184 G34	40-50	F	20.0	19.7		-0.4						
PA3189 G38	35-45	F	26.3	26.1		-0.2						
PA3190 G39	20-29	F	20.5	20.0	20.1	-0.5	0.1	-0.4				
PA3199 G42	50+	M		20.7					0.710055	18.376	15.612	38.186
PA3205 G48B	15-18	M	19.9	19.8		-0.2						
PA3207 G50B	Young Adult			21.8	22.3		0.5		0.717666	18.785	15.649	38.619
PA3214 G53	50+	M	22.6	20.8		-1.8						
PA3219 G61	30-40	F	25.6	25.0	25.2	-0.5	0.1	-0.4	0.712079	18.190	15.578	37.968
PA3220 G62B	18-21	F	20.0	19.2	19.3	-0.9	0.1	-0.7	0.709975	19.012	15.669	38.739
PA3222 G65F	Adult	F	19.3									
PA3230 G75	25-35	M	23.0	22.2	21.9	-0.8	-0.3	-1.1				
PA3231 G75	30-40	M	19.7	18.1	20.5	-1.7	2.4	0.8	0.709127			
PA3233 G77	25-35	M	19.8	20.3	20.8	0.5	0.5	1.0				
PA3235 G80	45-55	F	22.6	22.5		-0.1						
PA3236 G81	20-30	M	22.2	21.8	22.8	-0.4	1.0	0.6				
PA3237 G82	25-35	F	25.5	24.9	23.7	-0.7	-1.2	-1.9				
PA3239 G84	35-45	M		22.6								
PA3245 G98				19.8								
PA3247 G107	18-21	M	24.2						0.706674	18.716	15.633	38.411

Table 4.3 *Summary of Residential Isotopic Baseline Data*

Specimen Number	**Species**	**Common Name**	**$^{87}Sr/^{86}Sr$**	**$^{206}Pb/^{204}Pb$**	**$^{207}Pb/^{204}Pb$**	**$^{208}Pb/^{204}Pb$**	**$\delta^{18}O$**
ANT.196400 3317 G56	*L. trichodactylus*	Vizcacha	0.709728	18.516	15.636	38.464	
ANT.256878 MP.99	*Agouti thomasi*	Agouti	0.712456	18.660	15.635	38.337	
MP 3167 G15-1R	*Agouti sp.*	Agouti	0.71451	18.568	15.627	38.360	
ANT.196399 G9	*Lapidium sp.*	Peruvian Hare	0.715241	18.646	15.636	38.426	
Machu Picchu Water 1	n/a	n/a	n/a	n/a	n/a	n/a	-13.78
Machu Picchu Water 2	n/a	n/a	n/a	n/a	n/a	n/a	-13.81

Table 4.4 *Descriptive Statistics for Residential Isotopic Parameters*

Parameter	**Sample N**	**Mean (‰)**	**Standard Deviation**	**Median (‰)**	**Min/Max (‰)**	**Range (‰)**
Early Childhood $\delta^{18}O_{ap}$[a]	54	22.9	2.6	22.6	18.3/27.7	9.4
Middle Childhood $\delta^{18}O_{ap}$	52	22.1	2.6	21.9	16.2/26.7	10.5
Adolescent $\delta^{18}O_{ap}$	25	21.4	2.0	21.0	17.8/25.2	7.4
Early Childhood 87Sr/86Sr	63	0.710605	0.004819	0.709129	0.703835/ 0.721183	0.017348
Early Childhood $^{206}Pb/^{204}Pb$	40	18.72	0.20	18.72	18.19 /19.15	0.96
Early Childhood $^{207}Pb/^{204}Pb$	40	15.6	0.02	15.6	15.58 /15.68	0.10
Early Childhood $^{208}Pb/^{204}Pb$	40	38.47	0.19	38.46	37.97 /38.88	0.91

[a] All oxygen isotopic statistics are expressed relative to SMOW.

Table 4.5 *One-Way ANOVA results for Residential Isotopic Parameters*

Parameter	**Sex**	**Age Category**	**Cranial Modification Type**[a]	**Cemetery Affiliation**
Middle Childhood $\delta^{18}O_{ap}$	n.s. p=0.23	n.s. p=0.295	n.s. p=0.443	n.s. p=0.143
Adolescent $\delta^{18}O_{ap}$	n.s. p=0.212	n.s. p=0.822	n.s. p=0.649	n.s. p=0.268
$^{206}Pb/^{204}Pb$	n.s. p=0.156	n.s. p=0.643	n.s. p=0.139	n.s. p=0.118
$^{207}Pb/^{204}Pb$	n.s. p=0.261	n.s. p=0.785	n.s. p=0.534	n.s. p=0.165
$^{208}Pb/^{204}Pb$	n.s. p=0.737	n.s. p=0.591	n.s. p=0.367	n.s. p=0.472

[a] from Verano (2003): 0=none; 1=tabular; 2=annular

Table 4.6 *Kruskal-Wallis Results for Residential Isotopic Parameters*

Parameter	**Sex**	**Age Category**	**Cranial Modification Type**[a]	**Cemetery Affiliation**
Early Childhood $\delta^{18}O_{ap}$	n.s. p=0.08	n.s. p=0.58	n.s. p=0.286	n.s. p=0.184
$^{87}Sr/^{86}Sr$	n.s. p=0.447	P=0.051*	n.s. p=0.839	n.s. p=0.43

[a] from Verano (2003): 0=none; 1=tabular; 2=annular

Table 4.7 *Spearman & Pearson Correlation Results among Isotopic Parameters*

	Infancy/ Early Childhood δ^{18}O	**Middle Childhood δ^{18}O**	**Adolescent δ^{18}O**	**^{87}Sr/^{86}Sr**	**^{206}Pb/^{204}Pb**	**^{207}Pb/^{204}Pb**	**^{208}Pb/^{204}Pb**	**Infancy/Early Childhood δ^{15}N**	**Middle Childhood/ Adolescent δ^{15}N**
Infancy/ Early Childhood δ^{18}O	--	--	--	n.s. r = -0.219 p = 0.207	n.s. r = 0.286 p = 0.165	n.s. r = 0.229 p = 0.27	n.s. r = 0.172 p = 0.411	n.s. r = -0.300 p = 0.370	--
Middle Childhood δ^{18}O	--	--	--	--	--	--	--	--	--
Adolescent δ^{18}O	--	--	--	--	--	--	--	--	--
^{87}Sr/^{86}Sr	n.s. r = -0.219 p = 0.207	--	--	--	n.s. r = -0.09 p = 0.578	n.s. r = 0.009 p = 0.955	n.s. r = -0.09 p = 0.583	n.s. r = 0.467 p = 0.205	--
^{206}Pb/^{204}Pb	n.s. r = 0.286 p = 0.165	--	--	n.s. r = -0.09 p = 0.578	--	r = 0.95 p < 0.0001**	r = 0.81 p < 0.0001**	n.s. r = -0.393 p = 0.383	--
^{207}Pb/^{204}Pb	n.s. r = 0.229 p = 0.270	--	--	n.s. r = 0.009 p = 0.955	r = 0.95 p < 0.0001**	--	r = 0.86 p < 0.0001**	n.s. r = -0.500 p = 0.253	--
^{208}Pb/^{204}Pb	n.s. r = 0.172 p = 0.411	--	--	n.s. r = -0.09 p = 0.583	r = 0.81 p < 0.0001**	r = 0.86 p < 0.0001**	--	n.s. r = -0.571 p = 0.180	--
Infancy/Early Childhood δ^{15}N	n.s. r = -0.300 p = 0.370	--	--	n.s. r = 0.467 p = 0.205	n.s. r = -0.393 p = 0.383	n.s. r = -0.500 p = 0.253	n.s. r = -0.571 p = 0.180	--	--
Middle Childhood/ Adolescent δ^{15}N	--	--	--	--	--	--	--	--	--

Table 4.8 *General Characteristics of Six Isotopic Groupings at Machu Picchu (‰).*

Group (# individuals assigned)	**$^{87}Sr/^{86}Sr$**	**$^{206}Pb/^{204}Pb$**	**$^{207}Pb/^{204}Pb$**	**$^{208}Pb/^{204}Pb$**	**$\delta^{18}O$**	**Potential Residential Characteristics**
1 (7)	0.707442 – 0.711433	18.252 – 18.582	15.603 – 15.629	38.168 – 38.386	19.1 – 21.2	Southwest Highlands of Peru; N. Inland Chile, NW Bolivia
2 (7)	0.714593 – 0.721183	18.608 – 18.815	15.636 – 15.654	38.336 – 38.623	20.4 – 25.6	Northwest Peru
3 (14)	0.703835 – 0.713409	18.623 – 18.977	15.623 – 15.661	38.273 – 38.709	20.5 – 26.0	Variable, spans multiple regions
4 (3)	0.704340 -0.707020	18.916 – 19.015	15.652 – 15.679	38.725 – 38.884	26.6 – 26.9	Southern Peru; Coast?
5 (1[a])	0.713423	18.924	15.667	38.882	21.6	Highland Bolivia?
6 (1[b])	0.712079	18.190	15.578	37.968	25.2	North Coast?

[a] PA 4761 G.99
[b] PA 3219 G.61

Figure 4.1 *Models of Expected Residential Isotopic Distributions by Social Class*

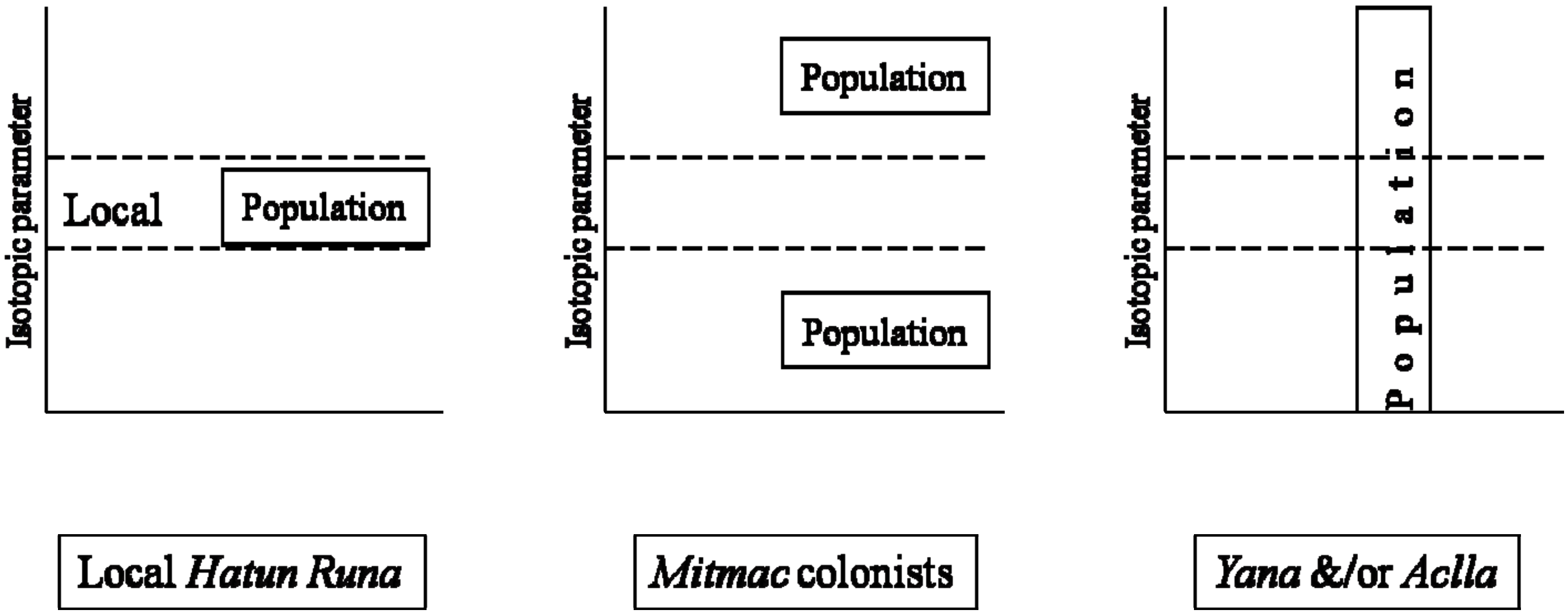
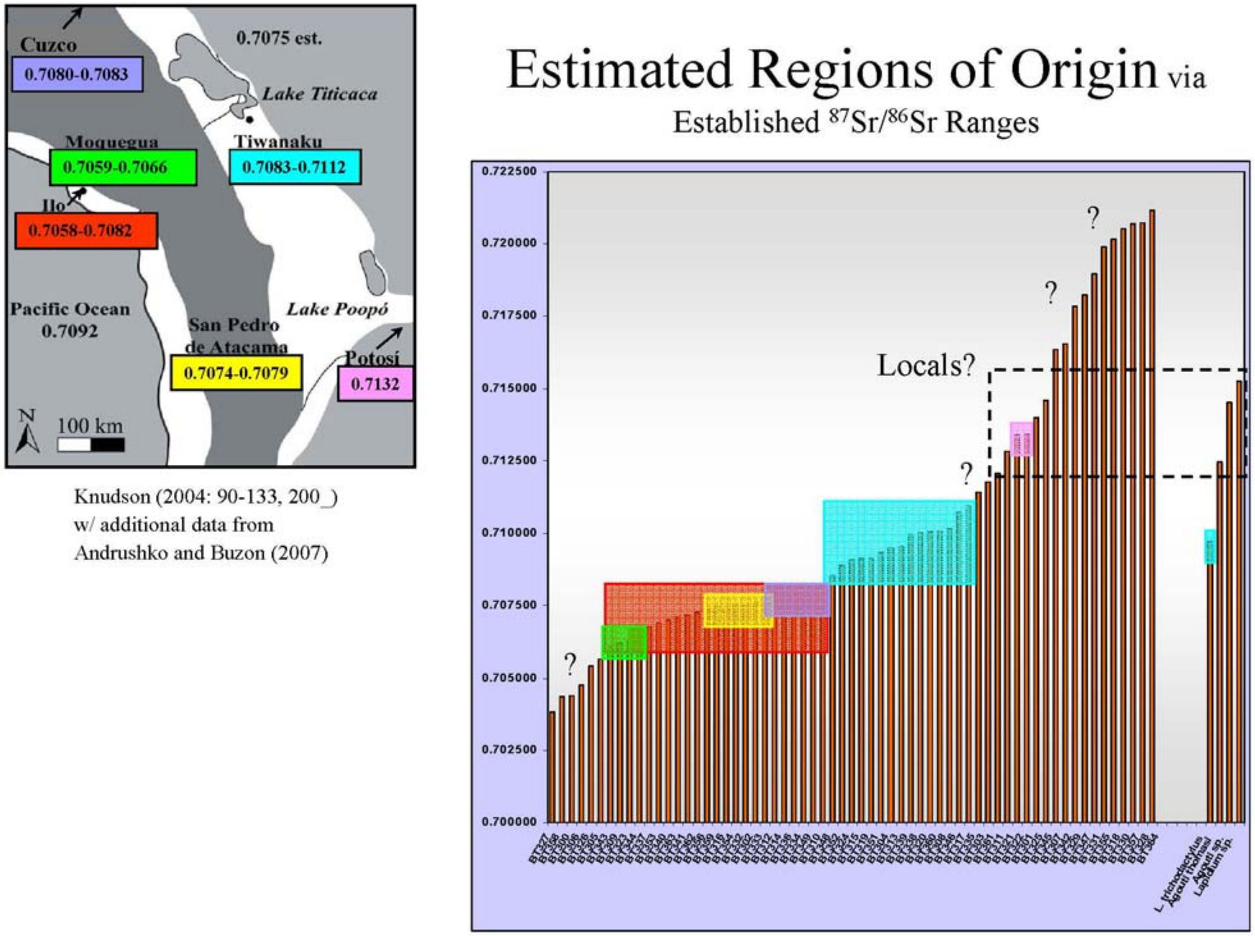
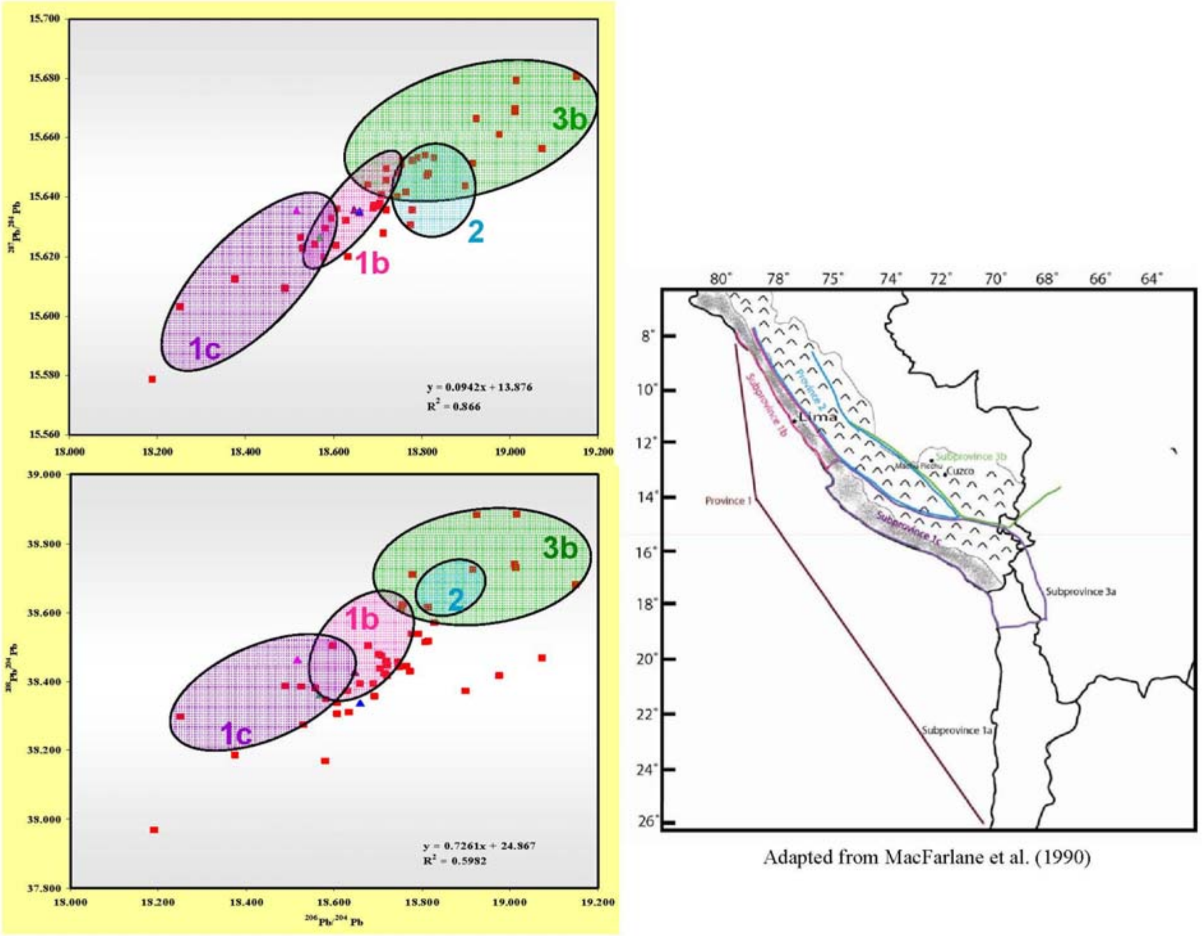


Figure 4.2 *Estimated Regions of Origin for the Machu Picchu Population based on* $^{87}Sr/^{86}Sr$ *Results and Published Data (Knudson 2004, Andrushko and Buzon 2007).*



Knudson (2004: 90-133, 200_)
w/ additional data from
Andrushko and Buzon (2007)

Figure 4.3 *Estimated Regions of Origin for the Machu Picchu Population based on* $^{20n}Pb/^{204}Pb$ *Results and Published Data (MacFarlane et al. 1990)*



Adapted from MacFarlane et al. (1990)

Figure 4.4 *Enamel Oxygen Isotopic Distribution at Three Developmental Stages*

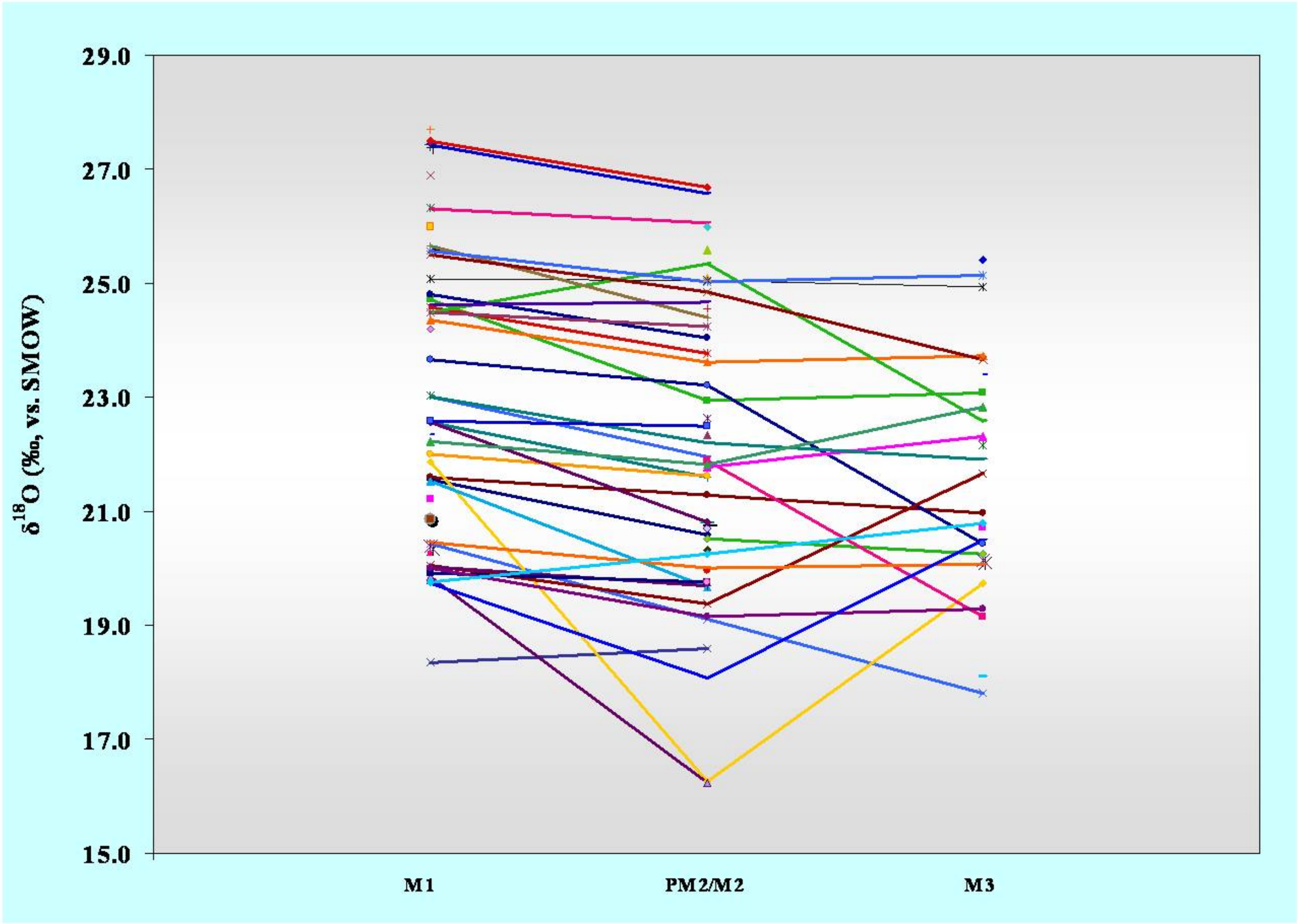


Figure 4.5 *Estimated Regions of Origin for the Machu Picchu Population based on Estimated $\delta^{18}O$ of Drinking Water Sources and Published Precipitation Data (Bowen and Wilkinson 2002; image reproduced with permission of the authors from* *http://wateriso.eas.purdue.edu/waterisotopes/media/IsoMaps/jpegs/o_SAmer/oma_SAmer.jpg*)

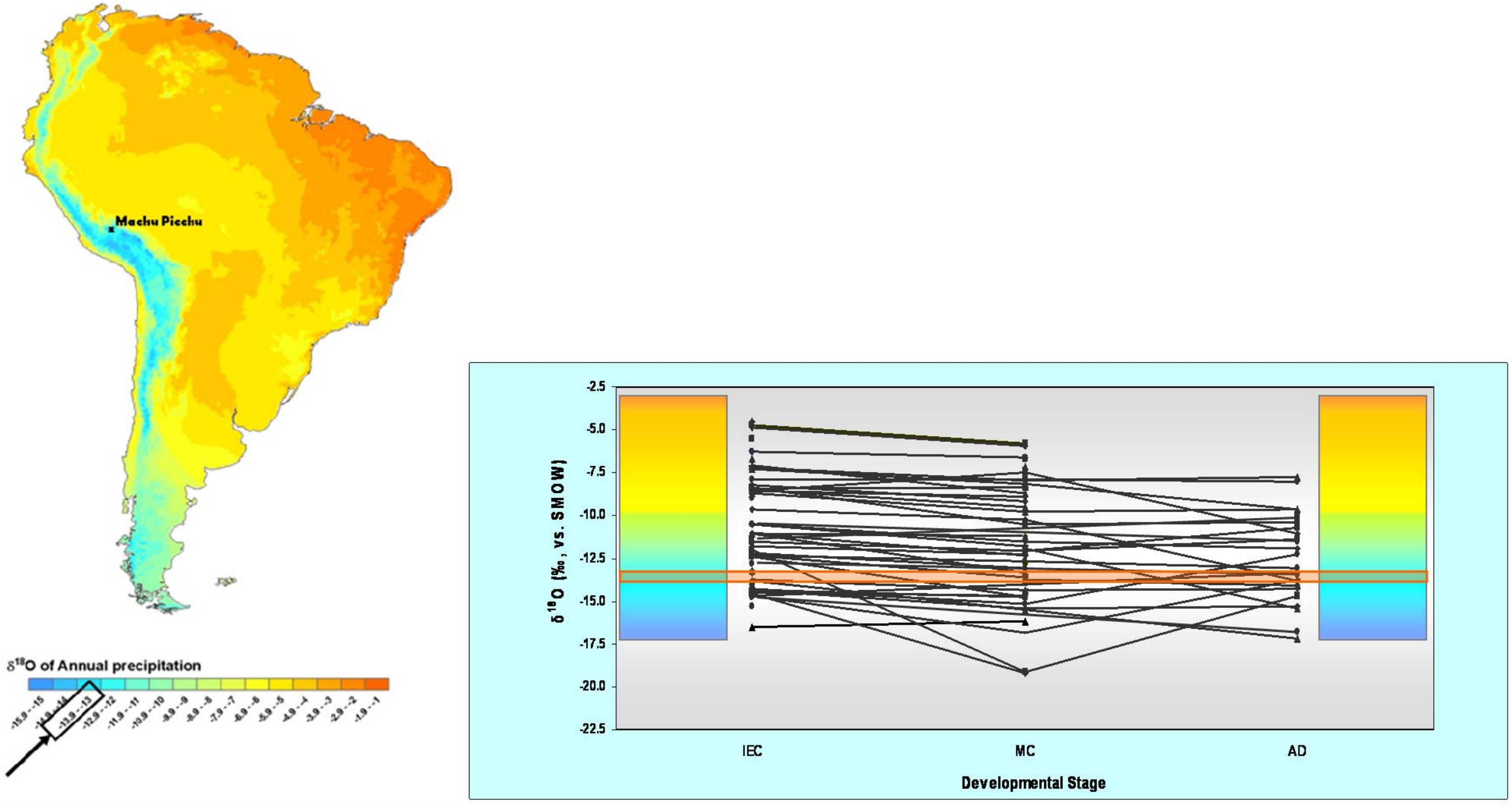


Figure 4.6 *Individual Magnitudes of Change in $\delta^{18}O$ across Two or More Developmental Periods*

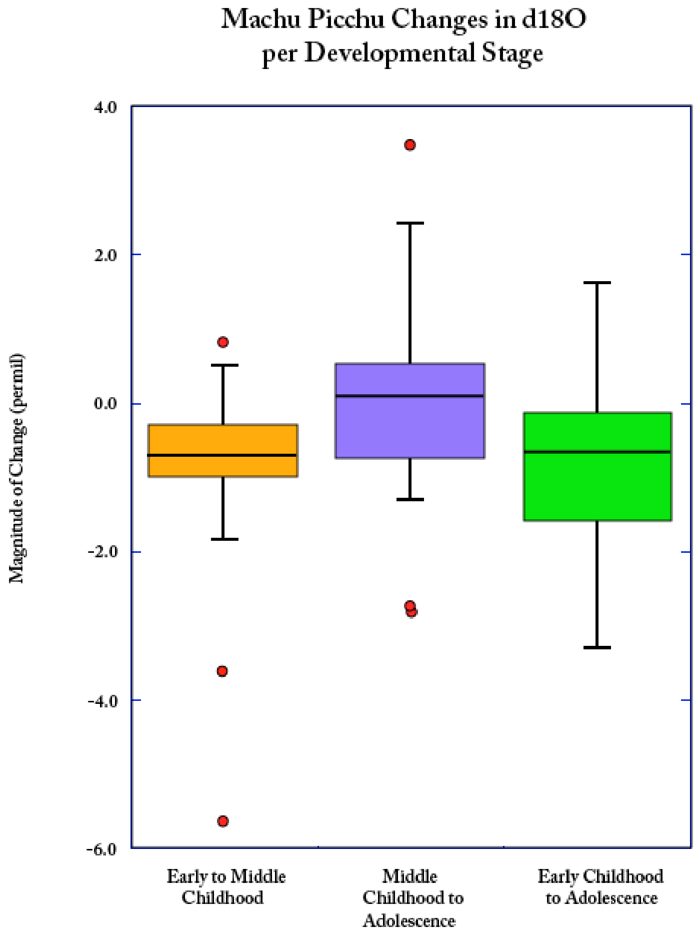
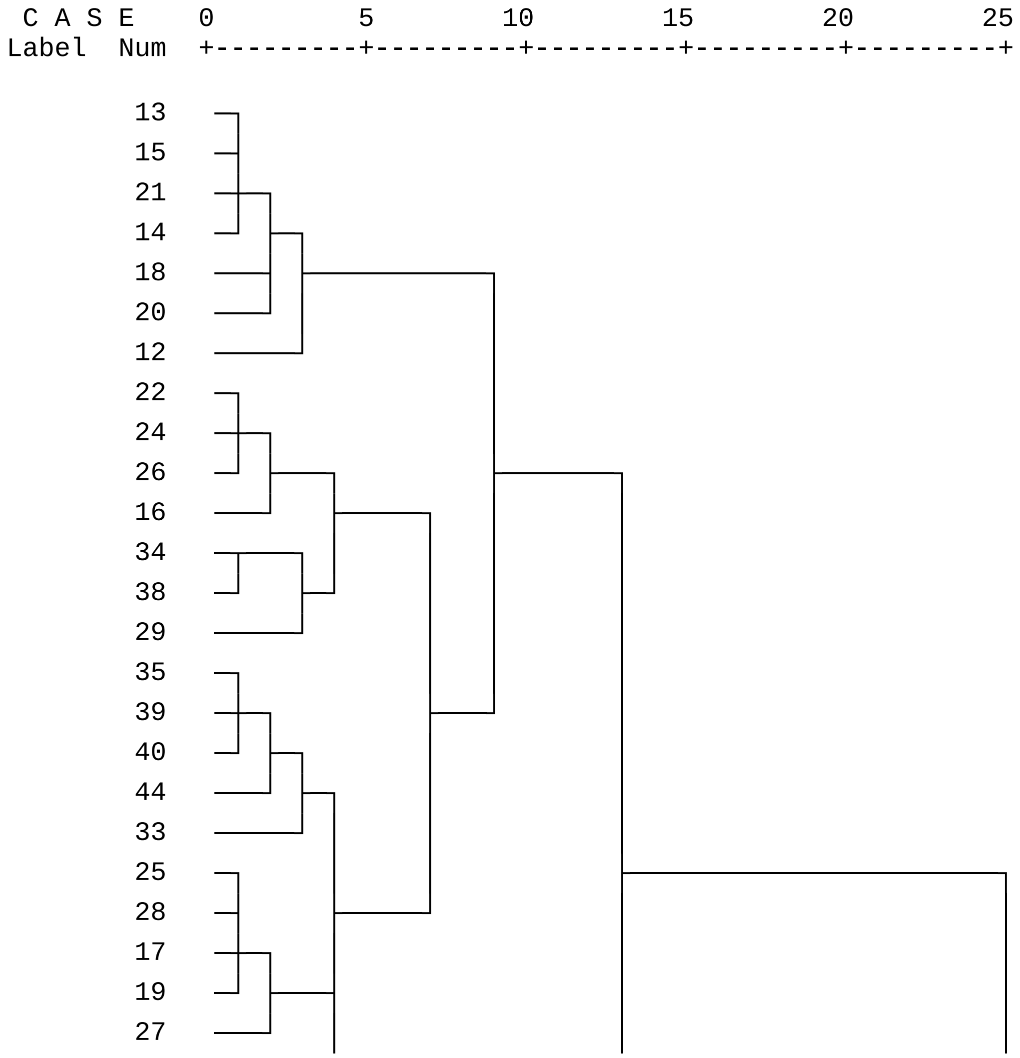


Figure 4.7a *Hierarchical Cluster Analysis Dendrogram*



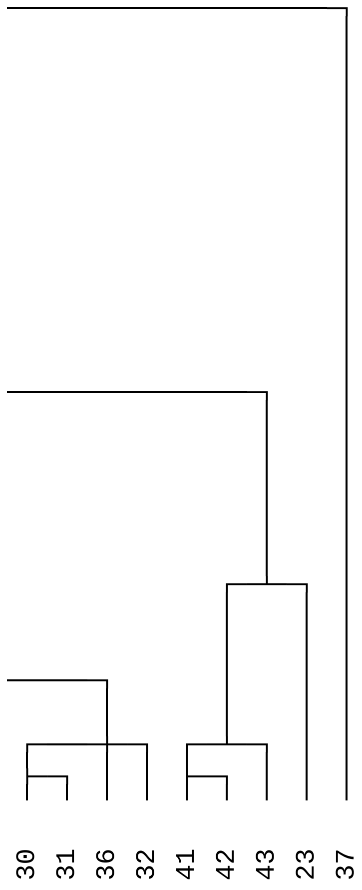

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Figure 4.7b *One-Way ANOVA of Six-Cluster Model*

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Zscore(Strontium)	Between Groups	26.289	5	5.258	24.966	.000
	Within Groups	5.686	27	.211		
	Total	31.976	32			
Zscore(Pb206)	Between Groups	23.639	5	4.728	18.429	.000
	Within Groups	6.926	27	.257		
	Total	30.565	32			
Zscore(Pb207)	Between Groups	26.839	5	5.368	23.709	.000
	Within Groups	6.113	27	.226		
	Total	32.952	32			
Zscore(Pb208)	Between Groups	26.625	5	5.325	17.656	.000
	Within Groups	8.143	27	.302		
	Total	34.768	32			
Zscore(d18O)	Between Groups	18.664	5	3.733	7.557	.000
	Within Groups	13.336	27	.494		
	Total	32.000	32			

Table 5.1 *Developmental Periods of Samples for the Machu Picchu Population*

Tooth Enamel		**Tooth Dentin**	
Infancy/Early Childhood	M1 (0 – 3.5-4 yrs.)	Infancy/Early Childhood	M1 (0 – 3.5-4 yrs.)
Middle Childhood	M2 (2.5 – 8.0 yrs.)	Middle Childhood/Adolescence	M2 & M3 (2.5 – 15.0 yrs.)
Adolescence	M3 (9 – 15 yrs.)	-	-

Table 5.2 *Summary of Human Dietary Isotopic Results by Individual*

Burial Number	**Age @ Death (yrs.)**[1]	**Sex**[1]	**IEC** $\delta^{13}C_{ap}$	**MC** $\delta^{13}C_{ap}$	**AD** $\delta^{13}C_{ap}$	**Dentine Collagen % Yield**	**IEC** $\delta^{13}C_{col}$	**IEC** $\delta^{15}N$	**MC/AD** $\delta^{13}C_{col}$	**MC/AD** $\delta^{15}N$	$\Delta 13C_{ap\text{-}col}$	**Bone** $\delta^{13}C_{col}$[2]	**Bone** $\delta^{15}N$[2]
PA3195 G41	40-50	2	-4.3	-4.5									
PA0531 G70			-12.7		-12.3								
PA4747 G3B			-5.2	-5.5									
PA3192 G40	30-40	2	-12.0	-11.8	-11.3								
PA3163 G9	20-25	1	-12.8		-9.0	18.3			-16.6	11.3	7.6		
PA4761 G99	Adult	1	-9.4	-8.9	-8.2								
PA3232 G77	40-50	2	-5.5	-4.4	-5.7	10.2	-11.9	11.7			6.4	-12.16	8.7
PA3168 G16	25-30	1	-7.4	-8.2	-7.7								
PA3246 G102			-4.2	-4.7	-4.5	25.2			-13.0	8.6	8.4	-13.34	7.22
PA3211 G52A	30-40	1		-6.5	-5.4	18.9			-13.9	8.5	8.0	-17.65	8.94
PA3186 G37	20-30	2	-2.8	-5.8	-5.4								
PA3179 G31	30-40	2	-4.3	-4.9	-4.4								
PA3191 G40	30-45	2	-9.9	-10.7	-5.7								

PA3248 G107	Young Adult	1	-8.9	-8.8		21.8	-14.8	12.9			5.9	-10.29	9.73
PA3202 G47A	6-May		-6.9	-5.6		19.3			-13.4	7.4	7.8		
PA0524 G46	17-20	2	-6.6	-5.5									
PA0522 G8	Adult	2	-5.2			19.7	-12.0	12.2			6.8		
PA3194 G41	30-35	1	-4.2	-3.4									
PA3158 G4G				-3.7									
PACoMd G37	Adult	2			-2.4	18.9			-10.9	11.1	8.5		
PA0525 G55			-6.3	-3.4									
PA3206 G49	18-22	2				18.8	-14.3	10.7				-12.69	9.82
PA3187 G37	30-40	2	-4.1	-2.9									
PA3160 G5	25-35	1		-2.4									
PA3221 G63	25-35	2	-3.9	-4.9			-13.2	10.2			9.3	-10.47	9.13
PA3209 G50	50+	2	-3.8		-3.4								
PA3222 G65	8 to 9		-4.7	-7.5		13.7	-12.0	12.0			7.3		
PA3158 G4F			-4.9										
PA3159 G4B	Young Adult	1	-6.1										
PA3158 G4C	Adult	1	-6.4	-3.6									
PA3158 G4C	50+	2		-8.3									
PA3158 G4A	Young Adult	1	-12.6	-12.4									
PA3158 G4B				-5.5									
PA3165 G11	50-60	2		-4.8									
PA3196 G42	40-50	1	-10.9	-10.5									
PA3157 G3A	30-40	2	-7.9	-7.1	-5.9								
PA3208 G50	11 to 13		-3.8	-3.9									
PA3164 G9B	20-25	1		-6.7									
PA3243 G93	30-45	2	-1.1	-1.1	-1.5								
PA3228 G72	10 to 11		-3.3	-3.8									
PA3238 G84	17-20	1	-5.2	-4.2	-2.9	12.6	-12.7	10.0			7.6	-10.05	9.64
PA3227 G71	19-24	1		-5.5	-11.7	21.2			-12.0	24.4	6.5	-16.3	12.79
PA3173 G23	16-18	1	-6.5	-6.8		10.4			-15.9	10.0	9.1	-15.57	9.17
PA3220 G62A	20-30	1	-3.7	-4.5	-5.5								

PA3197 G42	55-65	2	-4.8									
PA3156 G1	19-23	2	-6.7	-6.1								
PA4746 G2A	Adult	1	-2.8	-2.4								
PA4746 G2B	Adult		-3.3	-2.1								
PA3161 G5B	Middle Adult	2		-11.8		15.6			-18.8	13.7	7.0		
PA0521 G7	15-17		-2.2	-1.4		23.2	-9.1	8.3			6.9	-12.37	9.09
PA4749 G12	Adult	2											
PA3166 G13	45-55	2	-12.8	-13.4									
PA0523 G14A	18-21	2											
PA3182 G32	30-35	1	-5.7	-4.2									
PA3183 G33	25-35	1											
PA3184 G34	40-50	2	-6.2	-5.3									
PA3189 G38	35-45	2	-6.7	-4.4									
PA3190 G39	20-29	2	-6.9	-8.6	-7.2								
PA3199 G42	50+	1		-11.5									
PA3205 G48B	15-18	1	-7.2	-8.2									
PA3207 G50B	Young Adult			-4.5	-4.7								
PA3214 G53	50+	1	-8.6	-7.8		23.3	-14.5	10.5			5.9	-9.9	9.38
PA3219 G61	30-40	2	-5.5	-3.7	-4.6								
PA3220 G62B	18-21	2	-7.3	-9.2	-5.7								
PA3222 G65F	Adult	2	-7.2										
PA3230 G75	25-35	1	-7.6	-5.0	-5.1	11			-13.1	10.5	8.0	-13.15	7.31
PA3231 G75	30-40	1	-12.6	-13.5	-11.9	21.3	-18.3	13.9			5.7		
PA3233 G77	25-35	1	-13.3	-11.9	-12.1								
PA3235 G80	45-55	2	-6.9	-7.1									
PA3236 G81	20-30	1	-12.9	-13.1	-10.8	21	-18.7	16.5			5.8		
PA3237 G82	25-35	2	-4.0	-4.0	-2.8								
PA3239 G84	35-45	1		-3.4									
PA3245 G98				-4.1		14.2			-11.5	12.0	7.4	-10.23	8.33
PA3247 G107	18-21	1	-4.1			21.8	-11.7	13.2			7.6		

[1] From Verano (2003)
[2] From Burger et al. (2003)

Table 5.3 *Summary of Dietary Isotopic Baseline Data*

Specimen	**Common Name**	**Food Type**	**$\delta^{13}C$(‰)**	**$\delta^{15}N$ (‰)**
Zea mays	Maize	C_4 Grain, boiled	-11.82	7.75
Solanum sp.	Potato	Tuber, raw	-26.60	
Solanum sp.	Chuño	Tuber, boiled	-26.87	4.85
Solanum sp.	Moraya	Tuber, boiled	-26.72	6.97
Lama glama	Llama	Camelid bone	-17.53	6.15
Lama glama	Llama	Camelid bone	-10.62	6.83
Lama glama	Llama	Camelid bone	-19.96	4.13
Lama glama	Llama	Camelid bone	-14.80	5.99
Lama glama	Llama	Camelid muscle[1]	-22.20	6.00
Chenopodium quinoa	Quinoa	C_3 Grain, raw	-25.18	7.65
Chenopodium quinoa	Quinoa	C_3 Grain, raw	-26.03	8.68
Chenopodium quinoa	Quinoa	C_3 Grain, raw	-25.06	8.02
Chenopodium quinoa	Quinoa	C_3 Grain, toasted	-25.87	8.84
Chenopodium quinoa	Quinoa	C_3 Grain, boiled	-25.18	9.04
Amaranthus caudatus	Kiwicha	C_4 Grain, raw	-12.76	13.57
Amaranthus caudatus	Kiwicha	C_4 Grain, toasted	-12.63	13.59
Amaranthus caudatus	Kiwicha	C_4 Grain, boiled	-12.27	13.46
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.98	0.94
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.98	0.23
Phaseoleum lunatus	Lima Bean	Legume, raw	-25.75	0.11
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.11	0.90
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.28	1.43
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.20	0.85
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.69	0.82
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.76	0.77
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.75	0.34
Phaseoleum lunatus	Lima Bean	Legume, raw	-24.77	0.49
Phaseoleum lunatus	Lima Bean	Legume, boiled	-26.71	0.54
Cheilodactylus variegatus	Bilagay	Marine fish muscle (n=3)[1]	-13.2	20.5
Anisotremus scapularis	Sargo/Chita	Marine fish muscle (n=1)[1]	-16.4	19.7

Chromis crusma	Castañeta	Marine fish muscle (n=1)[1]	-16.6	19.0
Cilus montii		Marine fish muscle (n=1)[1]	-14.8	18.1
Doydixodon laevifrons	Alpargata (Baunco)	Marine fish muscle (n=1)[1]	-15.2	16.7
Elasmobranchii Batoidea sp.	Sawfish	Marine fish soft tissue (n=1)[1]	-12.2	20.2
Elasmobranchii Selachii sp.	Shark/Ray/Skate	Marine fish skin (n=1)[1]	-18.00	
Hemilutjanus macrophthalmus	Apañado	Marine fish muscle (n=1)[1]	-15.10	19.70
Isaca conceptionis	Cabinza	Marine fish muscle (n=1)[1]	-16.10	17.60
Labrisomus philipii	Trambollo Boca Amarillo	Marine fish muscle (n=1)[1]	-15.30	22.20
Mugil curema	Lisa Plateada	Marine fish muscle (n=1)[1]	-16.60	17.30
Mugiloides chilensis	Blanquillo/Rollizo	Marine fish muscle (n=1)[1]	-14.4	20.5
Neptomenus crassus	Cojinova	Marine fish muscle (n=1)[1]	-15.8	18.7
Odontesthes regia	Pejerrey	Marine fish muscle (n=1)[1]	-15.70	17.70
Opleghathus insignis	San Pedro	Marine fish muscle (n=1)[1]	-15.4	21.8
Paralabrax humeralis	Cabrilla	Marine fish muscle (n=1)[1]	-14.9	19.6
Paralichthys adspersus	Legunado	Marine fish muscle (n=1)[1]	-14.5	18.1
Pimelometopon maculatus	Peje Perro	Marine fish muscle (n=1)[1]	-15.2	19.8
Prionace glauca	Tintorera	Marine fish muscle (n=1)[1]	-16.6	17.8
Sarda chilensis	Bonito	Marine fish muscle (n=1)[1]	-15.8	20.1
Sciaena gilberti	Black Drum	Marine fish muscle (n=1)[1]	-14.9	19.8
Scortickthys vividis	Borrachilla Verde	Marine fish muscle (n=1)[1]	-12.4	19.7
Sicyases sanguineas	Peje Sapo	Marine fish muscle (n=1[1]	-15.1	18.5
Squalus acanthius	Tollo de Cachos	Marine fish soft tissue (n=1)[1]	-14.1	21.6
Trachurus symetricus	Caballa	Marine fish muscle (n=1)[1]	-17.4	17.8

Xiphias gladius	Albacora	Marine fish muscle (n=1)[1]	-19.1	16.9
Orestrias sp.	Pupfish	Lake fish muscle (n=1)[1]	-14.0	8.1
Lagidium viscacia	Vizcacha	Rodent collagen (n=1)[1]	-22.1	6.0

[1] From Tieszen and Chapman (1992)

Table 5.4. *Descriptive Statistics for Dietary Isotopic Parameters*

Parameter	**Sample N**	**Mean (‰)**	**Standard Deviation**	**Median (‰)**	**Min/Max (‰)**	**Range (‰)**
Early Childhood $\delta^{13}C_{ap}$[a]	57	-6.8	3.2	-6.3	-13.3/-1.1	12.2
Middle Childhood $\delta^{13}C_{ap}$	60	-6.3	3.2	-5.5	-13.5/-1.1	12.4
Adolescent $\delta^{13}C_{ap}$	27	-6.6	3.3	-5.7	-12.3/-1.5	10.8
Infancy/ Early Childhood $\delta^{13}C_{col}$	12	-13.6	2.8	-13.0	-18.7/-9.1	9.6
Middle Childhood/ Adolescent $\delta^{13}C_{col}$	10	-13.9	2.5	-13.2	-18.6/-10.9	7.9
$\Delta^{13}C_{ap\text{-}col}$	21	7.3	1.1	7.4	5.7/9.3	3.6
Infancy/ Early Childhood $\delta^{15}N$[b]	12	11.8	2.2	11.8	8.3/16.5	8.3
Middle Childhood-Adolescent $\delta^{15}N$	10	11.8	4.8	10.8	7.4/24.4[c]	17.0
Bone collagen $\delta^{13}C_{col}$[d]	13	-12.6	2.6	-12.4	-17.7/-9.9	7.8
Bone collagen $\delta^{15}N$[d]	13	9.2	1.4	9.1	7.2/12.8	5.6

[a] All carbon isotopic statistics are expressed relative to PDB. [b] All nitrogen isotopic statistics are expressed relative to AIR.
[c] if a single outlier value of 24.4 is removed, the Min/Max becomes 7.4/13.7‰, with a range of 6.3‰. [d] From Burger et al. (2003)

Table 5.5 *Spearman & Pearson Correlation Results among Dietary Isotopic Parameters*

	Infancy/ Early Childhood $\delta^{13}C_{col}$	**Middle Childhood/ Adolescent $\delta^{13}C_{col}$**	**Infancy/Early Childhood $\delta^{13}C_{ap}$**	**Middle Childhood $\delta^{13}C_{ap}$**	**Adolescent $\delta^{13}C_{ap}$**	**% Collagen Yield**	**$\Delta^{13}C_{ap\text{-}col}$**	**Infancy/Early Childhood $\delta^{15}N$**	**Middle Childhood/ Adolescent $\delta^{15}N$**
Infancy/ Early Childhood $\delta^{13}C_{col}$	--	--	r = 0.965 $p < 0.0001$**	--	--	n.s. r = -0.243 p = 0.471	n.s. r = 0.499 p = 0.119	r = -0.733 p = 0.007**	--
Middle Childhood/ Adolescent $\delta^{13}C_{col}$	--	--	--	--	--	n.s. r = 0.262 p = 0.465	n.s. r = 0.101 p = 0.782	--	n.s. r = 0.103 p = 0.777
Infancy/Early Childhood $\delta^{13}C_{ap}$	r = 0.965 $p < 0.0001$**	--	--	--	--	--	--	r = -0.758 p = 0.007**	--
Middle Childhood $\delta^{13}C_{ap}$	--	--	--	--	--	--	--	--	--
Adolescent $\delta^{13}C_{ap}$	--	--	--		--	--	--	--	--
% Collagen Yield	n.s. r = -0.243 p = 0.471	n.s. r = 0.262 p = 0.465	--	--	--	--	n.s. r = -0.338 p = 0.145	n.s. r = 0.130 p = 0.703	n.s. r = -0.164 p = 0.651
$\Delta^{13}C_{ap\text{-}col}$	n.s. r = 0.499 p = 0.119	n.s. r = 0.101 p = 0.782	--	--	--	n.s. r = -0.338 p = 0.145	--	n.s. r = -0.465 p = 0.149	r = -0.636 p = 0.048*
Infancy/Early Childhood $\delta^{15}N$	r = -0.733 p = 0.007**	--	r = -0.758 p = 0.007**	--	--	n.s. r = 0.130 p = 0.703	n.s. r = -0.465 p = 0.149	--	--
Middle Childhood/ Adolescent $\delta^{15}N$	--	n.s. r = 0.103 p = 0.777	--	--	--	n.s. r = -0.164 p = 0.651	r = -0.636 p = 0.048*	--	--

Figure 5.1 *Models of Expected Dietary Isotopic Distributions by Social Class*

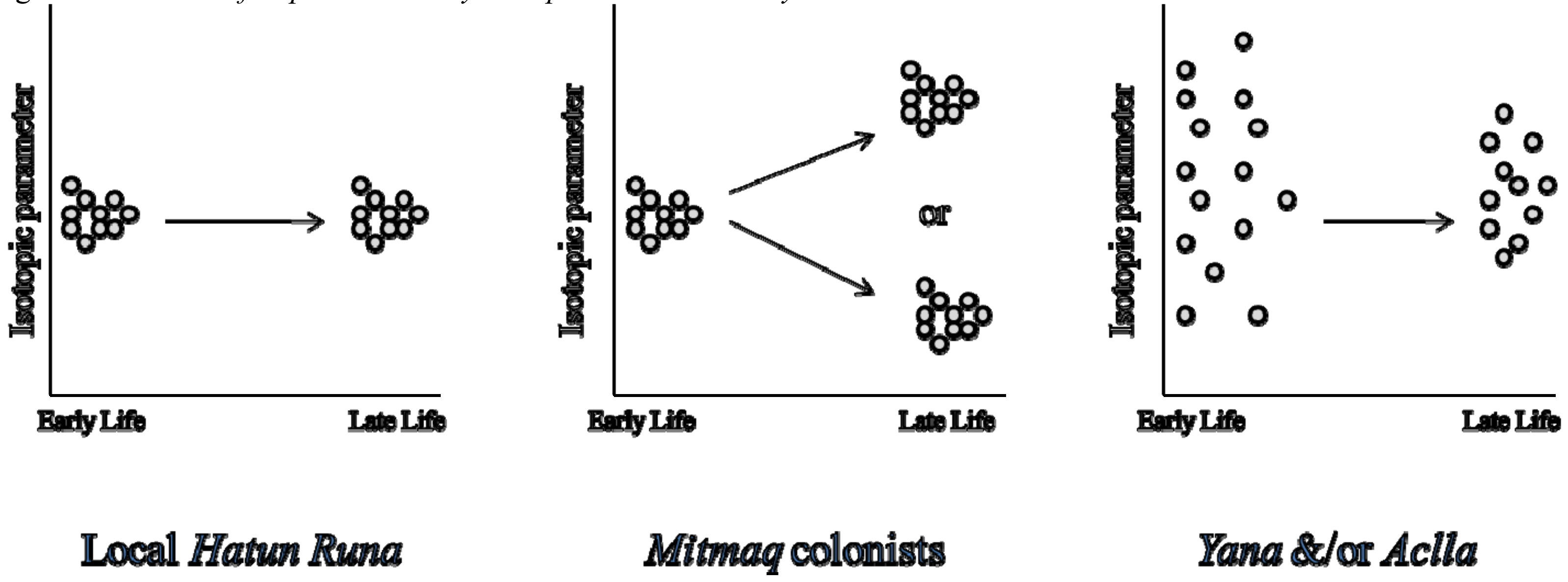


Figure 5.2 *Plot of Individual $\delta^{15}N$ Against Percent Collagen Yield*

Figure 5.3 *Plot of Individual* $\delta^{13}C_{col}$ *Against Percent Collagen Yield*

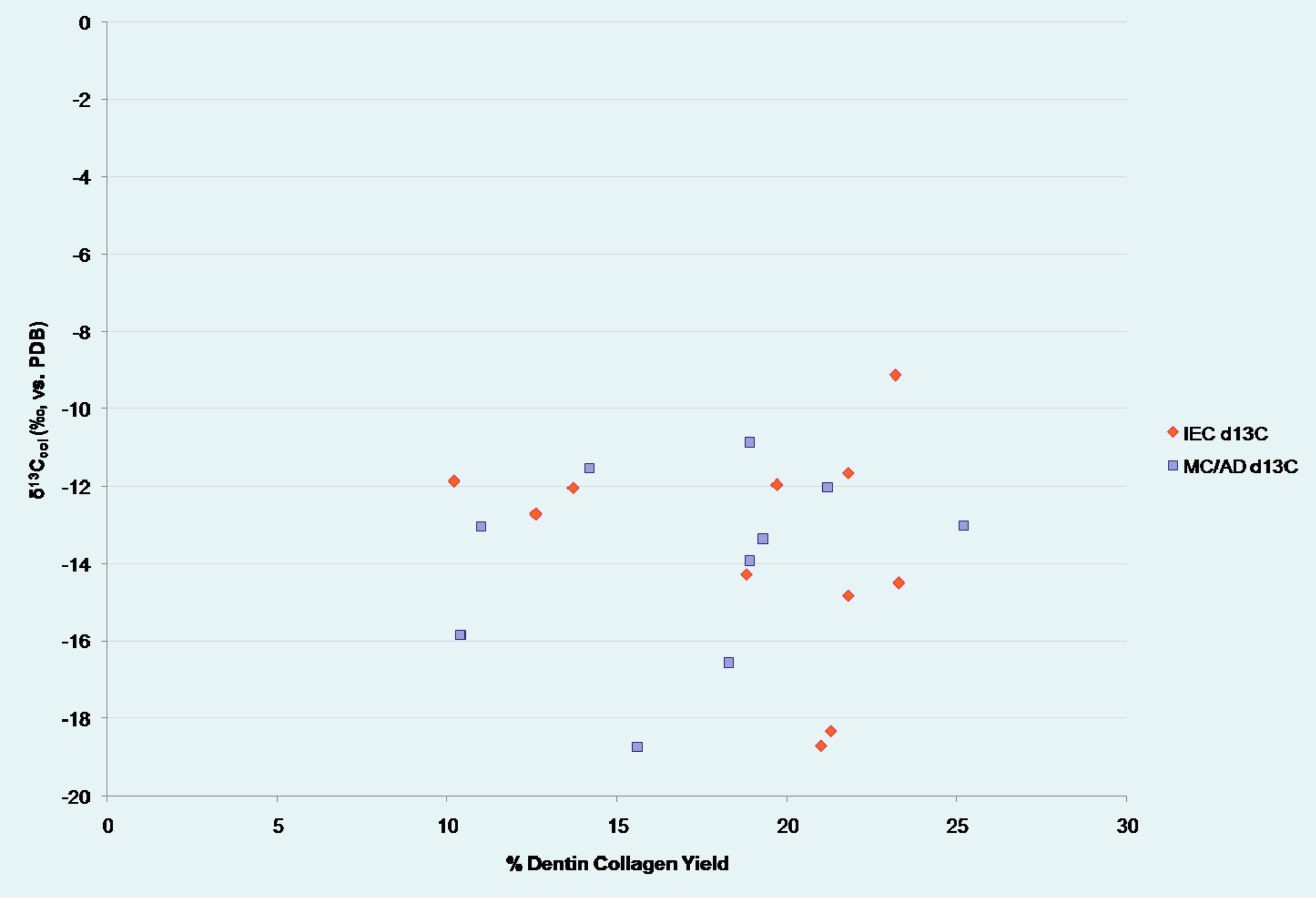


Figure 5.4 *Plot of Individual* $\Delta^{13}C_{ap\text{-}col}$ *Against Percent Collagen Yield*

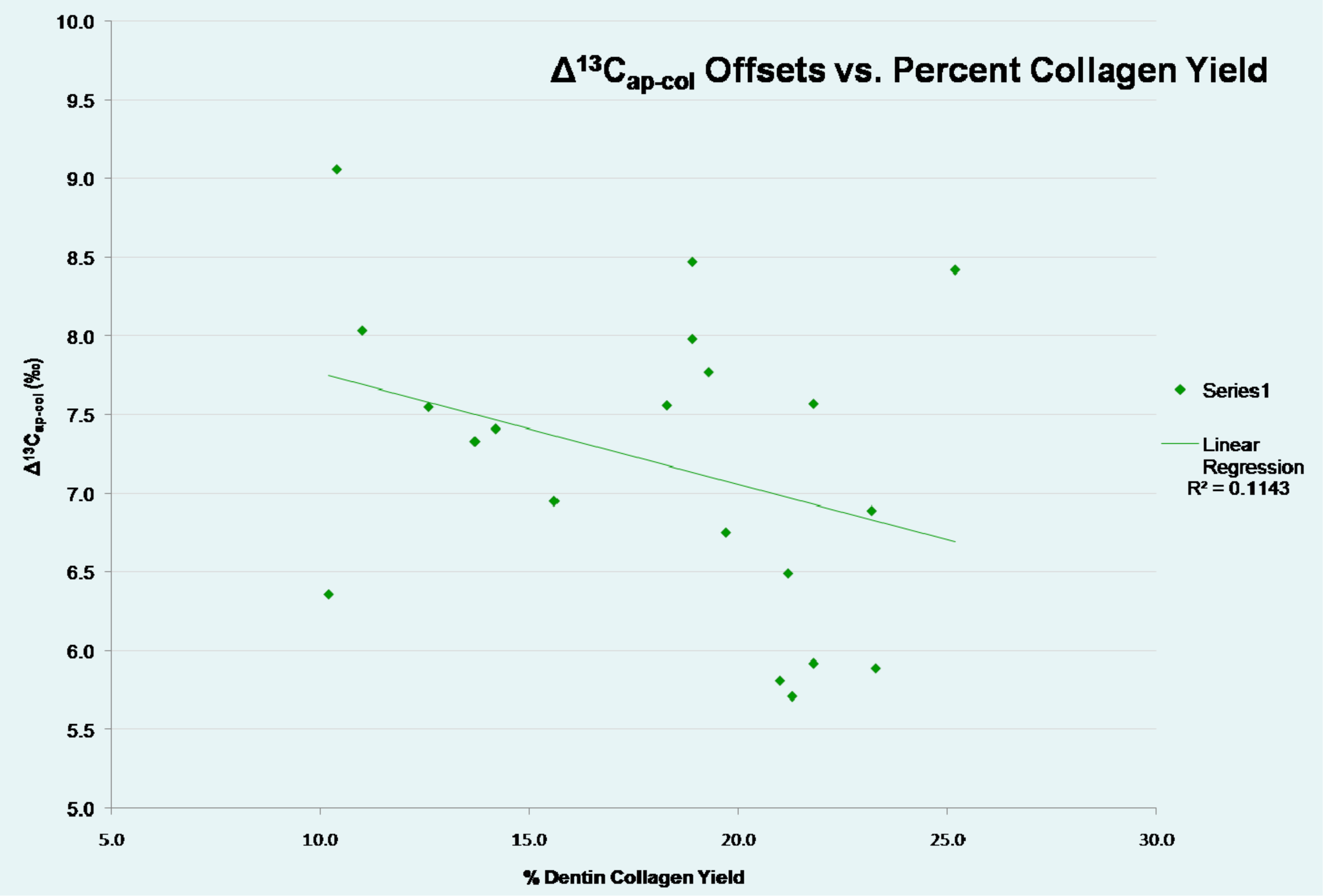


Figure 5.5 *Dentin $\delta^{13}C_{col}$ and $\delta^{15}N$ Results for the Machu Picchu Study Population*

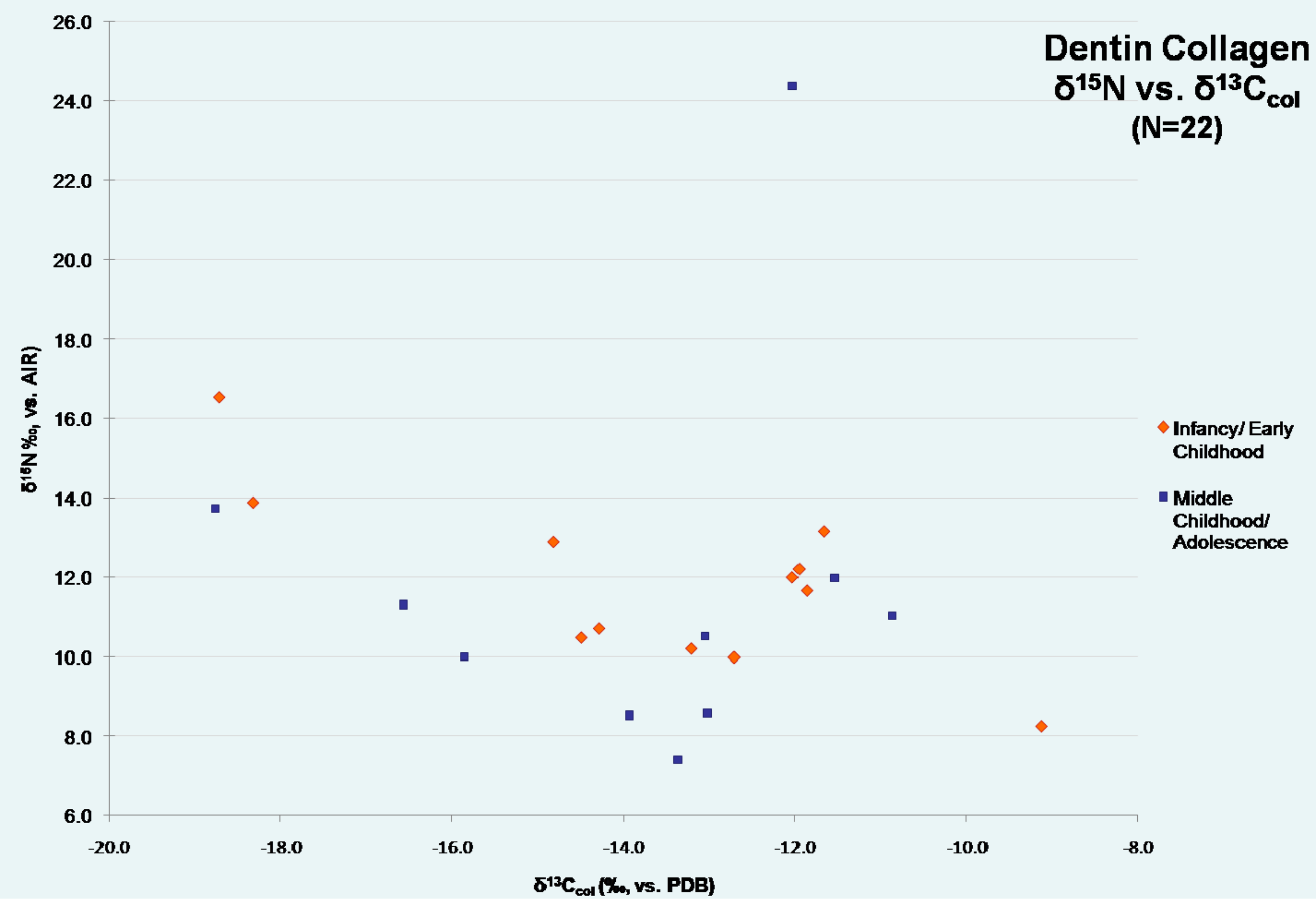


Figure 5.6 *Enamel $\delta^{13}C_{ap}$ for Each Individual for Early-Life Developmental Periods*

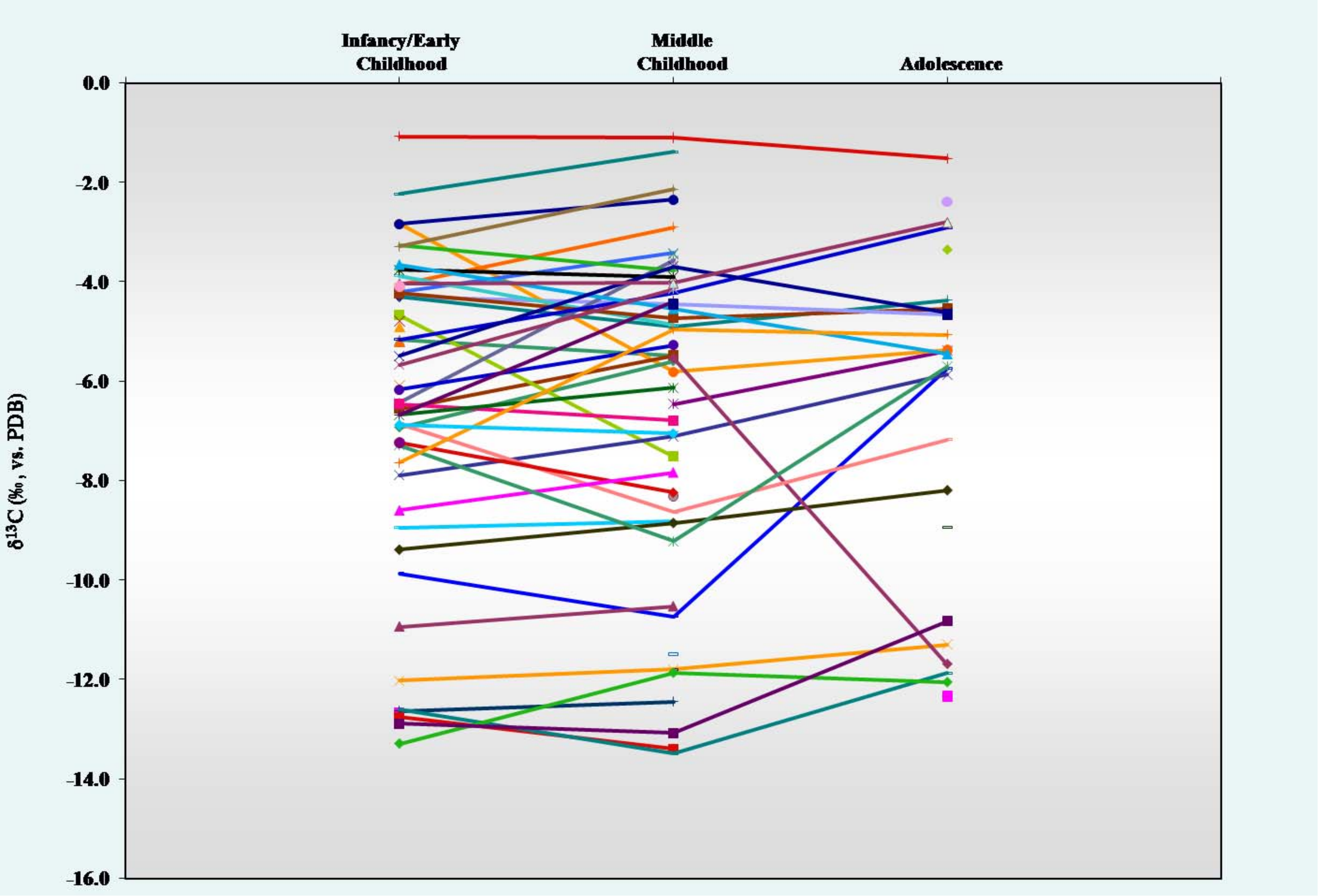


Figure 5.7 *Isotopic Results for Common Inca-Period Foods Against Human Dietary Isotopic Results*

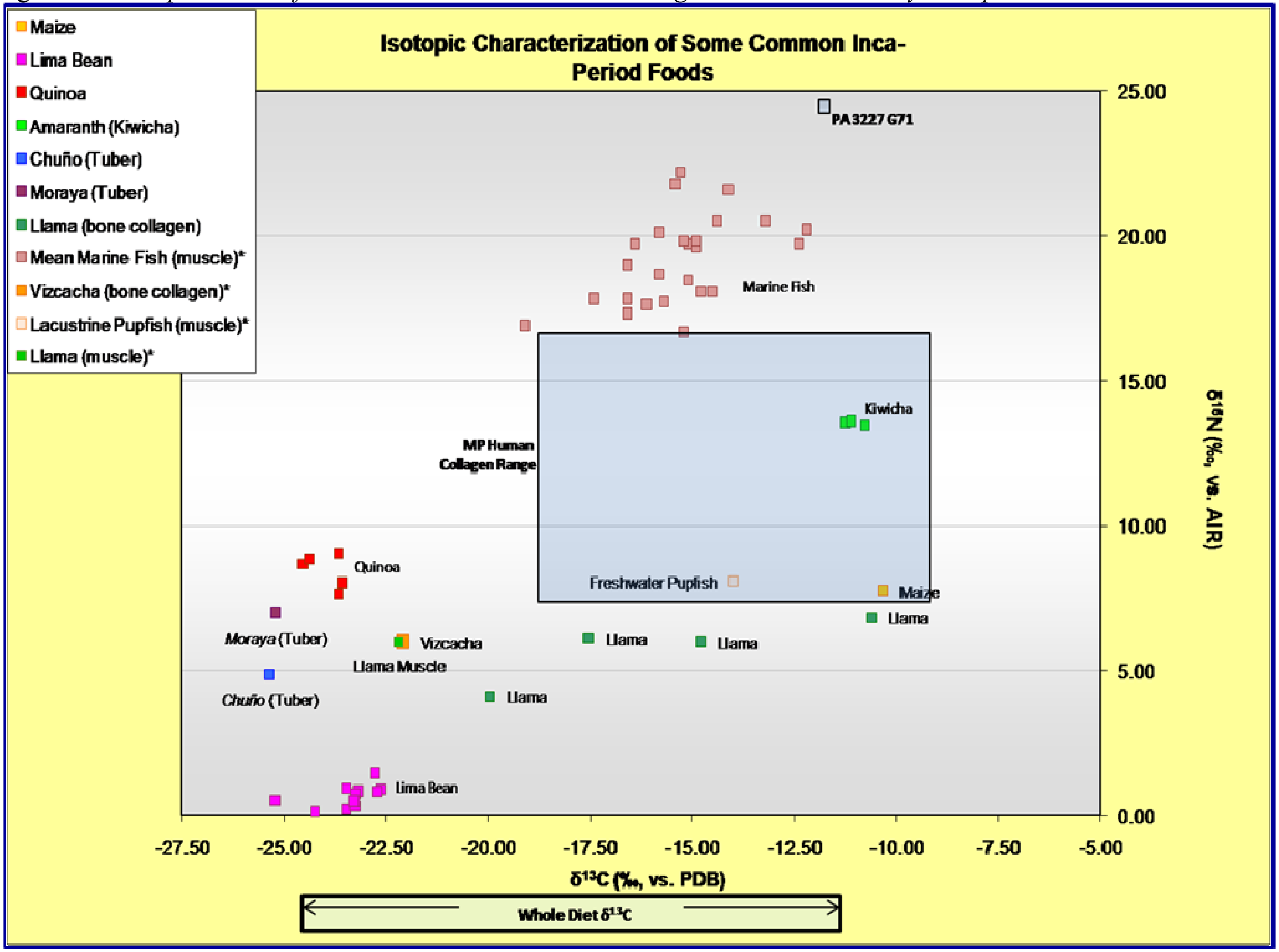
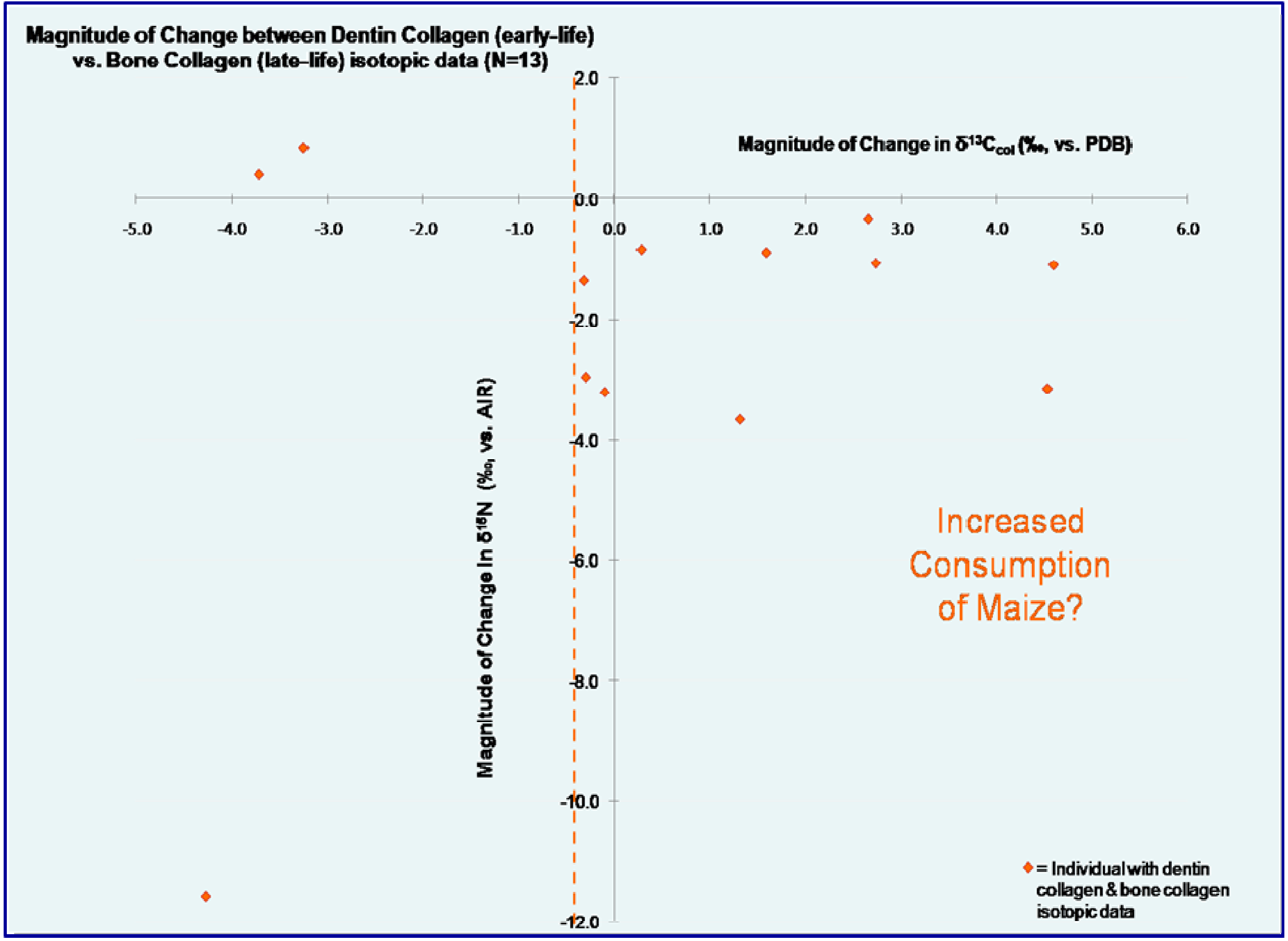


Figure 5.8 *Magnitudes of Change between Early-Life and Late-Life* $\delta^{13}C_{col}$ *and* $\delta^{15}N$



aDotted line represents 0.5‰ change accounting for differences in purification methods

Table 6.1 *Pathological Conditions at Machu Picchu*

Individual	Age	Sex	# Ant. EH	# Molar EH	# Caries	# Absc.	# AMTL	Ave. Ant. Wear	Ave. M1 Wear	Ave. M2 Wear	Ave. M3 Wear	Porotic Hyperostosis	Cribra Orbitalia	EAM Poros.	Brow Poros.
PA3195 G41	40-50	F			0	0	0						N		0
PA0531 G70				0	6	0	0		2	1	1				
PA4747 G3B			0	0	2	0	0	0	0	0				0	0
PA3192 G40	30-40	F		0	2	0	0		1	1	0	N		1	
PA3163 G9	20-25	M	6	0	0	0	0	0	1	0	1			1	1
PA4761 G99	Adult	M	0		0		0	0	1	1	0				
PA3232 G77	40-50	F	0	0	6	3	0	0	1	0	0	N	N	1	0
PA3168 G16	25-30	M	3	2	1	0	0	0	1	0	0	N	N	2	2
PA3246 G102				1	7	2	0		1		0	N	N	0	1
PA3211 G52A	30-40	M	0	2	2	1	0	1	2	1	1	N	N	2	2
PA3186 G37	20-30	F	2	0	1	0	0	0	1	0	0	N	N	1	0
PA3179 G31	30-40	F	1	0	8	1	4	1	1	1	0	Y	Y	2	2
PA3191 G40	30-45	F	0	0	0	0	4	1	1	0	0	N	Y	1	1
PA3248 G107	Young Adult	M	2	0	2	0	0	0	0	0	0	Y	Y	0	0
PA3202 G47A	5 to 6		0	0	0	1	0	0	0			N	N	0	2
PA0524 G46	17-20	F		0	0	0	0	0	0	0					
PA0522 G8	Adult	F		0		1	0		1	0	1				
PA3194 G41	30-35	M		0	2	2	4	0				N	N	2	2
PA3158 G4G				0	3	0	1	1	1	1			N		0
PACoMd G37	Adult	F	3				3	0		1	0				
PA0525 G55				0	0	1	0	0	0	0		N		0	0
PA3206 G49	18-22	F	3		1	0	0	0				N	Y	2	0
PA3187 G37	30-40	F			2	0	4		2	1		Y	N	1	2
PA3160 G5	25-35	M	1		2	0	2	0	1			N		2	1
PA3221 G63	25-35	F		0	0	0	5	1	1	0	0	N	Y	2	2
PA3209 G50	50+	F		0	1	0	1	0	1		0				
PA3222 G65	8 to 9		1	1	0	0	0	0	0	0		N	N	0	0
PA3158 G4F					0	1	0	1	1						
PA3159 G4B	Young Adult	M		1	0	0	1	1	1	1	0	N	N	2	

PA3158 G4C	Adult	M		1	1	3	1		1	0		N	N	0	
PA3188 G37	50+	F			1	3	9	1	2			N		1	1
PA3158 G4A	Young Adult	M	0	0	0	0	0	0	1	0		N		1	1
PA3158 G4B				3	0	0	0	0	0	0					
PA3165 G11	50-60	F	1		11	2	1	1	2	1		N	N	1	2
PA3196 G42	40-50	M		1	2	4	7	1	2	1	1	N	N	1	2
PA3157 G3A	30-40	F		2		3	5	0	1	0	0	N	N	2	1
PA3208 G50	11 to 13		0	0		0	0	0	0	0		N	Y	0	2
PA3164 G9B	20-25	M			4	11	15		0	0		N	N	1	1
PA3243 G93	30-45	F	4	3	3	4	5	0	1	0	0	N	Y	2	0
PA3228 G72	10 to 11					0	0		1			Y	Y	1	2
PA3238 G84	17-20	M		1	2	0	3	0	0	0	0	N	N	2	0
PA3227 G71	19-24	M	1	0	0	0	0	0	1	0	0	N	N	1	1
PA3173 G23	16-18	M	1	0	0	0	0	0	0	0		N	N	1	2
PA3220 G62A	20-30	M	2	0	3	1	1	0	0	0	0	N	N	1	2
PA3197 G42	55-65	F			4	4	11		1	1		N	N	0	0
PA3156 G1	19-23	F		0	2	1	2		1	0		N	Y	2	1
PA4746 G2A	Adult	M	3				0	0	0			N			
PA4746 G2B	Adult		2				0	0	1					1	
PA3161 G5B	Middle Adult	F				1	5	1				N		1	
PA0521 G7	15-17		2	2	2	0	0	0	0	0		N	Y	1	1
PA4749 G12	Adult	F					0								
PA3166 G13	45-55	F			2	1	6	1	2	1		N			
PA0523 G14A	18-21	F					5								
PA3182 G32	30-35	M			3	3	3	1	1	1		N		1	0
PA3183 G33	25-35	M					1								
PA3184 G34	40-50	F	7	1	16	4	5	1	1	1		N	N	1	0
PA3189 G38	35-45	F	1		2	2	4	1	2	1			N	0	
PA3190 G39	20-29	F		0	0	0	1	0	0	0	0	N	N	1	2
PA3199 G42	50+	M			4	3	8	1	2	1		N	N	0	1
PA3205 G48B	15-18	M		0	0	0	0	0	1	0		N	N	2	1
PA3207 G50B	Young Adult				2	1	6	0	1	0	0				

PA3214 G53	50+	M			5	6	7	1	1	1		N	N	1	1
PA3219 G61	30-40	F			3	2	6	0	1	1	1	N	Y	2	1
PA3220 G62B	18-21	F	3	1	0	2	0	0	1		0			1	
PA3222 G65F	Adult	F						1							
PA3230 G75	25-35	M	1		2	1	0	0	1	0	0	N	N	2	2
PA3231 G75	30-40	M				0	0	0	1	1	0	N	N	1	0
PA3233 G77	25-35	M			1	2	0	1	2	1	0	N	N	1	1
PA3235 G80	45-55	F	6		9	4	17	0		1	0	N	N	0	1
PA3236 G81	20-30	M	2	3	0	0	0	0	1	0	0	N	N	2	2
PA3237 G82	25-35	F	3	0	0	0	0	0	1	0	0	N	N	1	0
PA3239 G84	35-45	M	3		12	14	11	1	1			N	N	1	2
PA3245 G98					11	3	6	0	2	1		N	N	0	0
PA3247 G107	18-21	M	0	0	0	0	0	0	1	0	0	N	N	1	1

† Wear scores drawn from averages of numerical scores described in Buikstra and Ubelaker (1994): Mild= 1-3, Moderate = 4-7, Severe = 8-10.

‡ Wear scores drawn from averages of numerical scores described in Buikstra and Ubelaker (1994): Mild= 0-13; Moderate = 14-27; Severe =28-40.

◊0= Not present; 1=Mild; 2=Moderate.

Table 6.2 *Descriptive Statistics for Pathological Conditions at Machu Picchu*

Pathological Condition	Percent of Prevalence	Percentage of the Study Population (N=74) Measureable for Pathological Condition
Anterior Enamel Hypoplasia	Had ≥ 1 = 71% Had None = 29%	46%
Molar Enamel Hypoplasia	Had ≥ 1 = 36% Had None = 64%	57%
Caries	Had ≥ 1 = 66% Had None = 34%	61%
Abscesses	Had ≥ 1 = 52% Had None = 48%	89%
Teeth Lost Antemortem (AMTL)	Had ≥ 1 = 71% Had None = 29%	99%
Ave. Anterior Wear Scores[†]	Mild = 67% Moderate = 33% Severe = 0%	81%
Ave. First Molar Wear Scores[‡]	Mild = 23% Moderate = 59% Severe = 17%	86%
Ave. Second Molar Wear Scores[‡]	Mild = 58% Moderate = 42% Severe = 0%	74%
Ave. Third Molar Wear Scores[‡]	Mild = 82% Moderate = 18% Severe = 0%	46%
Porotic Hyperostosis	Not present = 93% Present = 7%	73%
Cribra Orbitalia	Not present = 77% Present = 23%	65%
External Auditory Meatus Porosity	None = 23% Mild= 49% Moderate = 28%	77%
Brow Porosity	None = 33% Mild= 35% Moderate = 33%	70%

[†] Wear scores drawn from averages of numerical scores described in Buikstra and Ubelaker (1994): Mild= 1-3, Moderate = 4-7, Severe = 8-10.

[‡] Wear scores drawn from averages of numerical scores described in Buikstra and Ubelaker (1994): Mild= 0-13; Moderate = 14-27; Severe =28-40.

Table 6.3 *Chi-Square Tests of Association between Pathological Conditions*

	#Caries	#Abscesses	#Teeth Lost Antemortem	Anterior Wear Score	Presence of Porotic Hyperostosis	Presence of Cribra Orbitalia	M1 Wear Score	M2 Wear Score	M3 Wear Score	#Anterior Enamel Hypoplasia	#Molar Enamel Hypoplasia
#Caries	--	p<0.0001**	p<0.0001	n.s. (p=0.315)	a.s. (p=0.076)	n.s. (p=0.648)	n.s. (p=0.236)	a.s. (p=0.081)	n.s. (p=0.688)	p=0.005**	n.s. (p=0.514)
#Abscesses	p<0.0001**	--	p<0.0001	a.s. (p=0.083)	n.s. (p=0.916)	n.s. (p=0.820)	n.s. (p=0.185)	p=0.017*	n.s. (p=0.669)	n.s. (p=0.158)	a.s. (p=0.074)
#Teeth Lost Antemortem	p<0.0001**	p<0.0001**	--	p=0.011**	n.s. (p=0.400)	n.s. (p=0.456)	n.s. (p=0.101)	a.s. (p=0.09)	n.s. (p=0.265)	p=0.006**	n.s. (p=0.510)
Anterior Wear Score	n.s. (p=0.315)	a.s. (p=0.083)	p=0.011**	--	n.s. (p=0.644)	n.s. (p=0.905)	p<0.0001**	p<0.0001**	n.s. (p=0.176)	n.s. (p=0.255)	n.s. (p=0.277)
Presence of Porotic Hyperostosis	a.s. (p=0.076)	n.s. (p=0.916)	n.s. (p=0.400)	n.s. (p=0.644)	--	p=0.014**	n.s. (p=0.919)	n.s. (p=0.347)	n.s. (p=0.595)	n.s. (p=0.829)	n.s. (p=0.709)
Presence of Cribra Orbitalia	n.s. (p=0.648)	n.s. (p=0.820)	n.s. (p=0.456)	n.s. (p=0.905)	p=0.014**	--	n.s. (p=0.233)	n.s. (p=0.185)	n.s. (p=0.687)	n.s. (p=0.614)	n.s. (p=0.311)
M1 Wear Score	n.s. (p=0.236)	n.s. (p=0.185)	n.s. (p=0.101)	p<0.0001**	n.s. (p=0.919)	n.s. (p=0.233)	--	p<0.0001**	p<0.007**	n.s. (p=0.877)	n.s. (p=0.810)
M2 Wear Score	a.s. (p=0.081)	p=0.017*	a.s. (p=0.09)	p<0.0001**	n.s. (p=0.347)	n.s. (p=0.185)	p<0.0001**	--	n.s. (p=0.118)	n.s. (p=0.425)	n.s. (p=0.256)
M3 Wear Score	n.s. (p=0.688)	n.s. (p=0.669)	n.s. (p=0.265)	n.s. (p=0.176)	n.s. (p=0.595)	n.s. (p=0.687)	p<0.007**	n.s. (p=0.118)	--	n.s. (p=0.392)	n.s. (p=0.834)
#Anterior Enamel Hypoplasia	p=0.005**	n.s. (p=0.158)	p=0.006**	n.s. (p=0.255)	n.s. (p=0.829)	n.s. (p=0.614)	n.s. (p=0.877)	n.s. (p=0.425)	n.s. (p=0.392)	--	n.s. (p=0.109)
#Molar Enamel Hypoplasia	n.s. (p=0.514)	a.s. (p=0.074)	n.s. (p=0.510)	n.s. (p=0.277)	n.s. (p=0.709)	n.s. (p=0.311)	n.s. (p=0.810)	n.s. (p=0.256)	n.s. (p=0.834)	n.s. (p=0.109)	--

*value is significant at (P ≤ 0.05)   **value is significant at (P≤0.01)

Table 6.4 *One-way ANOVA Results*

Parameter	**N**	**Sex**	**Age Category**	**Prevalence Porotic Hyperostosis**	**Prevalence Cribra Orbitalia**	**Severity Brow Porosity** ^{b}	**Severity Ext. Aud. Meatus Porosity** ^{b}	**Dental Wear Scores**	**# Anterior Tooth Enamel Hypoplasia**	**# Molar Tooth Enamel Hypoplasia**	**# Caries**	**# Abscesses**	**#AMTL**
Middle Childhood $\delta^{18}O$	52	n.s. (p=0.230)	n.s. (p=0.296)	p=0.05 (R^2=0.09)	p=0.0008** (R^2=0.27)	n.s. (p=0.405)	n.s. (p=0.639)	n.s.	n.s. (p=0.617)	p=0.015* (R^2=0.34)	n.s. (p=0.835)	n.s. (p=0.932)	n.s. (p=0.765)
Adolescent $\delta^{18}O$	25	n.s. (p=0.212)	n.s. (p=0.822)	n.s. (p=0.324)	n.s. (p=0.19)	n.s. (p=0.773)	p=0.015* (R^2=0.37)	n.s.	n.s. (p=0.660)	a.s. (p=0.082)	a.s. (p=0.084, R^2=0.47)	n.s. (p=0.355)	n.s. (p=0.150)
$^{206}Pb/^{204}Pb$	39	n.s. (p=0.156)	n.s. (p=0.643)	n.s. (p=0.394)	n.s. (p=0.426)	n.s. (p=0.127)	n.s. (p=0.535)	n.s.	p=0.019* (R^2=0.62)	n.s. (p=0.191)	n.s. (p=0.500)	n.s. (p=0.467)	p=0.035* (R^2=0.33)
$^{207}Pb/^{204}Pb$	39	n.s. (p=0.261)	n.s. (p=0.785)	n.s. (p=0.294)	n.s. (p=0.549)	n.s. (p=0.136)	n.s. (p=0.551)	p=0.03* (R^2=0.25) (w/M3)	p=0.032* (R^2=0.57)	n.s. (p=0.522)	n.s. (p=0.451)	n.s. (p=0.595)	p=0.023* (R^2=0.35)
$^{208}Pb/^{204}Pb$	39	n.s. (p=0.737)	n.s. (p=0.591)	n.s. (p=0.465)	n.s. (p=0.759)	n.s. (p=0.157)	n.s. (p=0.185)	n.s.	n.s. (p=0.117)	n.s. (p=0.311)	n.s. (p=0.278)	n.s. (p=0.666)	n.s. (p=0.275)
Infancy/Early Childhood $\delta^{13}C_{col}$	12	n.s. (p=0.174)	n.s. (p=0.429)	n.s. (p=0.714)	n.s. (p=0.463)	n.s. (p=0.281)	n.s. (p=0.727)	n.s.	n.s. (p=0.884)	p=0.012** (R^2=0.87)	n.s. (p=0.903)	n.s. (p=0.859)	n.s. (p=0.981)
$\Delta^{13}C_{ap\text{-}col}$	21	n.s. (p=0.429)	n.s. (p=0.554)	n.s. (p=0.220)	n.s. (p=0.861)	n.s. (p=0.112)	n.s. (p=0.416)	n.s.	n.s. (p=0.189)	n.s. (p=0.486)	n.s. (p=0.552)	n.s. (p=0.512)	n.s. (p=0.407)
Infancy/Early Childhood $\delta^{15}N$	12	n.s. (p=0.238)	n.s. (p=0.336)	n.s. (p=0.640)	n.s. (p=0.165)	n.s. (p=0.459)	n.s. (p=0.900)	n.s.	n.s. (p=0.969)	P=0.023* (R^2=0.83)	n.s. (p=0.711)	n.s. (p=0.949)	n.s. (p=0.587)
Middle Childhood/ Adolescent $\delta^{13}C_{col}$	10	n.s. (p=0.843)	Insufficient data	0 cases of PH	0 cases of CO	n.s. (p=0.494)	n.s. (p=0.198)	a.s. (p=0.06, R^2=0.64) (w/M3)	n.s. (p=0.288)	n.s. (p=0.837)	n.s. (p=0.589)	n.s. (p=0.672)	p=0.05* (R^2=0.70)

[a] from Verano (2003) [b] 0=none, 1=mild, 2= severe *value is significant at ($P \leq 0.05$) **value is significant at ($P \leq 0.01$)

Table 6.5 *Kruskal-Wallis Results*

Parameter	**N**	**Sex**	**Age Category**	**Prevalence Porotic Hyperostosis**	**Prevalence Cribra Orbitalia**	**Severity Brow Porosity** [b]	**Severity Ext. Aud. Meatus Porosity** [b]	**Dental Wear Scores**	**# Anterior Tooth Enamel Hypoplasia**	**# Molar Tooth Enamel Hypoplasia**	**# Caries**	**# Abscesses**	**# AMTL**
Early Childhood $\delta^{18}O$	53	a.s. (p=0.077)	n.s. (p=0.58)	p=0.032*	p=0.004**	n.s. (p=0.94)	n.s. (p=0.242)	n.s.	n.s. (p=0.452)	a.s. (p=0.067)	n.s. (p=0.647)	n.s. (p=0.890)	n.s. (p=0.622)
$^{87}Sr/^{86}Sr$	51	n.s. (p=0.447)	p=0.051*	n.s. (p=0.801)	a.s. (p=0.089)	n.s. (p=0.368)	n.s. (p=0.162)	a.s. (p=0.09 (M2)	n.s. (p=0.738)	n.s. (p=0.289)	n.s. (p=0.555)	n.s. (p=0.541)	n.s. (p=0.415)
Early Childhood $\delta^{13}C_{ap}$	56	a.s. (p=0.059)	n.s. (p=0.763)	n.s. (p=0.336)	a.s. (p=0.080)	n.s. (p=0.166)	n.s. (p=0.910)	p=0.044 * (M1); p=0.07 (M2)	n.s. (p=0.394)	n.s. (p=0.999)	n.s. (p=0.622)	n.s. (p=0.942)	n.s. (p=0.744)
Middle Childhood $\delta^{13}C_{ap}$	60	n.s. (p=0.625)	n.s. (p=0.274)	n.s. (p=0.381)	n.s. (p=0.166)	n.s. (p=0.149)	n.s. (p=0.459)	n.s.	n.s. (p=0.534)	n.s. (p=0.999)	n.s. (p=0.205)	n.s. (p=0.871)	n.s. (p=0.554)
Adolescent $\delta^{13}C_{ap}$	27	p=0.028*	n.s. (p=0.593)	n.s. (p=0.260)	a.s. (p=0.08)	n.s. (p=0.271)	a.s. (p=0.087)	n.s.	n.s. (p=0.455)	n.s. (p=0.671)	n.s. (p=0.254)	n.s. (p=0.238)	a.s. (p=0.094)
Middle Childhood/ Adolescent $\delta^{15}N$	10	n.s. (p=0.439)	Insuff. data	0 cases of PH	0 cases of CO	n.s. (p=0.199)	n.s. (p=0.229)	n.s.	n.s. (p=0.258)	n.s. (p=0.607)	n.s. (p=0.617)	n.s. (p=0.510)	n.s. (p=0.439)

[a] from Verano (2003)   [b] 0=none, 1=mild, 2= severe

*value is significant at ($P \leq 0.05$)   **value is significant at ($P \leq 0.01$)

Figure 6.1 *Photo of Fine Porosity of the Brow:*
(a) Mild (PA3247 G107)

(b) Moderate (PA3194 G41)

Figure 6.2 *Photo of Fine Porosity of the External Auditory Meatus:*

(a) Mild (PA3187 G37)

(b) Moderate (PA3239 G84)

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