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REFINING DIETARY ESTIMATES AT MACHU PICCHU USING COMBINED DENTAL MACRO/MICROWEAR AND ISOTOPIC ANALYSES

by

SARAH V. LIVENGOOD

Under the Direction of Dr. Bethany L. Turner

ABSTRACT

Reconstructing diet in Andean populations is complicated by ecological complexity and by large-scale population movements and trade networks during the period of imperial rule. It is therefore more difficult to reconstruct dietary patterns within these contexts. Previous multi-isotopic analysis of the skeletal population from the Inca site of Machu Picchu indicates marked variation in dietary composition both early and late in life. However, these data are limited in their specificity due to overlap in isotopic signals from different resource types. I compare existing isotopic data to enamel macro- and microwear data to more accurately profile diet composition in a Machu Picchu skeletal population subset. Results suggest there is little to no dietary variation between sexes and age groups. Results also reveal the role that maize played in the diet of this non-elite population, which may prove useful in more accurately estimating consumed food resources in this and other Andean populations.

INDEX WORDS: Machu Picchu, Inca, Dental microwear, Isotopic analysis, Peru

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SARAH V. LIVENGOOD

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

in the College of Arts and Sciences

Georgia State University

2012

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May 2012

ACKNOWLEDGEMENTS

There is no way I can fully thank everyone who has helped me complete this thesis, but I will start at the beginning and hope that I can acknowledge everyone. Donna, my first and one of the best friends I have in Atlanta, did not just find me a place to live, but through her friendship and love made this new place feel like a home. I am so glad that we started this program together, and I am proud to be finishing it with her. We started the program with a fantastic group of people, and I have to thank everyone in that cohort for making this one of the best and most “interesting” experiences of my life. I have learned so much from everyone in class, and (most importantly) our experiences and conversations outside of class. I would not have made it to this point without everyone’s laughter, support (I especially appreciate those who always had my back), and, of course, gossip.

A special thank you to Les for teaching me just about everything to do with the bioarchaeology lab, and her support when life got tough. Also a huge ‘thank you’ for delicious birthday cupcakes, and always having snacks to share in class or the lab. Another thank you to Tony for making sure I never got lost, showing me the secret to siding a fibula, and his continual friendship. The third and fourth semesters were the hardest, and I would not have made it through them without the Friday’s game/eating/drinking night with Emily, Sara, and Jason. All the time we have spent together has offered much needed laughs, which helped to relieve the stress, at least for the night. Thank you for all the help with GIS (Jason), statistics (Sara), and answering every thesis question (Emily). Also thank you, Emily, for taking care of Lily bug and loving her so much! And a special thanks to Sara and Emily for their support, again, when life got tough.

I could not thank everyone who got me through this process without thanking my family. Thank you for being there for me when I *really* moved away for the first time, for every phone call, and every holiday. Holidays are a much needed break from the rigors of academic life, and playing sardines for several hours in the dark, and a surprise birthday cake after I spent my birthday on the road reminded me of what is really important in my life and who will always care and love me, my family. And thank you to my family for not freaking out, too much, when I decided/ told you I married Nick.

Nick, our life has been a roller- coaster ride this past year, but I am so glad you are always there for me offering your love and support as our lives constantly change. Your willingness to move anywhere with me/ for me baffles me, but I am glad that you are the one I get to conquer the world with. I could not ask for a better best friend and husband. The next phase of my education seems daunting, but knowing you will be my side offers much needed comfort. And thank you for convincing me to get a puppy that has forever changed our lives, and always makes the worst days better. When I think of my family I think of you guys and know how lucky I am to have you.

Ultimately I would not have made it to this point without my advisors. Thank you Dr. Williams and Dr. Glover for always pushing me to expand my knowledge, and do better than my best. And a big thank you for always being enthusiastic about everything you teach, managing to find time to help me in your hectic schedules, and all of your edits! I also have to thank my past professors who have become such great friends. And with the list of teachers in my life to thank I cannot forget Jodi. She inspired me to pursue this crazy path, and even though time and space keeps us apart we can always pick up where we left off. Your friendship means the world to me.

Last, but certainly not the least, I have to thank my amazing advisor and friend Beth Turner. She trusted me to continue the work she started with this skeletal set, and has helped me every step of the way. She has taught me so much in and outside of class, and has made me a better anthropologist. She has given me the inspiration to follow my own path, wherever that may take me, and has always been there for a laugh or sometimes a good cry. Thank you, thank you, thank you for everything you have done to get me to this point.

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ABBREVIATIONS

BP	Before Present
CI	Confidence Interval
KMO	Kaiser- Meyer- Olkin
LEH	Linear Enamel Hypoplasias
PCA	Principal Components Analysis
SEM	Scanning Electron Microscopy

CHAPTER 1: DIETARY RECONSTRUCTION THROUGH DENTAL ANALYSIS

1.1 Purpose of this Study

Diet is at the foundation of behavioral and ecological differences among all species (Grine 2007, Ungar et al. 2008). Human subsistence patterns are an important aspect of the reconstruction of past human lifeways, and allow for a more comprehensive look at disease processes, migratory patterns, differential access to foods, changes in socio-political structure, and overall health (Grine 2007, Turner et al. 2010). The reconstruction of past human lifeways can be challenging due to a fragmentary bioarchaeological and archaeological record; despite this, among the most frequent finds at a site are teeth due to their strong matrix. Tooth enamel is mostly composed of hydroxyapatite, which not only contributes to its hardness, but it also stores trace elements and elemental isotopic ratios from foodstuffs. The hard structure of calcium apatite is what allows teeth to preserve more frequently in the archaeological record/over time in various conditions. Teeth are an important resource for understanding subsistence patterns due to their interaction with everything that is ingested. Diet can be inferred by overall tooth size morphology, enamel thickness along with the study of the biomechanics, and cranial and mandibular morphology (Grine 2007). *Homo sapiens* all have similarly shaped dentition and cranial and mandibular features, which makes morphological differences less useful in reconstructing diet unless studying changes in diet over long time spans (Van Gerven 1982). However, the bioarchaeological record can provide information about diet through dental malformations, dental microwear and isotopic analyses.

It is especially difficult to reconstruct subsistence patterns in Late Horizon period (AD 1438-1532) Andean populations because of the region's ecological complexity and population movements. It is known that *chicha,* a maize based beer, was an important component of feasting and rituals, and that maize was habitually eaten among the elite in various forms (Burger 2008), such as *mote,* hominy, popcorn, or ground forms (Hastorf 1993). However, the extent to which *chicha* or other forms of maize were important dietary components to lower classes is debatable, and evidence for the extent of its consumption has been based on historic records (Bartolomé de las Casas 1939[1552]: 64, 127-130, Murra 1980, Murúa 1964 [1600]: 69, Pizarro 1921[1571]: 198) and indirect archaeological and bioarchaeological evidence (Burger 2003, Hastorf and Johannessen 1993, Turner et al 2010). Outside of historic records, isotopic and osteological analysis has almost exclusively been utilized to understand diet in Andean populations. These analyses have been used as indirect evidence of *chicha* and/or general maize consumption, such as the isotopic analysis (Turner 2008, Burger et al. 2003) of the population used in this study. Turner (2008) found a decrease in nitrogen isotopic values and an increase in carbon isotopic values when comparing data from early life results from tooth apatite and late life results from bone collagen (Burger et al. 2003), indicating an increase in maize consumption. This study seeks to utilize dental microwear analysis in conjunction with macrowear and isotopic analyses (Turner 2008, Turner et al. 2010) to draw more specific conclusions about the diet of the Machu Picchu population and the role maize played in the diet of this population. I also investigate whether males or females had differential access to maize in Late Horizon period Peru. Currently the amount of data on maize consumption and its related dental microwear features is limited to a few studies (Organ et al. 2005, Gordon 1986, Teaford and Lytle 1996), but these studies have provided a solid foundation to interpret this correlation. The dental microwear analysis in this study contributes to understanding of the consumption patterns of the Machu Picchu individuals and the relationships between the diet of bioarchaeological populations and their respective dental microwear.

Dental microwear has had limited usage among human populations because of seasonal, annual, and geographic variation in diets along with preparation techniques that change the use-wear patterns food leaves behind. However, dental microwear analysis can be employed to understand the agents or food types that a population utilizes. According to Schmidt (2001, 2010), pits are the result of foods that require harder mastication and/or are hard enough to cause microscopic compression fractures. Scratches are the product of grit introduced in the preparation processes. Schmidt (2001) points out that the same agent can cause these microwear features, but overall the size and frequency of different dental features are fundamentally determined by food sources.

1.2 Expected Results

One objective of this study is to confirm Turner's (2008) conclusion that maize was more prevalent in the diet of Machu Picchu's inhabitants around time of death. By combining varied bioarchaeological analyses of diet, a more precise dietary profile can be obtained. More specifically, this study aims to discover what form of maize the non-elite population being studied consumed. I hypothesize that this study confirms Teaford and Lytle's (1996) conclusion that maize processed on grinding stones leaves behind 'large' scratches and pits, and more importantly, this work provides a better understanding of the microwear associated with maize consumption. The way maize is processed has a noteworthy effect on the type of microwear seen. There is the possibility that the Machu Picchu individuals were ingesting maize mostly by means of *chicha*, maize beer, which was an important component to the diet under Inca rule. If *chicha* was the primary source for maize consumption, I hypothesize that there will be a reduced number of abrasive dental microwear features, and the features will be smaller in size. Further analysis of the dental microwear data will discover any differential access to maize based on biological sex or age. Since there is a known relationship between food systems and social systems (Bordieu 1979, Hastorf 1996, Mead 1943) and food systems portray gender relationships (Hastorf 1996), diet should portray different social positions and functions. Hartmann (1981) points out that 'gender' in this context was inferred from the division of labor associated with the preparation of food. This sexual division of behaviors associated with food could mean differential access to food. I hypothesize that dental microwear analysis provides an avenue to investigate marked differences between the sexes in this population.

This study uses multiple analytical methods to reconstruct the subsistence pattern of a Late Horizon Peruvian population from Machu Picchu using human dentition. It is important to employ numerous methods to reconstruct dietary patterns because of the inherent limitations of each method (see Chapter 4). By combining various approaches, a more accurate reconstruction of the past dietary patterns can be achieved. Isotopic and dental microwear analysis techniques are the main focus, but the information that can be discerned from dental anomalies, such as caries and macrowear, is also explored.

CHAPTER 2: THEORETICAL AND METHODOLOGICAL BACKGROUND

2.1 Dental Caries

Most evidence about diet in the archaeological record is not direct. Archaeological data related to diet come in the form of artifacts, faunal remains, macrobotanical remains, pollen, phytoliths, and occasionally feces (Renfrew and Bahn 2008). Feces can be examined for food particles, which can be directly linked to a population only if the context is intact. Ultimately, conclusions from dental data should be combined with other archaeological data to obtain a more accurate analysis of past human lifeways. By looking at carious lesion or caries, the subsistence behavior of a person can only be inferred indirectly since these methods do not reveal exactly what was eaten, but whether what was eaten is having an effect on their health. Caries (Latin for rottenness) according to Roberts and Manchester (2005) are seen most frequently in archaeological populations. Caries manifest themselves on the tooth as small spots or larger cavities that result from the fermentation of food sugars with bacteria on the teeth (Roberts and Manchester 2005). The combination of bacteria and sugars demineralizes the enamel creating an open cavity for additional bacteria and foodstuffs to enter and infect the tooth (Roberts and Manchester 2005). Larsen (1984) utilized information about carie prevalence and related it to subsistence patterns in pre-agricultural and agricultural archaeological populations along the Georgia coast. He found that there was a 10% increase in the appearance of caries when populations shifted to a more agricultural lifestyle. This increase was attributed to the high amount of sucrose, the leading sugar that contributes to carious lesions, in maize (Larsen 1984). In order to confirm the conclusion that maize played the leading role in dental caries other analyses that infer the diet directly should be utilized. One method that can use teeth to directly conclude the prevalence of maize in a population's diet is isotopic analysis.

2.2 Isotopic analysis

Teeth provide a window into the past life of an individual, and in most cases that window is for a specific time period. The dental characteristic being examined determines whether information can be ascertained about the beginning or end of life. The formation of the tooth crown, amelogenesis, happens through the laying down of incremental layers of enamel prisms starting at the dental-enamel junction and progressing to the outer surfaces of the tooth (Goodman and Rose 1990, Ortner 2003). This process begins around the 6th week *in utero* until the 8th year of life (Goodman and Rose 1990: 61). Ameloblasts secrete proteins that become enamel at regular intervals; this circadian growth of teeth is reflected in the striae of Retzius, which cross the enamel and represent the daily growth of the tooth (Goodman and Rose 1990, Ortner 2003).

The study of oxygen, carbon, strontium and lead isotopes looks at the ratios of these isotopes during enamel formation (Grine 2007). Because of this time scale, multiple tooth types can be analyzed to acquire isotopic information encompassing early-life developmental periods (Sealy et al. 1995, Turner et al. 2005, 2009, Wright and Schwarcz 1998). For example, the isotopic values from the adult first and second incisors and first molar are representative of infancy or early childhood. The adult canines, second premolars, and second molar provide isotopic information for middle childhood, and the third molar, when present, provides information about adolescence (Hillson 1996).

Oxygen isotopic ratios in tooth enamel are affected by water consumption, which is affected by the surrounding environment (Dansgaard 1964, Gat 1996, White et al. 1998). Looking at the oxygen isotopes can provide information not only about the environment, but also about movement patterns of populations. This is especially useful when looking at the Late Horizon Inca period because of the relocations of people for labor. Both strontium and lead isotopic levels are influenced by the consumption of foods and also by the disparities in the local environment (Carlson 1996, Ericson 1985, Price 2002). Carbon and nitrogen isotopes can also be explored to provide information about different plants in the diet and the importance of marine or terrestrial subsistence (Katzenberg 2011).

Plants with different photosynthetic pathways, C_3 or C_4, will have differing ^{13}C and ^{12}C ratios, expressed as $\delta^{13}C$, which represent a "composite dietary signal" (Turner et al. 2010:518) of carbohydrates, fats, and proteins (Schoeninger and DeNiro 1983). In a Western Andean context C_4 plants that are consumed include amaranth and maize. C_3 plants in the Western Andes are typically small trees, shrubs, and grasses, which are introduced to human diet through the consumption of grazing animals. Terrestrial animals that humans may consume get their carbon signatures from atmospheric CO_2 based on the vegetation they are eating. The two different photosynthetic pathways turn CO_2 into sugars in the plant that are in turn incorporated into the animal's system (Katzenberg 2011). Carbon isotopic analysis has been useful in determining the introduction of maize into the diets of North and South American indigenous populations (Katzenberg 2011). Carbon isotopes are also used to determine if marine animals were part of the diet. Carbon is dissolved into an inorganic substance in the ocean causing marine plants to have a higher $\delta^{13}C$ values. The $\delta^{13}C$ is elevated by as much as 7‰ in oceanic species compared to terrestrial (Schoeninger and DeNiro, 1984). Freshwater lakes have similar values as terrestrial C_3

plants because their ecosystem is not as complex as oceans, but large, deep lakes have varying habitats, which can result in a large range of $\delta^{13}C$ values even among fish of the same species (Katzenberg 2011). This can result in variation in the $\delta^{13}C$ values in the humans consuming fish from these larger bodies of fresh water (Katzenberg 2011). Overall, carbon isotopic analysis is particularly useful when human populations are utilizing more than one food source that has heavier isotopes of carbon (Katzenberg 2011).

Nitrogen isotopes found in the collagen of tooth dentin and bone reflect the type of protein being consumed, which can come from a variety of sources including terrestrial animals, marine sources, and vegetation (Katzenberg 2011, Turner et al. 2010). ^{15}N and ^{14}N vary by trophic level, and typically increase 3‰ with each step in the ecosystem, but there is variation (Katzenberg 2011). Since marine food webs are more complex with more steps in the food chain, for example $\delta^{15}N$ values tend to be higher in seals and whales, which are on one of the highest trophic levels (Katzenberg 2011). The information about protein in the diet obtained from nitrogen isotope values does not reveal how much protein was being consumed, but the source of the protein on a trophic level (Katzenberg 2011), and in comparison with enamel and bone mineral isotopic values, can further elucidate dietary composition. To understand the overall isotopic variation present within an indicated population one has to understand the complex ecologies from where they are getting their food; nitrogen isotopic analysis assists in understanding variations in the local food ecology by distinguishing between plant and animal, and terrestrial versus aquatic protein. Isotopic analysis can provide a wealth of information on the movement and diet of a population, but there are limitations. It is important to know the archaeological context from which a sample came to recognize any taphonomic changes that can affect isotopic levels, and to properly reconstruct the ecology since chemical signatures are dependent on the environment and different foods can yield similar signatures (Katzenberg 2011).

2.3 Dental Microwear Analysis

Unlike isotopic analyses, dental microwear studies can obtain direct data about past behaviors, by observing the microscopic markings that food leaves behind on enamel surfaces (Teaford 2007). Dental microwear analysis first appeared in anthropological literature in Dahlberg and Kinzey's (1962) article where they applied microwear methods using light microscopy to modern and archaeological human samples demonstrating that variation in the abrasions on a tooth's surface correlated with dietary variation. The application of microwear analysis to bioarchaeological populations came after Baker et al.'s (1959) discovery that the phytoliths on grasses and soil grit were the cause of scratches on the enamel of sheep's teeth. This conclusion revealed a direct relationship between what was being eaten and the evidence left behind on the enamel, which was important for the discipline at the time. Current research shows (Sanson 2007) that it was only soil grit that left behind dental microwear and not phytoliths. Before the 1970s, low-magnification stereomicroscopy is used to analyze dental microwear (Ungar et al. 2008). There was a lot of controversy surrounding low magnification dental microwear analysis because it left out microwear that could be seen on a sub-micron level, thus the 1970s saw the development of scanning electron microscopy (SEM) (Ungar et al. 2008). SEM allowed wear patterns to be seen on curved aspects or the rough topography of the tooth. The main focus of microwear research during the 1970s was on the diets of hominins (Grine 1977, Puech 1979, Puech and Prone 1979) and the relationship between different diets and variations in microwear (Rensberger 1978, Walker et al. 1978). Studies of hominin microwear revealed that seasonal changes in diet and ingestive- behaviors left distinct microwear patterns on the incisors (Ungar et al. 2008).

The conclusions drawn in the 1970s about dental microwear and diet were re-evaluated in the resulting decades, and there was concern about the lack of standardized methods (Mahoney 2006, Ungar et al. 2008). For example, Mahoney (2006) found that the frequency of different microwear features and the type varied depending on whether the first, second or third molar was examined. Researchers also wondered whether diet could be directly concluded from microwear patterns. For example, Peters (1982) said that chert pieces and phytoliths made the same striations, making it hard to tell if grit or the actual food caused microwear. It was obvious that controls were needed to allow for comparison, and SEM settings had to be standardized (Ungar et al. 2008). This set the stage for new quantitative analyses confirming that microwear does, in fact, reveal diet and a re-demonstration of seasonal and ecological variation (Ungar et al. 2008). For instance, Covert and Kay (1981) suggested opossums showed no difference in dental microwear when they ate plant fibers versus when they ate the exoskeleton of insects. Gordon and Walker (1983) later argued that these two food substances leave behind similar microwear because of the grit that can be found in plant matter. Gordon (1984, 1988) also countered that there needed to be a larger focus on standardizing dental microwear methods, such as the SEM settings, position of tooth under the microscope, and which tooth facet to analyze. This need for standardized methods brought about resurgence in low magnification light microscopy.

Low magnification microscopy, which is used in this thesis, can be done at low costs and fairly quickly, which means larger samples can be analyzed, but sub-micron microwear, which can only be seen by SEM, is missed (Teaford 2007). SEM analysis of microwear is a lot more expensive, time- consuming, and subjective (Teaford 2007). According to Semprebon and colleagues (2004) low magnification has better replicability than SEM, which has high inter-observer error rates even with the assistance of a computer. On the down side it takes a lot of training to be able to recognize microwear features with a lower magnification, and inter-observer error rates are currently not available for the categorization of microwear sizes (Teaford 2007). Positively, postmortem wear does not pose a problem for low magnification analysis because wear patterns during life are in specific locations and only the obvious postmortem factors are visible, thus the elimination of samples because of excessive postmortem wear is not a problem (Ungar et al. 2006). Also, low magnification microscopy uses an external light source that can be manipulated to see features that are not immediately apparent.

Besides dental microwear methodological problems when it comes to understanding human diet there are a lot of questions about the effects specific foods have on the enamel surface, especially when food preparation techniques are involved (Teaford 2007). According to Lucas (1991) most foods in the human diet are not hard enough to leave behind microwear, but the preparation of foods can introduce abrasives that cause microwear. Dental microwear also has a "Last Supper" effect where only the last few meals are etched into the enamel, but it is still useful for assessing large dietary differences (Teaford 2007). Analyzing human diet can be problematic not only because of food processing, but also seasonal, geographic, and annual variation in dietary patterns (Teaford 2007). However, microwear analysis has been useful in discerning dietary shifts among human populations. For example, cereals leave distinct patterns that may start to appear in populations depending more on agriculture, and hunter-gatherer groups have a tougher diet that leaves behind more pits and larger scratches (Teaford 2007). Presently, new methodological controls, such as uniform magnification and utilizing the hypocone of the maxillary first molar for most studies, has increased quantitative analysis and contributed to the quality of new research.

2.4 Dental Microwear Analysis in Practice

Dental microwear analysis has had limited applications in bioarchaeological populations. There are a few studies that provide insight into the effects maize consumption has on microwear features (Organ et al. 2005, Schmidt 2001, Teaford and Lytle 1996), and its connection with isotopic data (Hogue and Melsheimer 2008). These studies provide a foundation for understanding the population analyzed in this study. Teaford and Lytle (1996) did an experimental study to better understand the exact wear that maize leaves behind when prepared on different grinding stones. This also allowed them to see if a dietary change could be documented since microwear can change in a few days. Lytle volunteered to eat one corn muffin with every meal over a two- week period. The first week corn muffins were made with maize ground with sandstone grinding tools. The second week the corn muffins were made with maize ground with fine-grained, igneous tools. The igneous tools are harder and produce less grit or abrasives than the sandstone (Teaford and Lytle 1996). Initial molds were taken to document Lytle's pre- experiment diet microwear, and then molds were taken after a week of eating the different corn muffins. There was a two-month period between when the last mold associated with the experimental diet was taken and the impressions for Lytle's post experiment diet. The percent of new features were calculated to understand the rates of change in microwear associated with each dietary change (Teaford and Lytle 1996). The pre- and post-test impressions had a similar percent of new features, 3.1 and 3.7% respectively (Teaford and Lytle 1996). This is not surprising since the pre- and post-test diet was a "normal American diet" (Teaford and

Lytle 1996:143), which tends to be heavily processed and preparation processes typically do not add abrasives. The rate of new microwear features increased about 30 times for the muffins made with sandstone ground cornmeal compared to the "normal" diet, and the igneous ground cornmeal increased microwear features about 13 times compared to the "normal" diet (Teaford and Lytle 1996). Teaford and Lytle (1996) showed that dietary change can be noted in a short period of time, and that food- processing techniques can be documented through dental microwear. It is especially important to note that they also found a correlation between increased number of microscopic scratches and a maize diet that involved exogenous processing (Teaford and Lytle 1996).

Organ and colleagues (2005) used this information about maize related microwear in their SEM analysis of a sample from a mission site in Spanish Florida. The mission site dated from AD 1656-1704, well after the Contact period in North America (Organ et al. 2005). Other sites of this nature (Hutchinson et al. 1998, Hutchinson and Norr 1994, Larsen 1984) have shown an increased reliance on agriculture, and the Native American remains associated with these sites have shown an increased prevalence of carious lesions and abscesses related to an increase in maize consumption (Larsen 1984). However, at the site of San Luis de Apalachee the remains have a low number of caries compared to other contact period sites (Organ et al. 2005). Organ and colleagues (2005) used multiple lines of evidence to better understand the influence of maize at this site by using isotopic and dental microwear analysis. The isotopic analysis (Larsen et al. 2001) revealed that maize made up a small percentage of the diet, and the microwear in the study was mostly small pits. As mentioned previously, dental microwear associated with maize is typically a high frequency of 'large' scratches and 'large' pits (Gordon 1986, Teaford and Lytle 1996).

2.5 Conclusion

When reconstructing dietary patterns, multiple lines of evidence should be used to create the most comprehensive picture of diet because every method of dietary analysis has its limitations. Utilizing multiple methods can help make sense of data, such as isotopes or dental microwear, which alone are inconclusive. For example, Williams and Holmes (2011) describe how the diet of *Australopithecus africanus* appears differently based of the method of analysis. The large molars with broad occlusal surfaces in *A. africanus* has been linked to hard-object feeding (Robinson 1972); while SEM studies show pitting, and dental microwear textural analysis shows an even more intricate enamel surface potentially created from hard object foods and C_3 vegetation (Williams and Holmes 2011). Isotopic studies have revealed that *A. africanus* consumed C_4 plants or grazing animals that consumed C_4 plants (Williams and Holmes 2011). One explanation that accounts for the isotopic and microwear data difference is the C_4 chemical signature may be from underground storage organs (USOs), which could leave larger microwear features due to grit from the ground (Williams and Holmes 2011). This example stresses the importance of combining dental analysis methods to create a synthetic reconstruction of ancient diet and subsistence. Isotopic and dental micro and macrowear analyses can be combined to understand a population's dietary history because where one method is lacking others have the potential to provide a better understanding.

CHAPTER 3: SUBSISTENCE PATTERNS IN LATE HORIZON PERIOD ANDES

3.1 Introduction

The Late Horizon period (AD 1430-1532) in Peru is the last period of the reign of the Inca state before Spanish conquest. Before contact the Inca people controlled areas from Columbia to Chile, and established trade networks, ceremonial centers, and other public works across their expansive empire. Subsistence is at the root of survival for all people, and the lives of the Inca people depended on their successful utilization of a terrain where only 2% was considered suitable for agriculture (Burger 1992). The Inca thrived in this challenging terrain by exploiting various ecological zones, and by depending on members of their kin group who were established in different zones (McEwan 2006: 84, Murra 1980). The Inca understood the importance of the region's complex subsistence patterns as their empire grew, and incorporated food practices that had been in place for thousands of years into their socio-political constructs.

Inca imperialism maintained these practices, acknowledged their importance, but also altered them to better serve the empire. For example the highland people practiced, "energy averaging" (Isbell 1978, McEwan 2006: 84) or creating a surplus of food, such as freeze- drying potatoes into *chuño* and llama meat into *charqui*, to utilize during times of low agricultural productivity. The Inca also practiced energy averaging on a much larger scale by building and filling large storage facilities or *qolqas* that were associated with administrative centers (McEwan 2006: 121). *Qolqas* were built on the slopes of the highlands where there was adequate drainage and air- flow. These storage facilities contained *chuño*, *charqui*, and other dried foods, and also weapons, tools, clothing, valuables, and raw materials such as, cotton, wool and feathers (McEwan 2006:122). According to D'Altroy (1992) there were 2,753 *qolqa* near the administrative center of Hatun Jauja, which had 170,000m^3 of storage space. Another example of the Inca adopting knowledge and technology of earlier cultures included the adaptation of terraforming on a colossal scale. The Inca expanded the use of terraces from modest agriculture terraforms to huge feats of landscape architecture (McEwan 2006: 123). The Inca created large administrative structures, such as Machu Picchu, on these expansive terraces, which previously provided level space for agriculture and smaller structures (McEwan 2006: 123). The Inca also continued to utilize terraces for farming since they provided soil with excellent drainage, and helped protect maize from frost due to heat radiating off of the retaining walls at night (McEwan 2003: 123).

The Inca also drew upon food traditions from earlier cultures. Diet among the Inca people during the Late Horizon period is particularly interesting because the Inca relocated groups of people as they expanded their state up and down the coast and highlands of South America. This movement of people was associated with the co-opting of existing agricultural production, the construction of ceremonial centers, and monumental structures through labor specialists in new areas, and by suppressing rebellions in newly conquered areas, all of which maintained the stability of the Inca empire (Pease 1982, Morris 1998).

The variation in subsistence patterns among the Andean people was due to the varying environments, and the need to exploit the resources from every zone to survive. In order to understand these ecological zones, one must understand the climate of the region. Overall the climate in these areas has remained stable since 5000 years before present (BP), suggested by paleoclimate data from the Quelccaya ice cap and cores from the Marcacoha lake, but these times of stability have been disrupted periodically by “aridity episodes” (Chepstow-Lusty et al. 2003). From 8000-5000 BP the highland region of the Andes was warm and arid, and the lakes in the area were shallow or completely dry (Chepstow-Lusty et al. 2003). The coastal region was warm and wet during this time, but the climatic conditions changed around 5000 BP and the coast became more arid, and the highlands had an increase in precipitation from 4000-2400 BP (Chepstow-Lusty et al. 2003). The wetter conditions in the highlands coincide with an increase in agriculture in the area as well (Chepstow-Lusty et al. 2003). Chepstow-Lusty and colleagues (2003) do note that the highlands saw increases in aridity around 900 BC, 500 BC, AD 100, AD 550, and AD 900-1800. A definite climatic shift occurred from AD 1100-1993 as noted in the lake cores, resulting in a reduction in precipitation and an increase in temperatures; however, these data may be complicated due to intensified terraforming during the Inca reign (Chepstow-Lusty et al. 2003). The landscape change would have an affect on the pollen in the area, and what conditions would be recorded in the lake core (Chepstow-Lusty et al. 2003). Despite this complication it can be concluded that there was some climatic change that would have reduced agricultural productivity and increased the need for the storage of food (McEwan 2006: 122). The climatic change, however, cannot be attributed to El Niño Southern Oscillation (ENSO) events (Chepstow-Lusty et al. 1998).

ENSO events cause disruption in the marine resources and climate due to the warming of the usually cold ocean water by the Humboldt Current from Antarctica (McEwan 2006: 20-21). Typically, winds keep the air surrounding the current cool over the ocean and the air can hold little moisture (McEwan 2006: 20-21). As the air moves inland there is a slight warming, and any moisture that is retained forms into clouds as the air increases in altitude and cools (McEwan 2006: 20-21). This pattern along with the rain shadow created by the Andes contributes to the dry coastal deserts which sometimes do not receive rainfall for up to fifty years or more until El Niño events occur, which can result in catastrophic rainfall (McEwan 2006: 21). While ENSO events have been recorded in recent times there is no conclusive evidence of an El Niño during or around the Late Horizon (1430-1532) period in Peru. Chepstow-Lusty and colleagues (2003) point out that there has been some debate of evidence of an ENSO event as recorded in cores from the Quelccaya ice cap, but these data, at this point in time, are not substantial enough to conclusively demonstrate that there were any ENSO events affecting the Inca.

3.2 Subsistence Strategies

Due to topography and climatic patterns there are three main zones in the area controlled by the Inca Empire: coastal, highlands, and the tropical lowlands (McEwan 2006: 19-24). The least populous area was the tropical lowlands, *montaña*, where the highlands transition into the Amazonian jungle (McEwan 2006: 24). Further into the tropical lowlands the humidity rises and the jungles thicken, within these jungles are many of the animals that inspired Inca art and religion and exotic plants that were often exploited (McEwan 2006: 24). The upper elevations of the tropical lowlands were called *Ceja de Selva* or eyebrow of the jungle. This area has beautiful views and a comfortable climate, so naturally this area was an ideal place for elite residences such as Machu Picchu (McEwan 2006: 24). The eyebrow of the jungle was also a great area for the cultivation of tobacco, coca leaves, and the acquisition of colorful feathers (McEwan 2006: 24). Most of the highland watershed feeds into the Amazon River to the east, but there are 40 seasonal rivers feeding into the Pacific Ocean to the west of the Inca highlands that support life; however, this sustainability is limited and irrigation canals are needed to fully support coastal agriculture (McEwan 2006: 21).

The coastal desert regions with irrigation produce a variety of agricultural products, including avocadoes, peanuts, beans, squash, gourds, maize, peppers, manioc, sweet potatoes, and tropical fruits (McEwan 2006: 21). People grow additional produce on the he higher elevated areas, *yungas*, on the coastal plateau, and the cold waters of the Pacific coast have a large quantity of animal protein that can be dried and preserved for trading purposes (McEwan 2006: 21). Maize was a popular crop in Late Horizon Peru, but dependence on this crop has never been as extensive as in other regions of the New World (Larsen 2000, Murra 1980). Maize, according to Murra (1980) can survive in the coastal and lower highland regions where it is warm and moist, but it arrived as a domesticate after tuber domestication in the Viru Valley, and has remained a non-staple crop of the region because of its need for a complex irrigation system.

Because the lower highlands and coastal populations were dependent on large agricultural production systems such as irrigation and fertilization, it was easy for the Inca state to take control and utilize these areas for larger state projects (Murra 1980). The coastal economy was also unique because different groups had specialized in either fishing or agriculture since pre-Inca times (Rostworowski de Diez Canseco 1999). Both fishing and agriculture were rigorous activities requiring specialized tools. The fisherman required boats, nets, and floats made from plants grown by the fishing communities, and the farmers needed knowledge of irrigation engineering (McEwan 2006: 85-87). Specialization in subsistence strategies contributed to increased social stratification, and the flourishing of craft specialization such as pottery, metallurgy, and textile production (Rostworowski de Diez Canseco 1999). These goods, the surplus of dried fish and agricultural products were then exchanged not only at a local level and throughout the highlands, but also up and down the coast among what Rostworowski de Diez Canseco (1999) calls “horizontal archipelagos.” This long distance trade occurred to obtain specific goods such as copper that was not readily available everywhere on the coast.

The Andean highlands start approximately 50 km inland from the coast, and continue to rise dramatically in elevation (McEwan 2006: 21). This rapid rise in elevation over short distances creates up to 20 ecological zones or microclimates (Burger 1992, McEwan 2006: 21). Terracing of the landscape opens up more area for the cultivation of crops, which is particularly needed since fields have to lay fallow for long periods of time seeing as the soil is not incredibly fertile (McEwan 2006: 21-22). Terraces could be 50-200 ft wide and up to 5000 ft long creating an additional 160 to 575 acres (Murra 1980). Diverse crops were also planted to protect against agricultural uncertainties such as unfertile soil, disease, bugs, and drought (McEwan 2006: 22). The lowest ecological zone, *quechua¸* is between 2300 m and 3200 m above sea level (McEwan 2006: 23). This area is the warmest of all highland regions and suitable for maize, squash, legumes, grains, and gourds (McEwan 2006: 23). Beginning at 3200 m and continuing until 4000 m is the *suni* area, which is made up of steep slopes where over 1000 varieties of potatoes and tubers are grown (McEwan 2006: 23). The highest region, the *altiplano* and *puña,* is unsuitable for sustainable agriculture, but the area is filled with grasslands that are the main food source for domesticated and wild camelid herds (McEwan 2006: 23). The Inca did not have as many domesticates as are found in the Old World, except for domesticated llama and alpaca herds along with *cuy* or guinea pigs. The camelids were valued for their meat, wool, and their ability to transport goods (McEwan 2006: 23). Llama wool was good material for rope and sacks, while alpaca and vicuña wool were typically used for making cloth. Slaughtered, these animals provided leather for shoes, weapons, rope, meat that could be freeze- dried into *charqui,* and tallow (Murra 1980). Other animals such as fish from rivers and lakes, birds, deer, and *cuy*, the domesticated guinea pig, were additional sources of meat in the area (McEwan 2006: 23-24). Murra (1980) put forward the idea that people living in the highlands relied on trade with members of their *ayllu*, kinship groups, which were established in the coastal region and throughout the terraced highland landscape.

The successful utilization of the highlands for subsistence would not be possible without the establishment of kin groups and the social construct of reciprocity among its members. The *ayllu* were integral in the acquisition of staples from various ecological zones. Despite the numerous ethnic groups and languages distributed throughout the various landscapes, every group had a similar social organization with a heredity ruler, or *curaca*, at the head. They believed everyone in the group had descended from a common mythical ancestor who was given the land and water the *ayllu* owned as a group (McEwan 2006: 96-97). The *ayllu* were large, patrilineal and endogamous groups divided into smaller communities where land was distributed among these communities and its members (McEwan 2006: 97). There was a market system (Rostworoski de Diez Canseco 1999) and rudimentary monetary systems (Holm 1966, Hosler et al. 1990, Rostworoski de Diez Canseco 1999) in the coastal region, but this was not the case in the highlands. Because the highlands were dominated by various ecological niches the model of no market or monetary system dominated the empire, meaning each group needed to be self-sufficient, relying on its members for help to cultivate and harvest crops with all the products being shared.

In contrast to Rostworoski de Diez Canseco's (1999) idea of horizontal archipelagos are "vertical archipelagos" or verticality suggested by Murra (1980). These vertical archipelagos were in place where one group utilized numerous altitudinal zones. Members of the *ayllu* were sent into varying altitudes, including coastal regions, to live and cultivate the crops and/or make use of the animals in the area. The products from one area would be distributed among the kin group in exchange for goods from another allowing for self- sufficiency (Murra 1980). Multiple crops being planted in one ecological zone, the drying of meats and potatoes, *charqui* and *chuño*, and the construction of storehouses in dry areas allowed groups to save for the inevitable droughts and low crop yield years. This distribution of resources formed the basis of the labor tribute system under Inca rule, and helped facilitate the transportation of mass quantities of agricultural products throughout the empire (D'Altroy and Earle 1985).

There was another level of labor tribute that involves the most elite and skilled men and women. These men and women never returned home like everyone else who gave their labor as tribute to the Inca Empire; they remained at administrative and religious centers throughout the realm. Machu Picchu was staffed by *yanacona,* who were considered servants, but of a more elevated status relative to labor colonists (*mitmacona*) or the general population (Burger et al. 2003, Salazar 2001, Villar Cordova 1962). They were chosen to serve royalty and nobles because of their elite skills and abilities (Rostworowski de Diez Canseco 1999). The *yanacona* were typically attached to royal or elite estates, and no longer had ties with their kin group, and because of their service to the state were exempt from the reciprocal labor system in place to collect taxes and tributes (Rostworowski de Diez Canseco 1999). Also associated with royal estates were *acllacona,* or chosen women (McEwan 2006: 100-102, Rowe 1982). The *acllacona* were young girls between the ages of ten and twelve years old who were chosen from villages to be tribute for the state (McEwan 2006: 100). These girls either became servants to the gods, wives to the emperor or a part of the servant class, *yana/aclla* (McEwan 2006: 102). Each group had their own specialized duties, but most *acllas* spent their time weaving and making *chicha* (McEwan 2006: 102, Rostworowski de Diez Canseco 1999). It has been proposed (Turner et al. 2009, 2010) that the servant population at Machu Picchu would have been a mix of *yanacona* and *acllacona* (Rowe 1982). It has also been suggested that the population at Machu Picchu consisted of *mitmacona*, who were relocated from their home because of their labor specializations, and *hatun runa* or commoners (Rostworowski de Diez Canseco 1999, Turner 2008).

3.3 Role of Imperialism in Dietary Patterns

The Inca state reached its acme during the 1400s. The reciprocity and self-sufficiency of communities did not continue in the same capacity once the Inca controlled a region because the state monopolized the "*corvée* services of peasantry and the whole of the productive effort of the retainers" (Murra 1980:121). Most trade was eliminated among kin groups and replaced with a state controlled exchange system. A tribute or tax was required of most people not already serving the elite through administration or craft specialization (Murra 1980). This tax was collected through working on the state agricultural lands, weaving cloth, bearing arms, or working on public work projects such as mining, terracing, irrigation engineering, or construction of state and religious structures (McEwan 2006: 90-92). The state was strategic in when and who was taken to work their lands and projects. They attempted to cause minimal disruption to the kin groups subsistence economies; according to Murra (1980), kin groups were to remain self- sufficient, but varying degrees of disruption would be expected when the state utilized individuals. The state also provided food, shelter, and tools to the tax- payers working on state projects, and additional incentives, such as maize, *chicha*, and coca, were given to reward the taxpayers and keep them content (Murra 1980). Because of these incentives and the importance of maize in religious ceremonies, maize became a focal point for the state and production of the crop increased. The state also limited the amount of land they took from local groups trying to make use of unused land when they conquered an area, and terracing and/or irrigating it for religious or state purposes (Murra 1980). These lands were important to the survival of the Inca state because it was dependent on "agriculture capable of producing systematic surpluses beyond the subsistence levels of the peasantry" (Murra 1980:13). The agricultural practices may have been the same, but the socio-economic and political implications of food changed during Inca rule. As mentioned previously, maize was often used in festivals as *chicha*, and the state also provided food to the taxed laborers, thus a surplus owned by the state was needed to "fund" these activities. Surpluses were kept in large state storehouses that Europeans originally thought the Inca utilized in a welfare capacity (Rostworowski de Diez Canseco 1999), but most of the surplus was used for religious or state purposes (Murra 1980).

Archaeological evidence (Burger 1989, Murra, 1980, Stanish et al. 2010), such as potato effigies, llama bones, and wool textiles in the coastal region, and cotton, maize, and peppers found in the highlands, suggests that there was trade between the coast and highlands as early as 3500 years prior to imperial rule. However with the state in control of the surplus, commodity exchange was now their responsibility. This new market/exchange system or lack thereof resulted in restriction of road usage and hunting privileges (Murra 1980). The importance of trade on a local level also decreased with the expansion of the Inca state, which now provided goods usually acquired via more traditional trade networks (Murra 1980). Inca imperialism did not just affect the subsistence strategies and larger trade networks of kin groups, but also changed the composition of the Andean people's diet as a whole. Hunting regulations and restrictions on killing domesticated camelids affected the amount and type of protein consumed by the different social classes. In order to kill a llama one had to have the permission of the ruler, but since he was not typically accessible for consultation, the ruling elite of an area could make decisions about the slaughtering of domesticated animals (McEwan 2006: 88-89). These restrictions meant that llama and *cuy* were typically eaten in religious or other ceremonial contexts (Bray 2003, Rowe 1946). Meat and maize-based dishes were also more prevalent in the diet of elite Incas (Bray 2003, Murra 1960) and commoners had a diet based on tubers, legumes, cereal grains, and other plant foods (Turner et al. 2010).

3.4 Conclusion

Dietary variation among the non-elite declined as a meal with various dishes became a sign of wealth and prestige (Bray 2003). The horizontal and vertical economies played less of a role as subsistence was defined, constrained, and distributed by the Inca state (Turner et al. 2010). The division of social classes and of men and women can be seen in the consumption of meat and vegetables (Bray 2003), and was based more on quantity consumed and quality of preparation rather than the specific dietary components (Turner et al. 2010). Pottery also provides evidence of the important role food played in the maintaining social stratification and overall politics through its elaborate style and widespread usage of more functional forms. Bray (2003) takes a structuralist view of Peruvian material culture, particularly pottery, by theorizing that the classic polychrome vessels typically associated with the Inca state are linked to the development of social relations and identities (Hodder 1982a, 1982b). This pottery style was produced and distributed widely throughout the region (Bray 2003). The vast number of vessel forms for dining, storage, and the preparation of food demonstrates the important connection between food and politics in Late Horizon Peru (Bray 2003).

CHAPTER 4: STUDY DESIGN

4.1 Introduction

The Inca site of Machu Picchu in the south-central Peruvian Andes was rediscovered by Hiram Bingham in 1911, and originally envisioned to be a lost city and haven for the last remaining Inca women after the Spanish conquest (Eaton 1916, Bingham 1979). Eaton (1916) originally performed sex and osteological analysis on the skeletons from Machu Picchu, but concern with his methods and conclusions has led to numerous subsequent analyses on the collection at Yale University's Peabody Museum of Natural History; most recently the publication of Verano's (2003) work on this population using current osteological methods. Turner (2008) did multi-isotopic analysis of the skeletal population that indicates marked variation in dietary composition early in life as well as residential origin. Along with Verano's (2003) analysis that observed various cranial modifications, these studies (Turner 2008, Turner et al. 2010) indicate that the population in question was not native to the region surrounding Machu Picchu, and as discussed possibly a mix of *yanacona* and *acllacona* (Turner et al. 2009). Interestingly, this sample also had a decrease in nitrogen isotopes and an increase in carbon isotopes throughout their lives, which is a pattern that has been associated with an increased reliance on maize (Turner et al. 2010), but whether maize was being consumed as *chicha* or other maize-based dishes is unknown. This is because early-life isotopic data comes from tooth enamel and dentine, which forms at the beginning stages of life, and the information about late-life diet comes from a subset of individuals with bone collagen data published by Burger et al. (2003). The decline in $\delta^{15}N$ values and increase in $\delta^{13}C$ values is tentative since the late life data and early life data are from different individuals. Therefore additional methods need to be utilized to understand if the changes in isotopic values are related. Dental microwear provides an additional measure of late-life diet since it reveals the last few days of consumption patterns.

I studied the skeletal set and its archaeological context along with the previous mentioned isotopic research (Burger et al. 2003, Turner et al. 2009, 2010) on the collection, and further investigate the diet of the Machu Picchu population through dental microwear analysis. The synthesizing of osteological, isotopic, and dental microwear data can provide a more nuanced interpretation of dietary variation in this population and the impact the relocation to Machu Picchu and direct provisioning by the Inca state may have had on them.

4.2 Machu Picchu Background

Machu Picchu, 2430 m above sea level, is situated on a ridge connecting the Machu Picchu and Huayna mountains (Turner 2008). It is located 80 km northwest of the Inca capital Cuzco in the Urubamba province and considered to be a royal Inca estate built ca. AD 1450-1470 by Pachacuti (McEwan 2006: 44, Turner 2008). Pachacuti, the ninth *Sapa Inca* (king), ruled from AD 1438 to 1471 and has been credited with the creation of the *Tawantinsuyu* Empire, better known as the Inca Empire (McEwan 2006: 44). He consolidated the Inca state and his power by seeking to conquer the regions that had put up resistance in the past, one of those areas being the Urubamba Valley, where he set up his royal estate (McEwan 2006: 44, 76-77; Niles 2008). After retiring from his military campaigns, Pachacuti focused on public work projects, such as the construction of storehouses, terraces, highways, aqueducts, and royal estates (McEwan 2006: 75-77). He also focused on improving the overall socio-political structure of the state by rebuilding the capital, Cuzco, codifying Inca law, institutionalizing taxation, formalizing ancestor worship, creating an agricultural and religious calendar, and reorganizing the Inca class system (McEwan 2006: 75-77). Inca ideology included ancestor worship, in the case of elite residences they continued to be under the control of the mummy of the previous ruler, who was taken care of by *panacas*, or caretakers of the royal estate, and thus never passed to the next ruler (McEwan 2006: 99-100, Niles 2008). Each new ruler had to make their own wealth putting an increased importance on royal estates, which were not only a place of solitude and retreat, but also a source of revenue (McEwan 2006: 100, Niles 2008). During the expansion of the Inca state, land rights no longer belonged to kin groups, but controlled by the state (Murra 1980). Local rulers and to individuals received land rights as a reward for their service to the state (Murra 1980). The only non-state owned land were the royal estates of the emperor (Murra 1980), even newly acquired land was generally divided into areas for the religious and state purposes and for the local population, Machu Picchu was no exception (Figure 4.1), having areas dedicated to residential and agricultural works (Zegarra et al. 2000). Newly acquired lands were also terraced as a part of public work projects (McEwan 2006: 131-133), and the terracing at Machu Picchu reduced erosion and created cultivatable fields (Zegarra et al. 2000). There was an agricultural area on the eastern slope of Machu Picchu. Zegarra (2004) calls this area a complex since it is made up of six terraced fields or complexes. This complex is close to agriculturally related storehouses and the Inca road (Zegarra 2004). Overall, Wright and colleagues (2000a) conclude that the terraced complexes make up 3.7 acres, and could have produced 5,280 pounds of maize along with other crops. These crops would have been stored in six large two-story storehouses near the road (Zegarra 2004). Recent excavations (Wright et al. 2000a, Zegarra 2004) also found pollen, which provided evidence of maize, potatoes and legumes.

4.3 Skeletal population

The skeletal population from Machu Picchu consists of 177 individuals and that Eaton (1916) and his colleagues collected in the early 20th century from three cave interments (Bingham 1979 [1930]). Despite the scatter of bones found on cave floors, the collection consists of associated sets rather than commingled remains (Verano 2003). Verano (2003) also noted that carnivore and rodent markings on skeletal elements provide the most parsimonious explanation for missing or damaged limbs rather than the mishandling of remains during burial ceremonies as had previously been suggested. The associated grave goods were utilitarian in nature (Salazar 2001, Turner et al. 2009), and the burial of children and infants suggests that the women at the site were reproductively active (Verano 2003); interestingly the status of *yanacona* could be inherited (McEwan 2006: 100). No royal mummies were found since the mummies and their *panaca* are typically located at the imperial center of Cuzco (Rowe 1946). The skeletal collection has previously undergone isotopic and osteological analysis (Salazar 2001, Turner 2008, Turner et al. 2009, 2010, Verano 2003), as mentioned, and was housed at the Peabody Museum of Natural History at Yale University 2011 when the remains were repatriated to Peru.

Previous analyses (Eaton 1916, Salazar 2001, Turner 2008, Turner et al. 2009, 2010, Verano 2003) of this sample include data from individuals not used in the dental microwear analysis due to the fragmentary nature of many of the remains. This study compares existing carbon and nitrogen isotopic data to enamel macro- and microwear data to more accurately profile diet composition in a subset (n= 41) of the Machu Picchu skeletal population. Dental microwear analysis can obtain direct data about human behaviors in the context of diet (Teaford 2007). Isotopic analysis reveals that the Machu Picchu residents were getting their protein and carbohydrates from a variety of sources early in life (Tuner et al. 2010). There is also a suggestion that maize consumption became more important once an individual was in residence at Machu Picchu, and dietary protein was drawn from sources with lower $\delta^{15}N$ values (Turner et al. 2010). Isotopic analysis shows this dietary shift only occurs in some individuals while others seemed to maintain a diet similar to their earlier life (Turner et al. 2010). Overall the Machu Picchu skeletal population's varying diet supports the conclusion that these individuals consumed very different diets prior to their relocation to Machu Picchu; in concert with additional isotopic data used to estimate residential origin (Turner et al. 2009), this suggests that individuals were from varying regions across the Inca state. Verano (2003), through multivariate analysis of craniofacial measurements, confirmed Eaton's (1916) earlier conclusions about cranial modification variations in the skeletal sample to be indicative of the Inca's movement of their subjects. However, isotopic dietary reconstruction is limited in its specificity due to overlap in isotopic values from different resource types; for example, maize, amaranth and marine proteins yield similar $\delta^{13}C$ values. Similarly, strontium isotopes can also provide insight into diet in early- life when the tooth enamels forms (Turner et al. 2009). Dental microwear analysis alongside isotopic and osteological analyses can provide an understanding of any variance among the group based on diet.

4.4 Dental Microwear Methods

Dental impressions were made from 41 individuals using polyvinylsiloxane material by Turner (2008) at the Peabody Museum of Natural History at Yale University, and these are now located in the Bioarchaeology lab at Georgia State University. The individual's teeth are first cleaned with 95% alcohol (Semprebon et al. 2004) with a piece of cotton soaked in acetone before making the impressions (Ungar et al. 2008). Casts were made with high quality epoxy material that was poured into the impression and allowed to harden (Semprebon et al. 2004, Ungar et al. 2008). The left maxillary first molar (M^1) of the casts were examined for microwear at 35 times magnification under a stereomicroscope with an external fiber optic light source (Semprebon et al. 2004). The left maxillary first molar (M^1) is used to maintain standardization of microwear methods (Semprebon et al. 2004). If the individual did not have a left maxillary first molar (M^1) and the right M^1 was examined. In some cases the posterior dentition of the maxilla did not preserve and the left or right mandibular first molar (M_1) were analyzed. Small, large and puncture pits and fine, coarse and hypercoarse scratches were counted on the most mesiobuccal cusp, the hypocone, again to maintain standardization (Semprebon et al. 2004). This count is done twice at two locations on the cusp and then each count is averaged.

The external fiber optic light source casts shadows, which can help discern the size of pits and scratches (external oblique illumination); it is important to move the light slightly when examining features to make sure all are counted (Semprebon et al. 2004). Pits are classified as large, small, or puncture pits, and scratches can be fine, coarse, or hypercoarse (Figure 4.2). Pits look like compression fractures with a length to width ratio less than 4:1, and scratches are linear with a length to width ratio that exceeds 4:1. Pits and scratches come in different sizes. Small pits look shiny and white because they are shallower, which allows them to refract more light, and a large pit or scratch looks darker and less shiny because they are deeper (Semprebon et al. 2004). Puncture pits are the largest of the pits with a deep, symmetrical appearance, which are darker than large pits because of low refractivity (Semprebon et al 2004). Scratches can be fine, which are shiny because they are shallow and narrow; sometimes they are barely observable (Semprebon et al. 2004). Scratches can also be coarse because they are wider, and more easily observed. The largest scratches are hypercoarse scratches, which appear dark because they are etched deep into the enamel (Semprebon et al. 2004). On occasion, puncture pits occur at the end of a hypercoarse scratch where an object was dragged across the enamel (Semprebon et al. 2004).

CHAPTER 5: STATISTICAL METHODS AND RESULTS

5.1 Statistical Methods

Dental microwear requires statistical analysis to understand overall diet and consumption patterns of individuals. Of the forty-one individuals available for analysis only twenty-four had been aged and sexed. While this small sample size can be problematic in many studies because it can lead to research bias, previous dental microwear analysis studies have shown that a lot of information can still be acquired with small samples (Gordon 1988). In this study, statistics were run in two sets. One set included all of the individuals (n=41) without age or sex playing a role. Analyzing the entire sample of individuals (Appendix A) led to a better understanding of dental microwear patterns in the whole population. The second set of analyses was performed on the twenty four individuals who had a known age or sex to see if there were any differences in dental microwear due to those factors. The twenty-four individuals who were aged and sexed were divided into four age categories (Appendix B) according to the standards developed by Buikstra and Ubelaker (1994) for archaeological populations: adolescent/12-19 years (n=5), young adult/20-34 years (n=9), middle adult/35-49 years (n=8), and old adult/50+ years (n=2). All of the ages were in the form of ranges that sometimes overlapped two age categories. The minimum and maximum age for each individual were averaged together to find the median age, which was used to place each individual in an age category (1-4). A third set of analyses was also done on eight individuals who had $\delta^{15}N$ and $\delta^{13}C$ values from Burger and colleagues' (2003) analysis, and those who had early life Sr and O isotopic values. A fourth set of analyses was run on the individuals who had macrowear and microwear data and who were aged and sexed. A

Spearman's correlation was used to see if there was a relationship between carious lesions (n=20), abscesses (n=38), macrowear (n=37), and microwear.

Normality was first tested using the Kolmogorov-Smirnov test and the Shapiro-Wilk test on all the features by age category (n=21), and all the features within the whole sample (n=41). Both normalcy tests were run because the Shapiro-Wilk test is better with small sample sizes. Unfortunately there were several non-normal distributions for the features according to age category, and individually only small pits had a normal distribution. ANOVA tests assume normal distribution. Therefore a normal distribution was created for the data using a log transformation. The log transformation resulted in a normal distribution (Shapiro- Wilk test) for 16 out of 28 comparison if the old adult category is included. The old adult category was eliminated from further statistical analysis because the category did not produce a significance value before or after the log transformation due to its constant traits and small sample size (n=2). There are 16 out of 21 comparisons with normal distribution with the old adult category removed; the distribution is not normal for puncture pits and hypercoarse scratches in all age categories along with fine scratches for adolescents. ANOVA tests also assume there are no outliers that affect the test. Outliers were discovered for total pits, fine scratches and coarse scratches when examined by age group; and small pits, large pits, total pits, and coarse scratches when examined by sex. Outliers were kept to maintain sample size, and because a wide range of variation is normal within groups of humans; removing the outliers would eliminate natural variation.

In this study the microwear data were compared among the four age categories using a two-way and one-way analysis of variance (ANOVA) with a significance level of 0.05. A Tukey's post hoc test was also used to pin point within group differences. The variables analyzed were average small pits, large pits, fine scratches, and coarse scratches; and the total pits and scratches. A Mann Whitney U Test was also used to compare the puncture pits and hypercoarse scratches since this test does not assume normal distribution. A Mann Whitney U test was used to find any variation between the diets of males and females based on microwear features. A principal components analysis was also performed to identify any redundancy or unrelated variables.

5.2 Results of Dental Microwear Analysis

The results of the dental microwear analysis (Figures 5.1 and 5.2; and Table 5.1, 5.2, and 5.3) look specifically at the dental microwear for the individuals (n=24) that have been aged and sexed. There are no obvious increases or decreases in microwear type across the ages, however all ages appear to have a higher frequency of small pits than any other feature, except for hypercoarse features in old adults, which may be due to a small sample size. Small pits do appear to decrease in frequency for middle and old adults compared to adolescents and young. Adolescents have a higher frequency (0.2727) of fine scratches than any other age group. All age groups, except old adults, have similar frequencies for coarse scratches. However the frequency of coarse scratches is under 0.12 for all age groups, both male and females, and the total population. Overall, males, females and the total population have a higher frequency of small pits than any other trait. Large pits have the second highest frequency for females and total population, but fine scratches are the trait with the second highest frequency for males.