THESIS

# A DIETARY ANALYSIS OF A HUMAN SKELETAL SAMPLE FROM KICHPANHA, BELIZE

Submitted By

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ABSTRACT

A DIETARY ANALYSIS OF A HUMAN SKELETAL SAMPLE FROM KICHPANHA, BELIZE

The purpose of this study is to improve the understanding of diet at the Maya site of Kichpanha, Belize. Archaeological investigations began at Kichpanha in the late 1980s and continued into the early 1990s. During these investigations much was learned about the history of occupation at Kichpanha and a fairly large skeletal assemblage was recovered. However, preservation of the skeletal material was poor due to the moist conditions and alkalinity of the soil at the site. This made traditional osteological analysis of the recovered remains difficult and limited the types of research that could be carried out on these materials. Previous osteological analyses of these remains concluded that the prevalence of dietary stress or illness among subadults in this population was high as was evident from the high rates of porotic hyperostosis and enamel hypoplasias in the skeletal sample. Frequently these skeletal pathologies among prehistoric populations in the Americas are related to a heavy reliance on maize resulting in iron deficiency anemia. Dental analysis looking at caries rates and calculus also support the hypothesis that the inhabitants of Kichpanha relied heavily on maize. Further analysis of the plant residues found in the dental calculus from individuals from Kichpanha provides direct

evidence that maize was part of their diet, but other C3 plants were also included in the diet.

The carbon stable isotope data analyzed in this study suggests that maize may not have comprised as large of a proportion of the diet at Kichpanha as the previous osteological data had suggested. Instead the isotope data seems to indicate that the proportion of $C_3$ plants and protein sources was in the diet at Kichpanha was relatively high when compared to other Maya sites and that the diet at Kichpanha was fairly stable throughout the site's occupation.

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# CHAPTER 1

## INTRODUCTION

The purpose of this study is to better understand the diet of the Maya living in Kichpanha, Belize from the late Preclassic through the Terminal Classic period. Previous research into the Mayan diet has relied on indirect methods such as dental pathology (Cucina and Tiesler 2003; Magennis 1999:133-150; Seidemann and McKillop 2007), porotic hyperostosis (Jansen 1995; Wright and Chew 1998), the identification of plant and animal remains recovered from middens and hearths (Götz 2008; Mason and Lope 2008; Miksicek 1991:70-84; Shaw 1999:83-99), evidence from epigraphy, art, and linguistics (Taube 1989), and, with limited success, organic residue analysis (Evershed 2008; Haslam 2006; Reber and Evershed 2004). Studies looking at dental pathologies for evidence of diet have analyzed carries, dental wear, antemortem tooth loss, alveolar resorption, and the accumulation of calculus (Cucina and Tiesler 2003; Magennis 1999:133-150; Seidemann and McKillop 2007). In these studies it has been assumed that increases in dental pathologies result from an increase in consumption of processed maize foods such as porridges and corn breads which are sticky and high in sugar. Rates of porotic hyperostosis also are thought to have a positive relationship with the amount of maize in a population's diet. Diets high in corn are believed to lead to iron deficiency anemia which can result in the development of porotic hyperostosis, especially in populations that consume the pericarp (White 1988).

While dental pathology and the presence of porotic hyperostosis are good indicators of stress in a population, they can't reliably provide direct evidence about what exactly people were eating and how important different foods were to their diet. The recovery of food remains from middens and hearths does provide specific data about what foods people were eating. However, differential preservation as well as ease of recovery limits this method's usefulness in determining the proportions of the diet that specific foods make up. Culturally based methods such as epigraphy, art, and linguistics can provide insights into the cultural importance or significance of certain foods (maize being a great example of this), but again, these types of data can only inform us that a population was utilizing a specific food source and will not necessarily tell us anything about their level of dependence on that food source.

For the purpose of this study I have utilized another method, stable isotope analysis. More specifically, I have analyzed $^{13}C/^{12}C$ ratios in bone collagen and bioapatite from dental enamel from a sample of the skeletal population of Kichpanha. While stable isotope analysis does not answer all possible questions about a population's diet, it does provide a very useful and specific type of information. Carbon stable isotope ratios indicate what proportion of an individual's diet consisted of $C_4$ plants versus all other food sources. This method is particularly useful in prehistoric Mesoamerica where the only major $C_4$ food source was maize. This is important because it allows researchers to track changes in consumption patterns and relate them to social, political, and environmental changes in Mesoamerica.

In the following chapter I discuss the theory and method of stable isotope analysis, the types of questions stable isotope analysis have been used to address, and the previously published stable isotope studies addressing diet in Maya populations.

In the third chapter I introduce Kichpanha and review the history of the site and the research that has been conducted in relation to the site. This chapter also outlines my methods for preparing and analyzing bone collagen and dental enamel.

In Chapter 4 I present my carbon isotope data from Kichpanha as well as provide a comparative dataset of carbon isotope data from other Maya studies. These data are analyzed and discussed in Chapter 5. I discuss temporal trends in the data, how diet varies according to social status at Kichpanha, I compare the bone collagen and dental enamel data from Kichpanha, and I compare the Kichpanha dataset to other published Maya carbon isotope datasets.

In Chapter 6 I discuss what this study can tell us about diet at Kichpanha from the Late Preclassic through the Terminal Classic period and why it may have been similar or different from other Maya sites. I will also suggest other possible research that could further refine our understanding of the diet of the prehistoric Maya inhabitants of Kichpanha.

# CHAPTER 2

## STABLE ISOTOPE ANALYSIS AND ITS USE IN MAYA DIETARY STUDIES

This section will introduce the method and rationale of stable isotope analysis from human remains and to discuss the isotopic studies which have been carried out on prehistoric Mayan remains in an attempt to better understand their diet. While the Maya are referred to as a single entity, Mesoamerica, as a whole, is very ecologically diverse and therefore, diet will obviously vary between people living in different environments. However, according to Coe, the Mayan region is less diverse then the entirety of Mesoamerica and thus can be viewed as really having only two types of distinct ecosystems, the highlands and the lowlands (Coe 2005: 14).

The highlands are defined as any area with an elevation over 1,000 feet and are very mountainous regions with landscapes dominated by active and extinct volcanoes. Rainfall in the highlands is adequate for agriculture; however, the thin soil is quickly depleted of nutrients and requires long stretches of rest to rejuvenate. Based on current agricultural practices, at the higher elevations, ten years of cultivation necessitates a 15 year fallow period for the soil to recover its productive potential. At lower elevations (still above 1,000 feet), the fallow period is much shorter, allowing up to 15 years of continuous cultivation and requiring only five years to recover. The highlands have relatively scarce wildlife when compared to the lowlands; however, this may be the result of higher population densities in the highlands (Coe 2005 14:20).

The lowlands have significantly higher temperatures than the highlands. The Peten-Yucatan peninsula is composed of a flat limestone shelf which has risen above sea level over a very long period of time. Water is one of the primary limiting factors for agriculture throughout much of the Maya lowlands, particularly in the Yucatan Peninsula. There, a limited amount of rain falls each year (70-90 inches) and is restricted primarily to the rainy season. In addition, the rainy season in the Yucatan is unreliable and the region periodically suffers severe droughts. There are also very few permanent lakes or rivers in this area and the water table is at least 210 feet below the surface. In contrast, the southern Peten, Belize, parts of Chiapas, and Tabasco receive heavy precipitation during the rainy season and *cenotes*, natural depressions formed by the collapse of underground caves, serve as water reservoirs during the dry months and were focal points of many prehistoric Mayan settlements. The soil in many parts of the Peten is deep and rich; however, the soil of the Yucatan Peninsula tends to be shallow and nutrient poor. In contrast to the highlands, lowland agricultural fields average only two years of productivity requiring four to seven years to recover in the Peten and 15 to 20 years in the Yucatan (Coe 2005: 14-20). However, there is extensive evidence of terracing and raised field agriculture in the Petexbatun region of the Peten, Guatemala, the Rio Bec region of Mexico, the Upper Belize River Valley in western Belize, and the Vaca Plateau in southern and central Belize. The archaeological investigations of the terraces in these regions suggests that terracing began in the Early Classic (possibly some in the Late Preclassic), then greatly expanded during the Late Classic. These agricultural practices would have greatly increased the productivity of the land in these areas, but require a large investment of labor and a relatively high level of social organization (Kunen 2001).

Elements and Isotopes

An element is defined by the number of protons (positively charged subatomic particles) in the nucleus of an atom. For instance, carbon, an important element in stable isotope analysis has six protons. Nitrogen, another important element in this type of analysis has seven protons. Neutrons (subatomic particles with no net charge) are also part of the nucleus of an atom and provide stability to the nucleus by preventing the positively charged protons from repelling each other. The number of neutrons in the nucleus of an atom may vary without drastically changing the characteristics of the atom. Atoms with the same number of protons but different numbers of neutrons are called isotopes. While the number of neutrons in atoms of an element can vary, that variation can affect the stability of the nucleus of an atom. If there are too few or too many neutrons in the nucleus of an atom the atom will correct the problem through radioactive decay as is the case for $C_{14}$ (14 denotes the number of protons (6) plus neutrons (8)) which decays through beta-emission. Conversely, as the name implies, stable isotopes vary in the numbers of neutrons present in the nucleus of an atom, but not enough to affect the stability of the nucleus. Therefore, these isotopes do not decay.

While the isotopes of an element behave very similarly, they are not exactly the same. Each proton and neutron weighs one atomic mass unit (amu), and having greater or lesser mass will affect how quickly an atom reacts with the other atoms in its environment (Pollard et al. 2007: 230-236). The degree of this effect depends on the relative difference in mass between molecules; therefore, the addition of one extra neutron to a smaller, lighter molecule will have a much greater affect then the addition of a neutron to a large, heavy molecule (Schoeninger and Moore 1992). It is this slight

difference in behavior that makes certain stable isotopes useful to biologists and anthropologists.

Photosynthesis

During photosynthesis, plants incorporate a disproportionately large amount of $C_{12}$ (relative to what's available in the air) into their tissues because $C_{13}$ forms stronger chemical bonds with oxygen in $CO_2$ and diffuses more slowly than $C_{12}$ (Wright 2006: 78). The change in the ratio of $C_{13}$ to $C_{12}$ from the air to that found in plant tissue is called isotopic fractionation. Atmospheric carbon dioxide consists of 98.9% $^{12}CO_2$ and 1.1% $^{13}CO_2$ (the radioactive molecule, $^{14}CO_2$, only makes up about $1x10^{-10}$ %) (Tykot 2006: 131). The two most common photosynthetic pathways and those most important to anthropological studies are the $C_3$ or Reductive Pentose Phosphate Pathway (more commonly known as the Calvin cycle), and the $C_4$ or Hatch-Slack pathway (Wright 2006: 78).

In the Calvin cycle, carbon dioxide reacts with the enzyme ribulose pentaphosphate carboxylase to produce ribulose 1,5 pentaphosphate, a five carbon chain with $-PO_4$ (phosphate) functional groups. This molecule is then reduced to triose phosphate, a three-carbon chain with one phosphate group (thus $C_3$). During this process, the reduced reactivity of $C_{13}$ produces an isotopic fractionation of 34‰ in the plant relative to the air resulting in a $\delta^{13}C$ around -27‰. In the Hatch-Slack pathway, bicarbonate is fixed in mesophyll cells with phosphoenolpyruvate to molecules with three-carbon chains resulting in the four-carbon acids malate, aspartate, and oxaloacetate. These acids are then sent to the bundle sheath where decarboxylation occurs by

phosphoenolpyruvate caboxykinase. The fractionation resulting from the phosphoenolpyruvate carboxykinase in $C_4$ is much smaller than that which results from carboxylation by ribulose 1,5 pentaphosphate in $C_3$ plants. The result is that the tissues of $C_4$ plants have a $\delta^{13}C$ around -13‰ (Wright 2006: 79)

Isotope Analysis

In the Late 1960s, archaeologists began to realize that radiocarbon dates determined for pieces of carbonized maize were consistently about 200 years younger than what they expected. As a result, researchers began measuring stable isotopes and correction factors were developed for radiocarbon dates derived from maize and other non-wood organic materials. At a conference in 1970, researchers realized that there was a bimodal distribution of stable carbon isotope ratios related to photosynthetic pathways. Plants utilizing the Calvin cycle averaged $\delta^{13}C$ of -26.5‰ while those utilizing the Hatch-Slack pathway averaged $\delta^{13}C$ of -12.5‰. The Calvin cycle ($C_3$) is the most common photosynthetic pathway. Plants utilizing the Hatch-Slack pathway ($C_4$) include maize, sugarcane, millet, sorghum, and certain species of amaranth and chenopodium (Tykot 2006: 132).

In 1964, the theory that carbon isotope values in animal tissues could provide information about diet was first presented by a biochemist named P. L. Parker who published an article detailing the carbon isotope analyses he had conducted on marine plants and animals. In 1971, the first dietary study of an archaeological human specimen based on stable isotope analysis was carried out by N. J. van der Merwe and J. C. Vogel on the remains of an Iron Age Khoi from South Africa. In this study the researchers

analyzed the carbon isotope ratio of bone collagen extracted from the Khoi individual's remains and produced a $\delta^{13}C$ of -10.4. They interpreted this as indicating that this individual's diet relied heavily on $C_4$ plants, most likely sorghum (Tykot 2006: 132). The hypothesis that diet affects the carbon isotope composition of human skeletal material was further tested and confirmed in the late 1970s and early 1980s in laboratory studies carried out by Bender and colleagues and DeNiro and Epstien, following Vogel's field study in 1978 (Schoeninger and Moore 1992).

The data used by researchers in isotopic studies is not expressed in absolute values, but is instead a ratio ($\delta$) of proportions of isotopes present in a sample versus the proportions of isotopes present in a standard. In the case of carbon the standard is PeeDee Belemnite (PDB), a fossil limestone from South Carolina; for nitrogen the standard is air. The ratio is expressed in ‰ (‰) (similar to percent but multiplied by 1,000 instead of 100) and is calculated as $\delta = [(R_{sample} - R_{standard})/R_{sample}] \times 1{,}000$ where R = the ratio of the heavier isotope to the lighter isotope (for carbon, $R = C_{13}/C_{12}$). Because PDB has a very high proportion of $C_{13}$ to $C_{12}$, $\delta^{13}C$ in plant and animal tissues is always expressed as a negative number with $C_3$ plants having values of approximately -27‰ and $C_4$ plants having values between -9‰ and -16‰ with an average of approximately -13‰ (Schoeninger and Moore 1992; Wright 2006: 78-79; Wright and White 1996). The $\delta^{13}C$ of atmospheric $CO_2$ is -7‰ (Tykot 2006:133). Therefore, the more maize a person eats the less negative the value of $\delta^{13}C$ will be when measuring the isotopic ratio of their tissues.

The other most common isotopic ratio archaeologists study is that of nitrogen (although there are others such as oxygen and strontium). $\delta^{15}N$, in contrast to $\delta^{13}C$ is not

differentially affected by photosynthesis. Instead, $\delta^{15}N$ directly relates to environmental factors affecting the soil such as temperature, moisture, and soil salinity. Due to the way that plants incorporate nitrogen into their tissue, direct comparisons of $\delta^{15}N$ must be restricted to people living in and subsisting on foods from the same ecological zone or area. $\delta^{15}N$ is useful to biologists and anthropologists because it increases at a fairly consistent rate of +3-4‰ per trophic level. This means that the more animal products a person consumes the higher their $\delta^{15}N$ will be. However, in coastal settings this relationship can be confounded because aquatic plants typically have a $\delta^{15}N$ about 4‰ higher than that of terrestrial plants. There can be further difficulties with this measurement because certain organisms living in the water, such as blue-green algae, can actually lower the $\delta^{15}N$ of the water making the $\delta^{15}N$ of aquatic plants similar to that of terrestrial plants (Schoeninger and Moore 1992; Wright 2006: 80-81; Wright and White 1996).

Skeletal Components

Before archaeologists began conducting isotope studies, it was already known that bone collagen had a slow turnover rate. While no exact rate is known, the turnover rate is estimated to be between five and seven years for most bones and can be more or less depending on the density of the bone. Bone apatite is thought to have a similar rate of renewal, possibly a little faster. Therefore, isotope analysis of these two skeletal materials provides information about an individual's diet during the last several years of their life.

Tooth enamel and dentin are quite different from bone collagen and bone apatite. It is entirely formed early in life and once formed has no subsequent deposition. As a result, isotope analysis of these materials provides information about an individual's diet for just a short period (a few years) during their childhood or adolescence, depending on what tooth is analyzed. Due to the fact that the timing of tooth development is known, analyzing different teeth from the same individual can provide information about changes in that person's diet during their childhood and early adolescence. Other materials that may be used from more recent or very well preserved populations include flesh, hair, and finger and toe nails. These materials have very fast turnover rates and so provide dietary information based on the very end of the individual's life (Schwarcz 2000; Tykot 2006: 137-138; Tykot et al. 1996; Wright and White 1996).

It is also important to know when assessing carbon isotopic ratios of skeletal material that most of the carbon in collagen is primarily derived from dietary protein. This is because exogenous amino acids (the building blocks of proteins) are preferentially used in collagen synthesis even though the enzymes necessary for collagen synthesis using non-essential amino acids are present in the cells. The result of this synthetic pathway is that the other organic components of the diet (carbohydrates and lipids) are underrepresented in bone collagen. It is believed that the presence of exogenous amino acids deactivates these enzymes necessary for endogenous synthesis and that this is less of a problem when studying populations with low protein diets such as agricultural populations relying heavily on $C_4$ vegetation (Schwarcz 2000: 189).

Ambrose and Norr (1993) conducted a controlled experiment using mice as a model to test how the routing of carbon affects $\delta^{13}C$ values for bone collagen. For the

experiment the researchers developed seven different experimental diets with varying proportions of protein, carbohydrate, and lipids. The experimental diets also had known and controlled $\delta^{13}C$ values for both the dietary components and the whole diet. What they found was that changes in the protein source of the diet caused large shifts in the $\delta^{13}C$ of bone collagen. In a diet composed of 5% $C_4$ protein (by weight) and 90% $C_3$ energy (carbohydrates and lipids) (the remaining 5% of the diet is composed of vitamins and minerals which only contribute 1% of the dietary carbon) the $\delta^{13}C$ of collagen shifted from -21.4‰ (that of a pure $C_3$ diet) to -14.7‰. That represents a 51% shift away from the value derived from a pure $C_3$ diet towards that derived from a pure $C_4$ diet. This indicates that the carbon derived from protein, which only makes up 6% of the atoms in the diet, accounts for 51% of the carbon atoms in the mice's collagen. Similarly, a diet composed of 5% $C_3$ protein and 90% $C_4$ energy resulted in a shift of 42% away from the values for a pure $C_4$ diet, towards that of a pure $C_3$ diet. In contrast, a diet composed of 70% $C_3$ protein and 21% $C_4$ energy results in a collagen $\delta^{13}C$ value of -20.7‰. What this indicates is that the 21% of the diet composed of $C_4$ carbohydrates and lipids only results in a 5% shift in $\delta^{13}C$ away from that of a pure $C_3$ diet. In a diet composed of 70% $C_4$ protein and 21% $C_3$ energy, the resulting $\delta^{13}C$ value was -9.7‰. This represents a shift of 88% away from the values for a pure $C_3$ diet. Ambrose and Norr also found that protein derived from animal sources is slightly more effective at shifting the isotope ratio of collagen than is plant protein. What this study indicates is that while carbohydrates and lipids do contribute carbon to bone collagen, carbon from protein is preferentially routed to collagen (Ambrose and Norr 1993).

Bone apatite, on the other hand, is different in that the carbon in bone apatite is equally derived from the whole diet. An important issue to address when conducting studies using apatite is that it is very susceptible to diagenesis, the reaction of bone material with chemicals in soil and ground water resulting in ionic exchange (Coyston et al. 1999: 226). That is not to say that bone collagen is immune to diagenesis but that it is protected by bone's mineral matrix of hydroxyapatite which allows it to survive for very long periods of time, even in harsh soil conditions. However, while the collagen structure may remain intact that does not mean that all of the molecules that make up the collagen will remain unchanged. While bone mineral (apatite) decomposes due to physical and chemical soil properties, collagen is primarily broken down by microbes in the soil that use the protein in bone as their nutrient substrate. Acidic soil can hydrolyze bone collagen, but only after the mineral matrix has been destroyed. Grupe and colleagues conducted a controlled laboratory study of collagen diagenesis to test how microbial degradation affects carbon and nitrogen stable isotope ratios derived from the analysis of bone collagen (Grupe et al. 2000: 173-185).

Testing the Effects of Diagenesis

To test the effects of soil bacteria Grupe and colleagues inoculated previously sterilized, macerated femora from modern martens with gram-negative *A. piechaudii* and *P. fluorenscens* and gram-positive *B. subtilis*. *A. piechaudii* and *P. fluorenscens* are known to utilize amino acids as both carbon and nitrogen sources. *B. subtilis* tends to use glucose and ammonium as sources of carbon and nitrogen respectively. These particular

bacteria were chosen because they are all known to decompose collagen and *B. subtilis* is one of the most important decomposers of detritus.

The inoculated bones were then stored for six to nine months without light in "optimum growth temperature and aerobic conditions." Although these conditions were not explicitly outlined, they state that these bacteria are capable of growth at temperatures as low as four degrees Celsius but grow faster at higher temperatures. Freshly prepared samples of collagen from modern martens and modern humans were also collected to be used as a baseline in the study. In addition, they also tested a large sample of archaeologically recovered remains from a variety of sites with different soil conditions to compare with the experimentally obtained data.

Both the carbon and nitrogen isotopic ratios were altered in the bones inoculated with bacteria. When the ratios of the inoculated marten remains were compared with those of the control group it was found that the $\delta^{13}C$ from the collagen extracted from the inoculated marten remains had decreased up to 2.4 ‰ (made more negative) and that $\delta^{15}N$ showed an increase of up to 3.4 ‰, the equivalent of an entire trophic level. In assessing the integrity of the collagen recovered from the archaeological specimens the researchers were able to detect solubilized collagen in the serum protein amino acids. This resulted from decomposition following inhumation and varied depending on characteristics of the soil and the antiquity of the bones. Surprisingly, the best preserved specimens had the most solubilized collagen remnants in the non-collagen protein extracts. This occurs because solubilized collagen is quickly leeched from bone and, therefore, bone with more intact collagen will be actively losing more collagen whereas highly degraded bone will have already lost a great deal of collagen so the reaction will

have slowed. They concluded that in archaeological human bones that have amino acid profiles with reduced numbers and altered concentrations of amino acids, isotopic ratios present in these bones may reflect diagenetic processes working on the remains and not the diet of the person under examination (Grupe et al. 2000: 173-185).

One method that is commonly employed to test the integrity of collagen is to compare the atomic ratios of carbon to nitrogen (C/N). Studies of modern bone collagen have shown that the ratio of carbon to nitrogen in human bone collagen falls within a range from 2.9 – 3.6. It is assumed that if the ratio found in collagen from archaeological specimens falls within this range then the collagen is relatively intact or at least within the bounds of usefulness. If the ratio is outside this range then it must be concluded that the collagen is too degraded to provide reliable data pertaining to the individual's diet (Wright 2006: 85). Unfortunately, Grupe and colleagues did not assess, or at least report, this ratio in their study.

In 1996, Tykot, and coworkers published the results of a study they conducted at the site of Cuello in Belize analyzing carbon isotopes in bone collagen, bone apatite, and tooth enamel of a Preclassic sample (Tykot et al. 1996). When comparing the results for collagen, apatite, and tooth enamel, $C_4$ foods were estimated to have contributed 58% of the carbon found in bone collagen and 38% of bone apatite. The percent of $C_4$ contribution to tooth enamel was not calculated; however, the $\delta^{13}C$ of tooth enamel was more positive than either of the other two materials suggesting a very high proportion of maize in the subadult diet. Because collagen derives most of its carbon from dietary protein, Tykot and colleagues interpreted the difference in $\delta^{13}C$ between collagen and apatite as resulting from the consumption of dog meat with its high $C_4$ isotopic signature

and the subsequent routing of carbon derived from protein for collagen synthesis. They suggest that these findings indicate that while maize was an important part of the diet, it did not comprise an overwhelming percentage of the diet during the Preclassic period at Cuello (Tykot et al. 1996; van der Merwe 2000).

Carbon stable isotope analysis has been used to address four questions of Mayan skeletal populations. The most common question is how the diet of the population at a site changed over time. The second question is how diet varied within a population according to social status. A third question which has been addressed is variance in diet between males and females. Finally, the diets of subadults have also been compared to those of adults within a population.

I will use the data derived from the skeletal population from Kichpanha to address these same questions in Chapter 5. In the next section will discuss how these questions have been addressed and the results of the previous carbon isotope studies carried out on Mayan skeletal populations.

Changes in Diet through Time

Many researchers carrying out stable isotope studies attempt to answer multiple questions with their data set. One of the basic and most common questions asked is how diet changed over time at a particular site. All of the Mayan sites at which stable isotope studies have been preformed have long occupational histories and skeletal populations which naturally lend themselves to questions of temporal change.

One of the earliest studies of carbon and nitrogen stable isotopes in Mesoamerica, and the earliest conducted using prehistoric Mayan remains, was carried out by Christine

White on individuals recovered from the site of Lamanai in Belize, published in 1988. The previous bone chemistry studies in Mesoamerica had looked at concentrations of certain elements present in skeletal tissue (trace elements) as opposed to ratios of isotopes present in the bones. Therefore, White conducted both types of analysis on her sample and was able to compare the results.

For the element analysis portion of her study, White looked at the strontium, magnesium, and zinc content of the skeletal material. Strontium gives information regarding overall maize consumption, and magnesium and zinc are related to pericarp consumption. There is an inverse relationship between the amount of strontium in an individual's bones and the amount of maize they consumed. What she found was that strontium content dropped off steeply from the Pre-Classic to the Early Classic, then gradually rose to a peak in the Terminal Classic, then gradually declined again into the historic period. What this implies is that maize consumption was most important at Lamanai during the Early Classic, and then gradually declined in significance as time progressed until the Terminal Classic when maize again increased in importance. The relationship between the magnesium curve and strontium curve suggested to her that the people living at Lamanai were not eating the pericarp of maize. This finding was expected based on ceramic evidence of alkali processing and ethnohistoric accounts of pericarp removal during alkali processing.

White found a similar trend in maize consumption in her analysis of carbon isotope ratios from the population at Lamanai. She found that $\delta^{13}C$ decreased over time (became more negative) from the Early Classic to the Terminal Classic then rises sharply in the Post-Classic. She determined based on the isotopic data that maize constituted

50% of the diet during the Early Classic, then dropped to a low of 37% during the Terminal Classic, then rose again during the Post Classic and Historic periods to a high of 65-70% of the diet. When assessing her nitrogen isotopic data, White found that $\delta^{15}N$ was stable throughout all time periods. This indicates there was no significant change in the consumption of meat, legumes, or marine resources from the Pre-Classic through the Historic period.

Interestingly, she found very little variation in elemental and isotopic signatures between individuals within each time period. One exception to this trend was an Early Classic elite male from a tomb burial who's $\delta^{13}C$ and strontium values show that he ate much less maize than the other Early Classic individuals tested (White 1988; White and Schwarcz 1989).

At Cuello in Belize, Tykot and colleagues analyzed a skeletal sample that spanned from the Early Middle Preclassic through the Late Preclassic. What they found was that males' $\delta^{13}C$ was slightly higher than that of females during the Early Middle Preclassic then decreased slightly, diminishing the difference, through the Late Pre-Classic while female $\delta^{13}C$ remained stable throughout the entire time period. They interpret this as suggesting that males had greater access to $C_4$ foods then females during the Early Middle Preclassic, but that their access was reduced as time progressed eliminating the difference in diet between men and women (Tykot et al. 1996).

At Copan, Honduras, David Reed analyzed isotopic ratios from a sample of 82 individuals. One of the goals of this study was to determine how diet had changed at Copan over time and how that change could be related to political and social changes occurring at the site. The Acbi phase is associated with a period of population growth

while the Coner phase is associated with population decline. When comparing individuals according to time period (or phase), Reed found that during the Acbi phase, residents of Copan were more dependent on maize and had a more restricted diet then during the Coner phase. As population declined and the political situation in Copan deteriorated, diet became more diverse (Reed 1999).

In the Pasion region of Guatemala, Lori Wright carried out an isotopic study comparing individuals from five different sites spanning in time from the Preclassic through the Terminal Classic. The purpose of her study was to test expectations of change in Mayan diet derived from the ecological model of collapse in the Pasion region. The ecological model of collapse attributes environmental degradation and an ensuing decline in health on maize agriculture. Dependence on maize is thought to have increased over time in association with increasing population pressure and the destruction of natural habitats due to expanding farm land along with over-hunting of wild fauna is believed to have further reduced the variety of foods available to the Maya. Based on this model Wright expected to find increasing $\delta^{13}C$ values over time along with decreasing $\delta^{15}N$ values indicating an increase in maize consumption and a decrease in animal consumption (Wright 1997:181-185).

When assessing all of the isotopic data together, Wright found that maize was an important part of the diet in the Pasion region; however, meat also made up a large portion of the diet and contributed a considerable amount of protein toward collagen synthesis. At Altar de Sacrificios $\delta^{13}C$ values show an increase in maize consumption from the Preclassic through the Late Classic. During the Terminal Classic, monumental construction at Altar de Sacrificios came to a halt, but a large population remained at the

site. During this time period there appears to have been a decrease in the importance of maize in the diet, returning to Early Classic levels. No change is seen in nitrogen isotopic ratios at the site; therefore, Wright concluded that the changes in maize consumption were related to changes in $C_3$ plant consumption, not animal products (Wright 1997:188).

At Dos Pilas a similar trend is seen, but due to the very small Terminal Classic sample (n=4) the findings are not statistically significant. Conversely, at Seibal there is no change in $\delta^{13}C$ values over time and the $\delta^{15}N$ for residents of the site are much higher than those found at Altar de Sacrificios. Since both sites are situated in similar ecological zones, Wright believes that the difference between the two sites must have been the result of local preference instead of food availability (Wright 1997:188-190).

At Seibal, while the proportion of maize in the diet remains stable throughout its occupation, a drop in $\delta^{15}N$ values from the Late Classic to the Terminal Classic indicates that there was a decrease in meat consumption at this time. However, when compared with the $\delta^{15}N$ from the other sites in the Pasion, even during the Terminal classic the $\delta^{15}N$ values at Seibal were higher than those found at any other site at any time. Wright hypothesized that these trends in the data could be associated with a shift from fish consumption to beans, or another $C_3$ plant, with no associated change in maize or terrestrial animal consumption. These findings are in opposition to the expectations of the ecological model and do not suggest a shortage of animal protein. Wright concludes that the data from the Pasion region does not support the ecological model of collapse. While maize was an important crop throughout the region there was not the expected universal increase in maize consumption over time and animal protein consumption did not decrease as the population in the region increased (Wright 1997: 190-195).

In their stable isotope study carried out at Altun Ha, Belize, White and colleagues looked at carbon and nitrogen isotopes from 72 individuals (47 adults and 25 subadults) representing elites and commoners spanning in time from the Preclassic to the Post Classic. They utilized both bone collagen and bone apatite in their analysis of carbon isotopes. Only collagen was used to look at nitrogen isotopes. Altun Ha is a small, but significant center located approximately 7km from the coast in northern Belize. Abundant remains of marine resources that may have been traded and consumed have been recovered from the site and its proximity to the sea is believed to have been a very important factor in the development of the settlement. Altun Ha was settled in the Middle Preclassic and by the late Preclassic is thought to have been a lithic production center for Colha, a site to the north of Altun Ha. During the Classic period, Altun Ha grew into a "first order" center and in spite of its relatively small size developed a very wealthy elite class as is reflected in the amount of prestige goods recovered from the site.

Both the $\delta^{13}C$ from collagen and that from bone apatite suggest that the diet at Altun Ha was based primarily on $C_4$ foods, supplemented with $C_3$ foods. The residents from Altun Ha also displayed high $\delta^{15}N$ values indicating that they were consuming ample animal protein. The high $\delta^{13}C$ values and $\delta^{15}N$ values at the site indicate that the residents were deriving most of their protein from marine resources. Marine and reef resources can raise the $\delta^{13}C$ values derived from bone collagen leading to an overestimate of maize consumption in the population. However, the high $\delta^{15}N$ indicating a reliance on reef resources helps to temper this type of error. While maize was an important crop at Altun Ha, the site has the lowest $\delta^{13}C$ values and the highest $\delta^{15}N$ values in the region

indicating that they were eating less maize and more marine resources than anyone else in the region (White et al. 2001).

When the data from Altun Ha is analyzed for chronological trends, two major shifts in subsistence are seen, according to White and coworkers. The first occurred between the Early Classic and Middle Classic and represented a steep decline in $C_4$ consumption. The second occurred at the transition from the Terminal Classic to the Postclassic and was characterized by a further decline in $C_4$ consumption. These decreases in $C_4$ consumption are interpreted by the authors to represent a decrease in access to maize, either due to an inability to produce sufficient quantities of maize, or the loss of trade networks supplying maize to the site (White et al. 2001).

At Chau Hiix, a relatively small site located between Altun Ha and Laminai in Belize, Metcalf and colleagues analyzed a sample spanning the Early Classic through the Historic period. This population included individuals of all ages, both sexes, and of differing status; however, in order to assess temporal changes in diet at Chau Hiix the researchers limited their sample to individuals recovered from Structure 2, a residential building. This strategy was explained as limiting the status variation within the sample population which could compromise or obscure temporal changes in diet. A weakness of this sample strategy is that no Classic or Early Classic individuals are present in the sample and the Late Classic sample consists of only two individuals, a child under the age of 4 and a young adult. The Terminal Classic sample is composed of 15 individuals spanning all age groups. The Postclassic population consists of five individuals, four young adults and one adolescent. The Historic period population is composed of three young adults. What Metcalf and colleagues found was that $\delta^{13}C$ values were higher

during the Postclassic and Historic periods than during the Terminal Classic. This change is more pronounced when comparing bone apatite values than when comparing collagen values. The researchers interpret this as meaning that the change in $\delta^{13}C$ values is most likely related to a change in protein consumption, not a change in maize consumption (Metcalf et al. 2009).

Sex

Some researchers have used stable isotope studies to determine if a difference between the diets of males and females existed among the Maya. In 1996, Tykot and colleagues analyzed a Preclassic sample from Cuello in Belize. They divided their sample both by sex and time period, although these divisions resulted in very small sample sizes. What they found was that during the Early Middle Pre-Classic males seemed to consume more maize then did females resulting in an average $\delta^{13}C$ that was 2‰ higher than for females from the same time period. However, the very small sample size (2 males and 3 females) limits the reliability of this finding. The researchers suggest that this difference between male and female $\delta^{13}C$ may be the result of males eating more $C_4$ enriched dog meat then females. The analysis of their Late Pre-Classic sample (7 males and 6 females) no difference was seen between the sexes. When the sample was divided by sex and examined for changes in diet over time Tykot and colleagues found that maize consumption seemed to decrease slightly among males throughout the Pre-Classic while they found no change in the diet of females (Tykot et al. 1996).

David Reed also conducted an isotopic study looking for differences between the diets of males and females at Copan. He analyzed 34 females and 37 males. After

removing three outliers Reed found that males had significantly higher values for $\delta^{13}C$ and $\delta^{15}N$. These results mean that males were eating more meat and more maize and that females had a greater proportion of $C_3$ plants in their diets (Reed 1999: 183-193; Whittington and Reed 1997: 157-170).

At Chau Hiix, Metcalf and colleagues looked for differences in diet between males and females. Their sample included 13 males and seven females. The males were from the Early Classic, Terminal Classic, Postclassic, and Historic time periods; the females were from the Terminal Classic, Postclassic, and Historic time periods. They found no statistical difference between the diets of the males and females in their sample and concluded that there was no systematic difference between the diets of men and women at Chau Hiix (Metcalf et al. 2009)

Social status

Another aspect of Mayan culture which researchers have used stable isotopes to address is whether or not diet varied according to social status. While it is quite possible that among the Maya diet varied according to social status, status can be difficult to determine archaeologically and studies of this type often suffer from small sample sizes.

At Lamanai White analyzed two tomb burials, a male and a female, as part of her study. When compared to the rest of the population, the male's $\delta^{13}C$ and strontium values show that he ate much less maize than the other Early Classic individuals tested and his $\delta^{15}N$ suggests that he was eating a larger portion of imported marine foods than were commoners at Lamanai. The $\delta^{13}C$ of the female was similar to that of the male indicating that the plant portion of their diets was similar; however, the woman had a

much lower $\delta^{15}N$ suggesting that she didn't have equal access to marine resources (White 1988; White and Schwarcz 1989).

David Reed conducted a carbon and nitrogen isotopic study comparing commoners and elites from the Late Classic period at Copan. A very large skeletal sample was recovered from Copan, so Reed was able to select a sample of 25 commoners and 57 elite individuals for this comparison. The status of individuals was determined by the location of their burial. In their 1997 publication, Whittington and Reed stated that the most likely source of meat at Copan was deer. They made no mention of the regular consumption of dogs which, in other studies, has been shown to consume diets primarily based on maize. This raises the $\delta^{13}C$ value of the dogs' tissues. This, in turn, raises the $\delta^{13}C$ values of individuals who consume the dogs (Tykot et al. 1996; van der Merwe et al. 2000). Reed states that there were very few faunal remains recovered from the site implying that meat made up a very limited proportion of the diet at Copan (Reed 1999:187-188). Five archaeological deer specimens were also analyzed to determine how their consumption would affect the isotopic signatures of individuals who consumed them. Based on the $\delta^{13}C$ of the deer studied, Reed determined that these deer were consuming a diet based on $C_3$ foods. This fact allowed him to assume that maize was the only $C_4$ food in the diet of residents of Copan. Using t-tests to compare the means of the carbon and nitrogen isotopic signatures of the commoners and elites at Copan, Reed found no difference between the two groups. However, there was a greater degree of variance in carbon isotope values among the elites then among the commoners at Copan. They interpret this as indicating that there was more variation between the diets of elites then between commoners. Because this variance did not show up in the nitrogen isotopic

values they conclude that the difference was not in meat consumption, but that the elites had access to a greater range of $C_3$ plant foods (Reed 1999).

Lori Wright also looked for differences in diet according to status in her analysis of diet at five sites within the Pasian region of Guatemala. Analyzing variation within the sites according to social status was difficult due to skewed and small sample sizes, but the data did show a trend during the Late Classic at Altar de Sacrificios and Dos Pilas of higher $\delta^{15}N$ for elites suggesting greater meat consumption among elites as compared to commoners. During the Terminal Classic no such trend is seen (Wright 1997: 181-195; Wright 2006: 191-203).

In their dietary analysis of a population from Altun Ha, Belize, White and colleagues looked at carbon and nitrogen isotopes from 72 individuals (47 adults and 25 subadults) representing elites and commoners spanning the Preclassic to the Post Classic. The results of the temporal study indicate that there was a steep decline in $C_4$ consumption from the Early Classic to the Middle Classic and a further decline during the Terminal and Postclassic periods. The $\delta^{13}C$ values of elites at Altun Ha tend to be higher than those of commoners; however, there is a large amount of variation in the measure among the elites. White and colleagues interpret this as indicating a limited access to maize and suggest that their data shows multiple levels of eliteness at Altun Ha and possibly lesser elites attempting to emulate greater elites through consumption (White et al. 2001).

At Chau Hiix, Metcalf and colleagues discuss in detail one individual who was the primary interment in an Early Classic Tomb. Based on the context they assume that this individual, an older adult male, was a ruler of Chau Hiix. Interestingly, this man had

the highest $\delta^{13}C$ value for collagen of any of the remains they analyzed ($\delta^{13}C$ = -7.6‰). However, the $\delta^{13}C$ value for his bioapatite was close to the mean for the rest of the population at Chau Hiix (-7.5‰). By assessing the difference between the $\delta^{13}C$ value of this man's bioapatite and collagen (the smallest of any individual analyzed) the researchers determined that this high status individual's diet consisted of a large amount of marine resources or $C_4$-fed terrestrial animals along with $C_3$ plant foods. This finding is consistent with what was found across the entire sample from Chau Hiix; however, this individual also had a slightly higher $\delta^{15}N$ signature which suggests that he may have eaten more meat and fish then the rest of the population, although the difference appears small (Metcalf et al. 2009)

Age

A final question addressed by Mayan researchers using stable isotope analysis is the how diet varies between subadults and adults within a population. In her investigation at Lamanai White examined the remains of individuals of all ages. She wanted to see if the diets of infants and children differed from that of adults. She found that when she compared the isotopic data of all age groups there was no difference. White concluded that people of all ages were living on the same diet and that this high maize diet during development lead to the high incidence of porotic hyperostosis seen at Lamanai (White 1988).

At Chau Hiix, Metcalf and colleagues looked at variation in diet by age by analyzing and comparing the $\delta^{13}C$ values for bioapatite from dental enamel from first, second, and third molars from all of the individuals in their skeletal sample for which

these teeth were present (not all of the individuals had third molars). They based their analysis on the premise that first molars provide dietary data for the first three years of life, second molars relate to ages 3-8, and third molars relate to ages 9-12. They then compared the data from each of the tooth types to each other both within individual time periods and across the entire sample population. The researchers found no significant difference between the $\delta^{13}C$ values for the molars either within time periods or for the whole population. They concluded that there was no significant change in diet between birth and 12 years of age at Chau Hiix.

They also compared the dental data to $\delta^{13}C$ values from bone bioapatite which provides information about diet during the last 10 – 30 years of life. They did find a significant difference between the dental data and the bone data with the dental $\delta^{13}C$ being consistently higher than that from bone. They concluded, based on this evidence, that maize and/or coastal resources made up a larger proportion of the subadult diet than the adult diet at Chau Hiix. This difference was present at all times at Chau Hiix, but was most pronounced during the Postclassic and Historic time periods when the average $\delta^{13}C$ values for enamel were -1.8 ‰ and -2.1‰ while those of bone bioapatite were -7.0‰ and -7.1‰. While the importance of maize and coastal resources increased at Chau Hiix during these time periods for individuals of all ages, Metcalf and colleagues conclude that these data show that during the Postclassic and Historic periods, the subadult diet at Chau Hiix was composed completely of maize and coastal resources (Metcalf et al. 2009).

The next chapter will introduce the site of Kichpanha and discuss the theory behind stable isotope analysis and describe my method for collecting data from the Kichpanha skeletal sample.

# CHAPTER 3

# AN INTRODUCTION TO KICHPANHA AND STABLE ISOTOPE DATA COLLECTION

The purpose of this chapter is to provide an introduction to the site of Kichpanha, and describe the method I used to extract and analyze the carbon isotope data from my skeletal sample from Kichpanha, Belize. Figure 3.1 shows the location of Kichpanha in northern Belize along with many other important Maya sites.

## Introduction to Kichpanha

The site of Kichpanha was first settled in the Middle Preclassic time period (1000 - 850 BCE). The earliest occupation appears to have been established along the northern shore of Kate's Lagoon, a freshwater lake, and along the boundaries of the wetlands associated with the lagoon. A well drained limestone ridge provided an area of dry land upon which the site was established (Shaw 1995a).

Kichpanha expanded in size and population throughout the Preclassic time period (before 250 CE); however, it remained modest in size relative to the nearby centers of Colha and Cuello. The most rapid growth of Kichpanha appears to have occurred

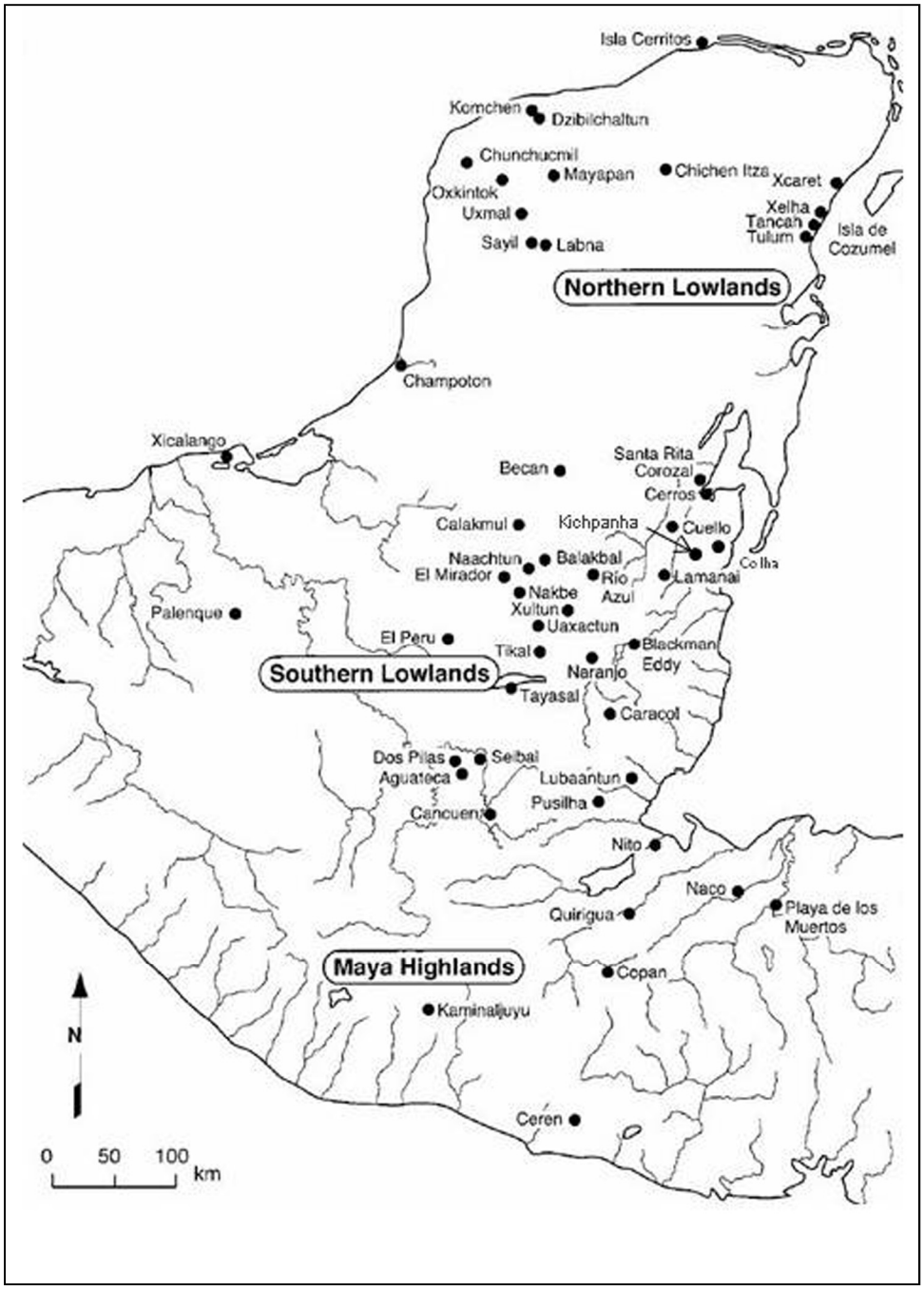



Figure 3.1 Map of the Maya Region Showing Many Preclassic and Classic Settlements and Cities (taken from Marcus 2003)

around 100 BCE and is evidenced by the extensive monumental construction that occurred during this time. Also, during this period the evidence of social stratification within the site is seen in both residential construction and patterning and in the treatment of the deceased (Shaw 1995a).

During the Early Classic period (250 CE – 600 CE) site growth plateaued and the population began to decline. Also, during the Early Classic time period monumental construction greatly decreased and was limited to modification of Preclassic structures and some residential construction including adding height to many of the residential platforms. Toward the end of the Early Classic, evidence of an upper class also tapers off (Shaw 1995a). It is unknown whether the elites moved on to other nearby cultural centers, or if their status simply declined through the generations until archaeologically recognizable social stratification was lost at Kichpanha.

By the Late Classic period (600 – 800 CE) there is no evidence of social stratification at Kichpanha and the site was inhabited by a relatively small group of people living in the Early Classic residential plaza north of the monumental center. Construction during this time was limited to minor remodeling of the Early Classic plaza (Shaw 1995a). A small agricultural community continued to inhabit Kichpanha into the Terminal Classic; however, by the end of this period the site had been abandoned (Magennis 1999:137).

Kichpanha is surrounded by a lush environment that would have provided a rich and varied diet for its inhabitants. Preliminary analysis of faunal remains from Kichpanha indicate that crocodilians, turtles, snails, and fish were extracted from Kate's Lagoon and the nearby wetlands and consumed at the site along with deer, peccary, dog,

armadillo, and agouti (a rodent related to guinea pigs). At this time there is no evidence of raised or ditched fields at Kichpanha and there is little arable land near the site; however, gardens along the margins of the wetlands and dooryard gardens were most likely used to supplement agricultural production (Shaw 1995a in Magennis 1999:137).

The initial archaeological excavations at Kichpanha were carried out in the late 1980s and early 1990s. Due to the high pH and moisture of the soil, skeletal preservation is very poor. There were very few intact bones recovered from the site and the degradation of the remains did not allow for the sexing or aging of most of the individuals recovered from the site. Therefore, those factors will not be considered in my analysis of the remains from the site. Despite the poor preservation, Jansen and Magennis were able to carry out studies assessing the health of the population and how the presence of specific indicators of health or "stress" changed over time within the Kichpanha population. Alisa Jansen's study focused on linear enamel hypoplasias and porotic hyperostosis (Jansen 1995), while Magennis' (1999) study looked at caries rates and dental calculus buildup. Jansen initially expected that the prevalence of linear enamel hypoplasias and porotic hyperostosis would increase over time in relation to the increasing social stratification that took place during the buildup of the Mayan Empire. Instead, what she found was that these indicators of stress were highest during the Protoclassic and Late/Terminal classic and lowest during the Early Classic, when social stratification within Kichpanha was at its pinnacle. In Magennis' study of caries she found that there was a slight drop in prevalence from the Protoclassic to the Early Classic, then the prevalence more than doubled during the Late/Terminal Classic. She

also found that the amounts and rates of calculus increased steadily from the Protoclassic through the Late/Terminal classic (Magennis 1999: 133-150).

In their analysis of plant remains recovered from dental calculus from Kichpanha, Cummings and Magennis found that the most abundant material was corn starch granules. The authors also found phytoliths from Palmae (plants in the palm family), a festucoid grass (a $C_3$ grass), pollen from Cheno-Am (*Chenopodium* or *Amaranthus*) in individuals from the Protoclassic time period, and manioc starch granules. They also state that there were remains from a wide variety of plants that they were not able to positively identify. While the analysis of plant remains found in dental calculus does indicate that certain plants were consumed (or possibly just placed in the mouth for working fibers as may be the case with the festucoid grass) it does not necessarily indicate the importance of any particular plant in the diet of the individuals who are analyzed (Scott Cummings and Magennis 1997).

Bone Collagen Extraction and Analysis

For this study, collagen from the leg bones of 42 individuals was analyzed. Most samples were taken from femora, unless there was no femur recovered from an individual burial. In that case tibiae were used. For burials containing multiple individuals, only right femurs were analyzed to prevent taking multiple samples from a single individual. Each sample consisted of a solid piece of bone weighing approximately 0.5g. Using solid pieces of bone preserves the collagen tendrils whereas crushing the samples would break up the collagen fibers. The samples were placed in 10mL test tubes with approximately 7mL of 0.5M hydrochloric acid (HCl). The tubes were then loosely covered with tin foil

and refrigerated at approximately 2˚C until demineralization of the skeletal matrix was complete. The time required for demineralization to occur varied between samples, but generally took between two days and one week.

When demineralization was complete the samples appeared yellow in color and were soft when prodded with a glass stirring rod. The samples were then centrifuged to separate the skeletal material from the liquid, and the acid was removed with a pipette and replaced with deionized water. The samples were rinsed in this manner three times to ensure that all of the acid was removed. Due to the variation in time required to demineralize different samples, the samples that finished demineralization first were processed then stored in deionized water at approximately 2˚C until all of the samples were demineralized and rinsed.

At this point the deionized water was removed and replaced with a pH 3 solution of deionized water and hydrochloric acid (0.001M HCl). A twist-off cap was then placed on the tubes and they were put into a block heater at 70˚C for 48 hours. The tubes were placed in the center of the block and covered with tin foil to insulate the tubes. Following this the samples were filtered using a fluted paper filter funnel and the remaining fluid was transferred to plastic screw top test tubes and frozen in a standard freezer. Once the samples were frozen they were moved to a -80˚C freezer for at least two hours to ensure that they were completely frozen. They were then placed in a freeze dryer for 48 hours to remove the water from the samples.

When the water was removed leaving only the collagen, the resultant samples appeared light yellow in color with a fibrous, fluffy texture similar to cotton candy. Next, approximately 1.2mg samples of collagen were placed into tin cups which were then

crimped closed in preparation for transfer to the mass spectrometer. The samples were then run through a mass spectrometer using the $CO_2$DIL65 method.

Dental Enamel Preparation and Analysis

Samples of enamel from 14 individuals were also tested. One purpose of testing enamel was to see if there was a difference in diet between subadults and adults at Kichpanha. Another reason for testing both collagen from long bones and hydroxyapatite from tooth enamel is that the carbon used in the formation of collagen is thought to come mostly from the protein in an individual's diet, whereas hydroxyapatite is thought to represent the whole diet. This is because amino acids (the building blocks of proteins) are preferentially used in collagen synthesis even though the enzymes necessary for collagen synthesis using non-essential amino acids are present in the cells. The result is that the other organic components of the diet (carbohydrates and lipids) are underrepresented in bone collagen. It is believed that the presence of exogenous amino acids deactivates enzymes necessary for endogenous synthesis and that this is less of a problem when studying populations with low protein diets such as agricultural populations relying heavily on C4 vegetation (Schwarcz 2000: 189). While it is expected that the Kichpanha population falls into the category of a population highly dependent on C4 vegetation with a low protein intake, it is worth testing both materials and assessing any similarities or differences between the information provided by the two materials. It should be noted that the values from bone collagen and teeth cannot simply be compared as tooth enamel tends to have a much higher concentration of $^{13}C$ then does bone collagen (Dupras and Tocheri 2007).

The third molar was chosen as the tooth from which to draw samples because it is the last to develop and provides information about an individual's diet in late childhood. Crown formation of the third molar takes place between the ages of nine and 13 years (Ubelaker 1989). Other teeth, which develop earlier, may reflect both the diet of the child and that of the mother since enamel formation of the other teeth may overlap with a child's period of nursing. First, the outside surface of the tooth was cleaned by removing a very small amount of the outer layer of enamel with a Dremmel tool. Then, for each tooth approximately 3.5mg of enamel was removed using the Dremmel tool, being careful not to include any dentin, and collected in tin foil. This is slightly more than is required for testing; however, it allowed for some loss during processing. The samples were then placed in 1ml test tubes and soaked in 0.1M acetic acid for ten minutes to remove diagenetic carbonates. The samples were then rinsed three times with deionized water. Next, most of the water was removed and the samples were placed in a drying rack until completely dry. The dried samples were then soaked in 85% phosphoric acid ($H_3PO_4$) at 25˚C for approximately 18 hours to produce CO2 gas. The gas was then analyzed with a mass spectrometer to determine the $\delta^{13}C$ values.

These methods provided data in the form of $\delta^{13}C$ values for each sample that allowed me to observe the diet at Kichpanha from the Preclassic through the Terminal Classic. This data along with a comparative data set consisting of published Maya isotope data is presented in the next chapter.

# CHAPTER 4

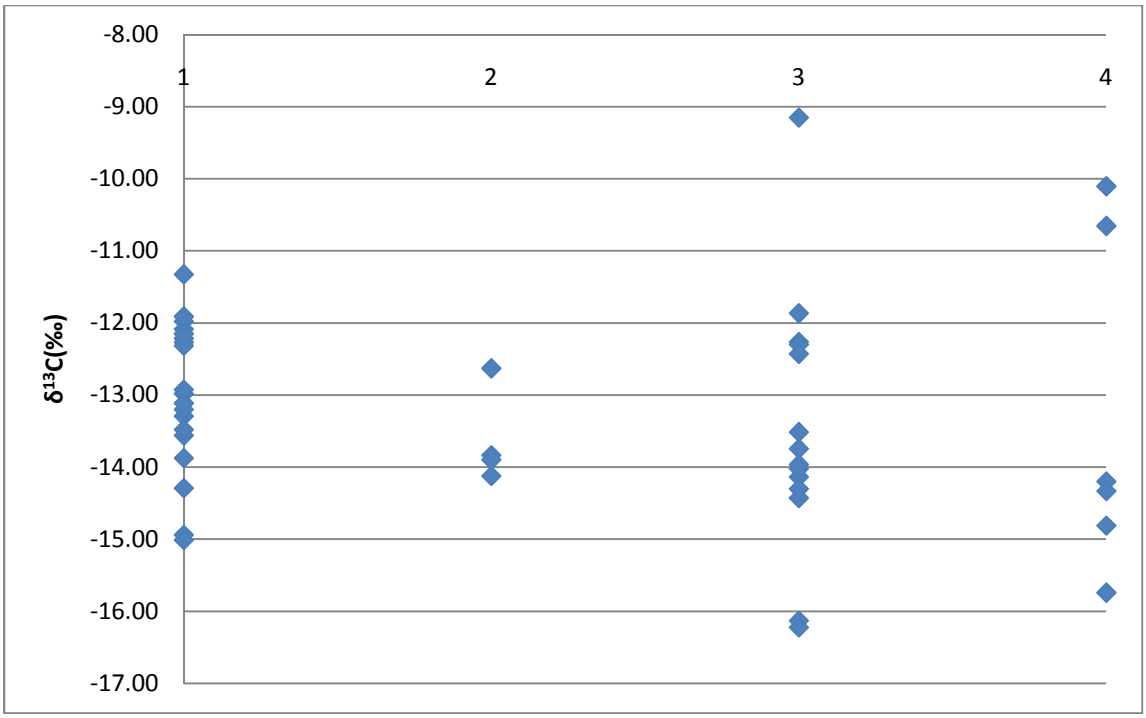
# STABLE ISOTOPE DATA FOR KICHPANHA AND A COMPILED DATA SET FROM PUBLISHED MAYA ISOTOPE STUDIES

The purpose of this study is to look at maize consumption at Kichpanha. I have collected and analyzed stable carbon isotope data from collagen extracted from leg bones of 42 individuals. Also, stable carbon isotope ratios were determined for 20 individuals based on carbonate extracted from bioapatite in the enamel of their third molars. Due to differences in the formation processes of bone collagen and enamel, the data for each material type can be compared to that presented for other Maya sites to provide a more complete picture of the diet of my sample population. Collagen and enamel stable carbon isotope data have been analyzed both for changes or trends within my sample population, and compared with values and trends reported for other Mayan sites.

While taphonomy has had a strong impact on the physical integrity of the remains recovered from Kichpanha, there is no evidence that diagenesis has altered the chemical makeup of the remains. A non-random sample of the individuals included in the collagen part of this study was analyzed for diagenesis. The sample is non-random because I wanted to test bones that would cover the range of physical degradation present in the skeletal population. In order to do this I looked at the carbon to nitrogen ratio found in the collagen recovered from these subjects. All of the samples tested for diagenesis proved negative. The carbon to nitrogen ratios all fell within the normal human range of

2.9 – 3.6. It is generally assumed that if the carbon to nitrogen ratio falls within this range no significant diagenesis has occurred and the collagen has remained intact (Wright 2006: 85). No similar test has yet been developed to test enamel (Metcalfe 2009); however, enamel is a very hard substance with no pores or Haversian canals and should be relatively resistant to digenetic changes (Lee-Thorp 2000:92-93). Therefore, if diagenesis has not affected the bone collagen in the Kichpanha sample, it seems unlikely that the enamel has been affected.

Of the 42 individuals whose collagen I was able to analyze, 18 lived during the Preclassic period (300 BCE – 250 CE), four lived during the Early Classic period (250 CE – 600 CE), 14 lived during the Late Classic Period (600 CE – 800 CE), and six lived during the Terminal Classic and Postclassic periods. The average $\delta^{13}C$ for the Preclassic sample is -13.0‰ with a range of -11.3‰ to -15.0‰ and a standard deviation of 1.0. The Early Classic sample, which is small, is also tightly clustered. The average $\delta^{13}C$ for this population is -13.6‰ with a range of -12.6‰ to -14.1‰ and a standard deviation of 0.67. For the Late Classic sample the average $\delta^{13}C$ is -13.5‰ with a range of -9.2‰ to -16.2‰ and a standard deviation of 1.8. The Terminal and Postclassic sample has an average $\delta^{13}C$ of -13.3‰ with a range of -10.1‰ to -15.7‰ and a standard deviation of 2.3.

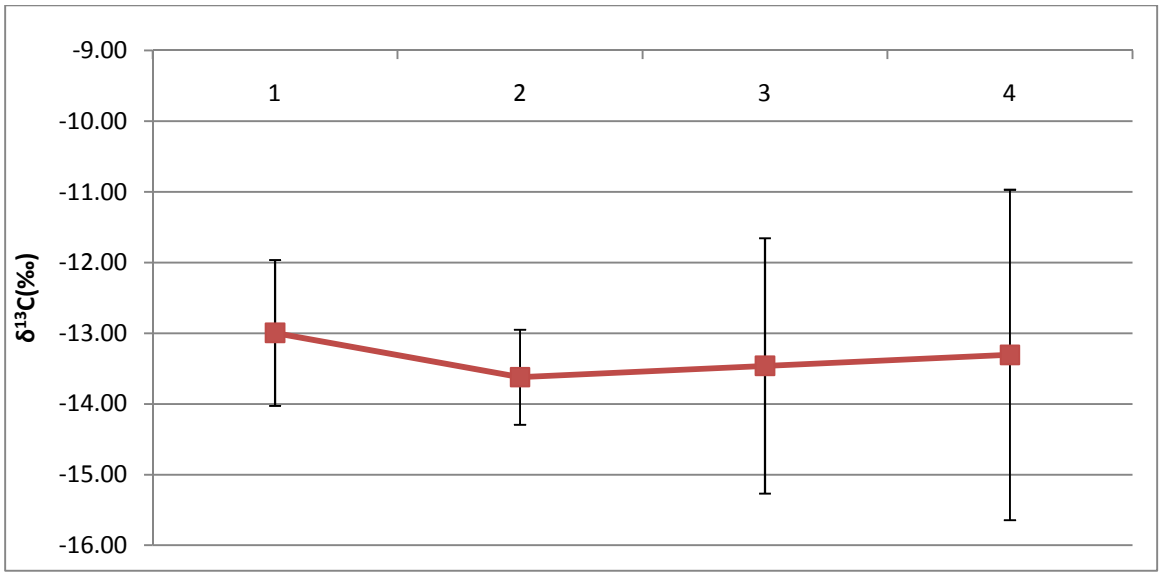



1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic/ Postclassic

Figure 4.1 Distribution of $\delta^{13}C$ Values for Collagen at Kitchpanha by Time Period

Table 4.1 Average $\delta^{13}C$ Values from Bone Collagen for a Sample Population from Kichpanha

| **Kichpanha** | Preclassic | Early Classic | Late Classic | Terminal/Postclassic |
|---|---|---|---|---|
| avg. $\delta^{13}C$ (‰) | -13.0 | -13.6 | -13.5 | -13.3 |
| st. dev. | 1.0 | 0.7 | 1.8 | 2.3 |
| n | 18 | 4 | 14 | 6 |




1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic/ Postclassic

Figure 4.2 Average $\delta^{13}C$ for Bone Collagen by Time Period at Kichpanha

I have also compiled the stable carbon isotope data for other Mayan sites which have been previously published.

Table 4.2 Average $\delta^{13}C$ (‰) Values from Bone Collagen for Nineteen Maya Sites

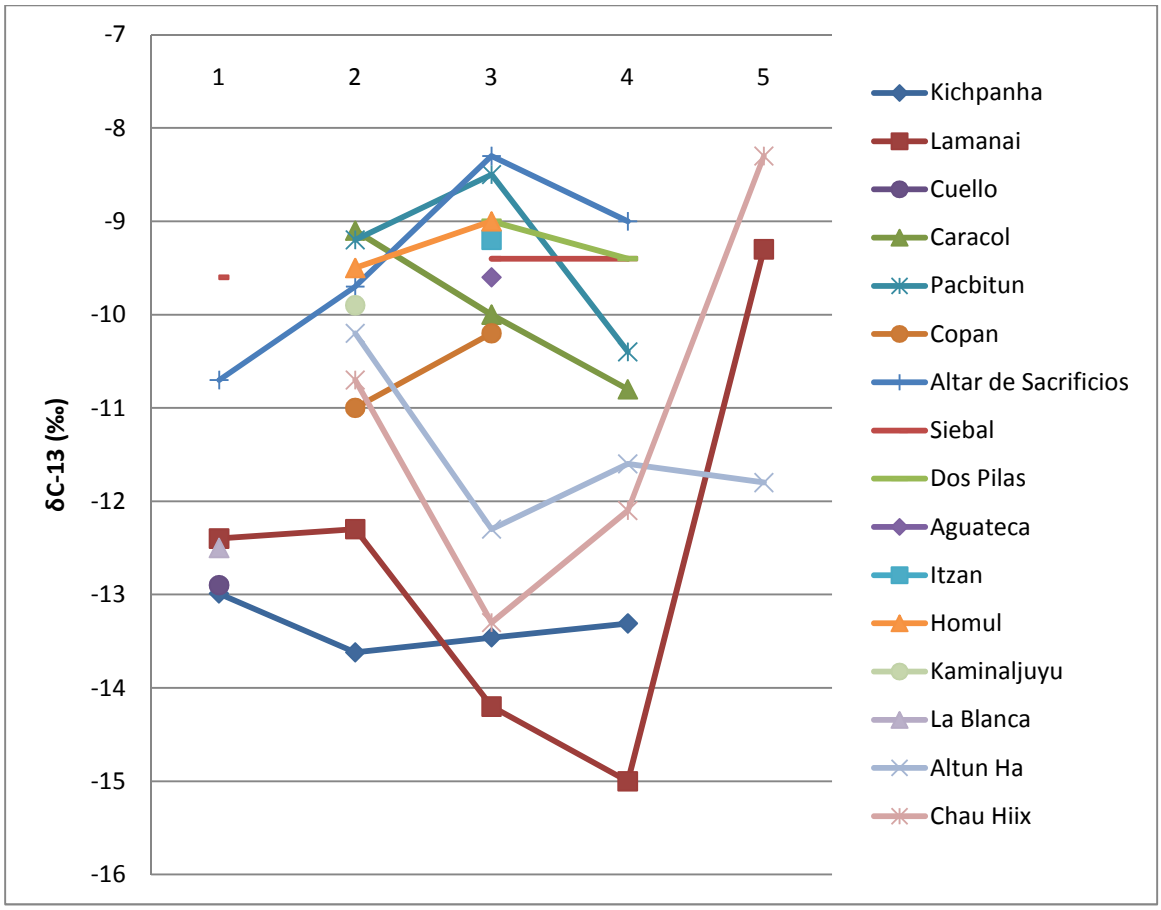
| **Lamanai** | | | | | |
|---|---|---|---|---|---|
| Time Period | Preclassic | Early Classic | Late Classic | Terminal Classic | Postclassic |
| avg. $\delta^{13}C$ (‰) | -12.4 | -12.3 | -14.2 | -15 | -9.3 |
| n | 5 | 2 | 5 | 6 | 50 |
| **Caracol** | | | | | |
| Time Period | | Early Classic | Late Classic | Terminal classic | |
| avg. $\delta^{13}C$ (‰) | | -9.1 | -10 | -10.8 | |
| n | | 8 | 72 | 5 | |
| **Barton Ramie** | | | | | |
| Time Period | | Early Classic | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | -11.4 | -11.2 | | |
| n | | 7 | 31 | | |
| **Cuello** | | | | | |
| Time Period | Preclassic | | | | |
| avg. $\delta^{13}C$ (‰) | -12.9 | | | | |
| n | 28 | | | | |
| **Pacbitun** | | | | | |
| Time Period | | Early Classic | Late Classic | Terminal Classic | |
| avg. $\delta^{13}C$ (‰) | | -9.2 | -8.5 | -10.4 | |
| n | | 1 | 3 | 26 | |
| **Pacbitun** | | 300CE - 550CE | 550CE – 700CE | 700CE – 900CE | |
| Time Period | | tzul | coc | Tzib | |
| avg. $\delta^{13}C$ (‰) | | -9.17 | -8.34 | -8.75 | |
| n | | 1 | 3 | 3 | |
| **Copan** | | | | | |
| Time Period | | Early Classic | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | -11.0 | -10.2 | | |
| n | | 2 | 39 | | |
| **Copan** | | 400CE – 800CE | | 800CE-950CE | |
| Time Period | | Acbi /Early Coner | | Late Coner | |
| avg. $\delta^{13}C$ (‰) | | -9.1 | | -9.4 | |
| n | | 5 | | 18 | |

Table 4.2 Average $\delta^{13}C$ (‰) Values from Bone Collagen for Nineteen Maya Sites, ctd.

| **Altar de Sacrificios** | | | | | |
|---|---|---|---|---|---|
| Time Period | Preclassic | Early Classic | Late Classic | Terminal Classic | |
| avg. $\delta^{13}C$ (‰) | -10.7 | -9.7 | -8.3 | -9.0 | |
| n | 9 | 6 | 7 | 16 | |
| **Seibal** | | | | | |
| Time Period | Preclassic | | Late Classic | Terminal Classic | |
| avg. $\delta^{13}C$ (‰) | -9.6 | | -9.4 | -9.4 | |
| n | 7 | | 11 | 16 | |
| **Dos Pilas** | | | | | |
| Time Period | | | Late Classic | Terminal Classic | |
| avg. $\delta^{13}C$ (‰) | | | -9.0 | -9.4 | |
| n | | | 14 | 4 | |
| **Aguateca** | | | | | |
| Time Period | | | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | | -9.6 | | |
| n | | | 8 | | |
| **Itzan** | | | | | |
| Time Period | | | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | | -9.2 | | |
| n | | | 5 | | |
| **Homul** | | | | | |
| Time Period | | Early Classic | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | -9.5 | -9.0 | | |
| n | | 18 | 4 | | |
| **Uaxactun** | | | | | |
| Time Period | | | Late Classic | | |
| avg. $\delta^{13}C$ (‰) | | | -10.7 | | |
| n | | | 6 | | |
| **Iximche** | | | | | |
| Time Period | | | | | Postclassic |
| avg. $\delta^{13}C$ (‰) | | | | | -7.8 |
| n | | | | | 43 |

Table 4.2 Average $\delta^{13}C$ (‰) Values from Bone Collagen for Nineteen Maya Sites, ctd.

| | | | | | |
|---|---|---|---|---|---|
| **Kaminaljuyu** | | | | | |
| Time Period | | Early Classic | | | |
| avg. $\delta^{13}C$ (‰) | | -9.9 | | | |
| n | | 96 | | | |
| **La Blanca** | | | | | |
| Time Period | Preclassic | | | | |
| avg. $\delta^{13}C$ (‰) | -12.5 | | | | |
| n | 3 | | | | |
| **Altun Ha** | | | | | |
| Time Period | | Early Classic | Late Classic | Terminal Classic | Postclassic |
| avg. $\delta^{13}C$ (‰) | | -10.2 | -12.3 | -11.6 | -11.8 |
| n | | 7 | 20 | 5 | 5 |
| **Chau Hiix** | | | | | |
| Time Period | | | Late Classic | Terminal Classic | Postclassic |
| avg. $\delta^{13}C$ (‰) | | | -13.3 | -12.1 | -8.3 |
| n | | | 1 | 15 | 5 |

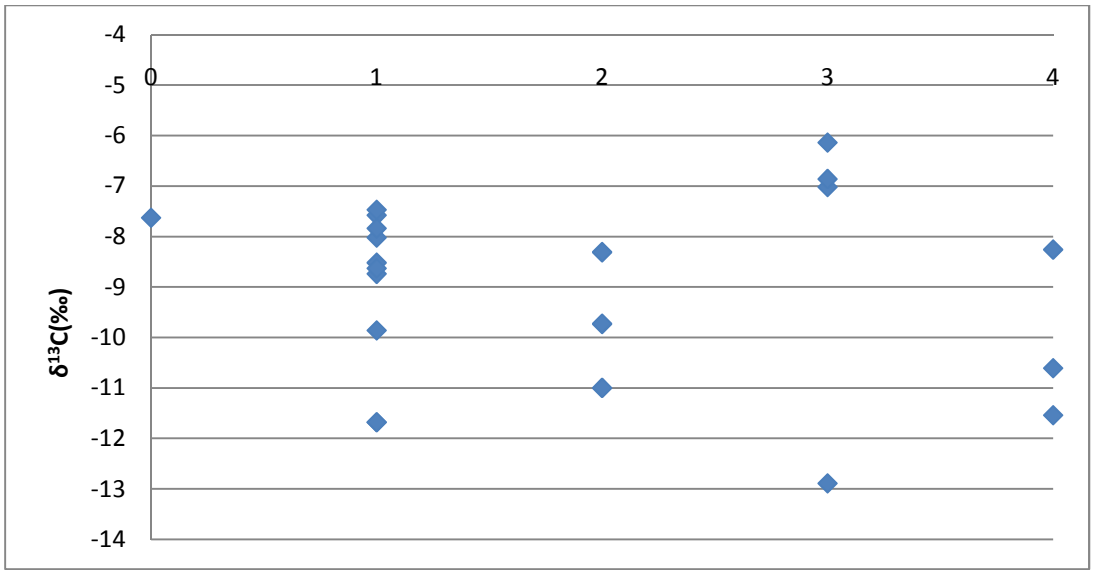



1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic
5 = Postclassic
For Kichpanha Terminal and Postclassic have been combined

Figure 4.3 Comparative Bone Collagen $\delta^{13}C$ Data for Sixteen Maya Sites

Of the 20 individuals whose dental enamel was analyzed, ten lived during the Preclassic time period, three lived during the Early Classic period, four lived during the Late Classic period, and three lived during the Post Classic. The values of the $\delta^{13}C$ data collected from dental enamel suggest that the diet of the inhabitants of Kichpanha may have changed slightly over time in a way that was not reflected in the $\delta^{13}C$ data derived from bone collagen. However, small sample sizes and fairly large standard deviations

within each time period makes these data difficult to interpret. The Preclassic sample is the largest consisting of ten individuals. The average $\delta^{13}C$ value for the Preclassic is -9.0‰ with a range from -7.5‰ to -11.7‰ and a standard deviation of 1.6. The Early Classic sample only consists of three individuals. The average $\delta^{13}C$ for the Early Classic is -9.7‰ with a range from -8.3‰ to -11.0‰ and a standard deviation of 1.4. The Late Classic sample consists of four individuals. The average $\delta^{13}C$ for this sample is -8.2‰ with a range from -6.1‰ to -12.9‰ and a standard deviation of 3.1. In the Late Classic sample there is one extreme outlier (burial 14 from Operation 1001/I) with a $\delta^{13}C$ value of -12.9‰. If this individual is removed from the sample the resulting average $\delta^{13}C$ is -6.7 ‰ with a range from -6.1‰ to -7.0‰ and a standard deviation of 0.5. The Terminal Classic sample consists of three individuals. The average $\delta^{13}C$ for this sample is -10.1‰ with a range from -8.3‰ to -11.5‰ and a standard deviation of 1.7.

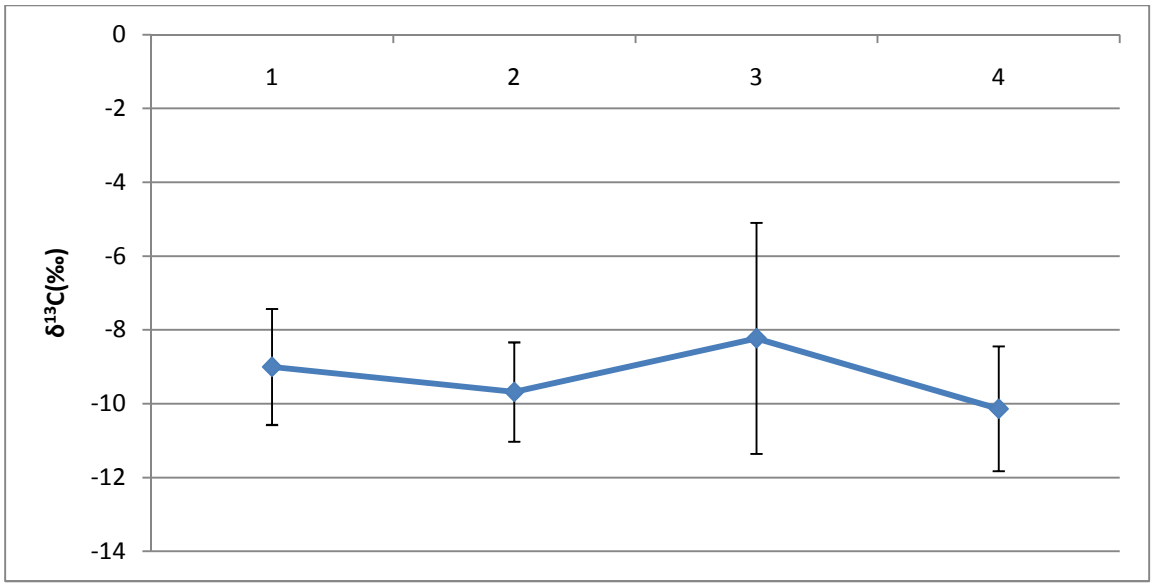



1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic

Figure 4.4 Distribution of $\delta^{13}C$ Values for Third Molar Dental Enamel at Kichpanha

Table 4.3 Average $\delta^{13}C$ Values from Dental Enamel for a Sample Population from Kichpanha

| | Preclassic | Early Classic | Late Classic | Terminal Classic |
|---|---|---|---|---|
| **Kichpanha** | | | | |
| avg. $\delta^{13}C$ (‰) | -9.0 | -9.7 | -8.3 | -10.1 |
| st. dev. | 1.6 | 1.3 | 3.1 | 1.7 |
| n | 10 | 3 | 4 | 3 |



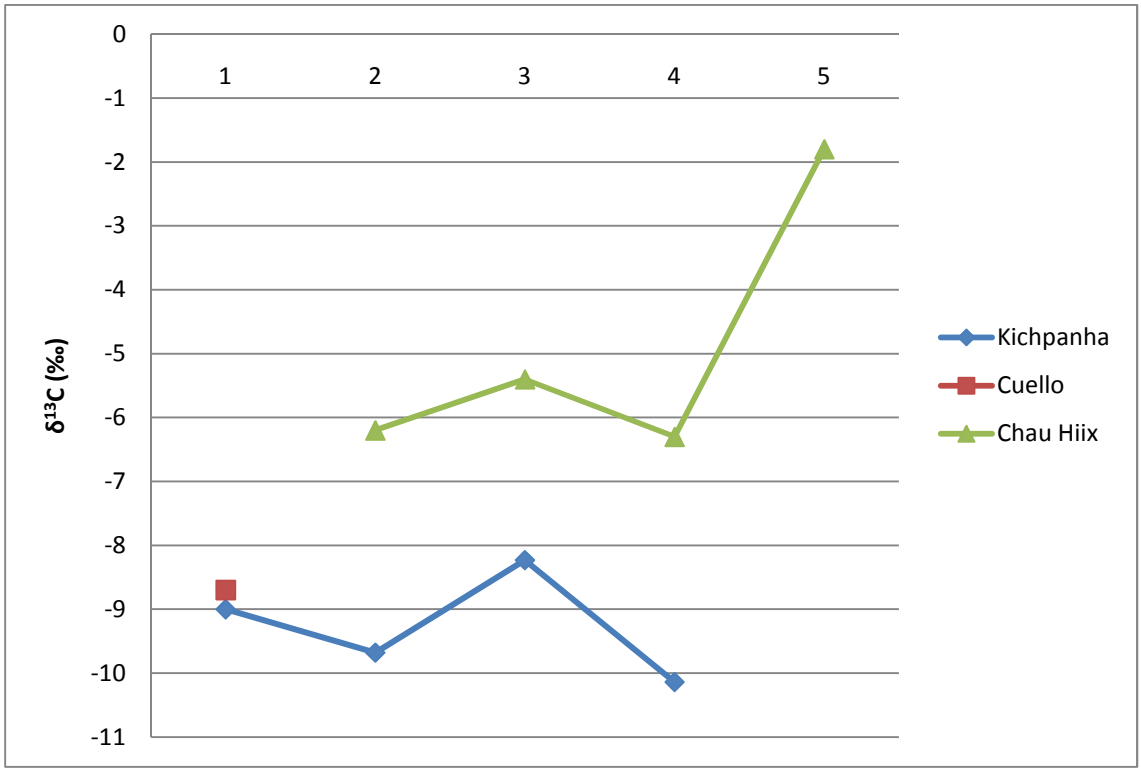

1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic

Figure 4.5 Average $\delta^{13}C$ Values for Third Molar Dental Enamel at Kichpanha by Time Period

I have also obtained the $\delta^{13}C$ data extracted from dental enamel from Cuello (Tykot et al. 1996) and Chau Hiix (Metcalf et al. 2009) to compare with that from Kichpanha. Coyston and colleagues also published $\delta^{13}C$ values for dental enamel from Pacbitun and Lamanai; however, the sample sizes are so small that they are not included here. Only four individuals from Pacbitun and five individuals from Lamanai were analyzed and they were spread across all time periods and the researchers were unable to be consistent in their choice of teeth due to the small dental sample (Coyston et al. 1999).

Table 4.4 Average $\delta^{13}C$ Values from Dental Enamel for Cuello and Chau Hiix

| | Preclassic | Early Classic | Late Classic | Terminal Classic | Postclassic |
|---|---|---|---|---|---|
| **Cuello** | | | | | |
| avg. $\delta^{13}C$ (‰) | -8.7 | | | | |
| n | 33 | | | | |
| **Chau Hiix** | | | | | |
| avg. $\delta^{13}C$ (‰) | | -6.2 | -5.4 | -6.3 | -1.8 |
| n | | 1 | 2 | 15 | 5 |




1 = Preclassic
2 = Early Classic
3 = Late Classic
4 = Terminal Classic
5 = Postclassic

Figure 4.6 Comparing $\delta^{13}C$ Data from Dental Enamel from Three Maya Sites

Initial observation of the data described above shows that Kichpanha had a relatively stable diet throughout the history of the site and that the diet at Kichpanha was different than most of the other Mayan sites previously analyzed. In the next chapter this information is analyzed for indications of change in the diet at Kichpanha over time, differences in diet between upper and lower class individuals, differences in dietary trends over time for subadults and adults, and a comparison of the data from Kichpanha and other Mayan sites is made.

# CHAPTER 5

# A DISCUSSION OF THE ISOTOPIC DATA FROM KICHPANHA

In this chapter I will discuss the $\delta^{13}C$ data collected from the Kichpanha skeletal sample. I use these data to look at trends in diet over time at Kichpanha, to compare the diets of upper class individuals versus that of commoners, to determine if trends seen in the adult diet match those seen in the subadult diet at Kichpanha, and to compare the diet at Kichpanha to other Maya sites.

## Temporal Trend

When looking at the collagen $\delta^{13}C$ data for Kichpanha it appears that diet remained stable at the site throughout its history. From the Preclassic through the Terminal/ Postclassic very little difference is seen in the data and there is not enough change to conclude that there was any change in diet. There is a small decline in $\delta^{13}C$ values from the Preclassic to the Early Classic; however, only four individuals from the Early Classic period were analyzed in this study and the difference in isotope value between these two time periods is not statistically significant. In fact, t-tests were used to compare the samples from each time period and there were no statistically significant differences in the $\delta^{13}C$ values of collagen between the sample populations from any of the time periods at Kichpanha. The standard deviations within the data for the Preclassic and Early Classic samples are relatively small (1.03 and 0.67 respectively) and increase

in the Late Classic and Terminal/ Postclassic (1.81 and 2.34 respectively). This result is surprising because during the Preclassic and Early Classic time periods at Kichpanha, a stronger class distinction is evident (Shaw 1995a) which I would expect to result in a larger range of variation in diet between individuals. I expected that the $\delta^{13}C$ data from these time periods would show that upper class individuals were consuming more difficult to acquire foods and less maize.

Social Status

While it is often difficult to identify social distinctions in the archaeological record, there are two individuals in particular from the Preclassic population at Kichpanha whose burial treatment seems to indicate that they were important people. One individual was recovered as a primary interment (Operation 3003 burial 4) accompanied by at least four secondary interments, two of which had identifiable femora which were analyzed for this study.

Table 5.1 Stable Isotope Data for Three Individuals from a Single Preclassic Burial (Operation 3003 burial 4) at Kichpanha

| | Primary Interment | Secondary Interment | Secondary Interment |
|---|---|---|---|
| Femoral Collagen $\delta^{13}C$ (‰) | -13.3 | -12.3 | -12.2 |
| Dental Enamel $\delta^{13}C$ (‰) | -9.9 | - | - |

The $\delta^{13}C$ value for the bone collagen of the primary individual is -13.3‰ which is slightly lower than the average of -13.0‰ for the time period, but well within the

standard deviation of 1.0. When comparing the $\delta^{13}C$ for the primary burial versus the secondary interments, both secondary interments have $\delta^{13}C$ signatures which are higher than the primary interment. Their $\delta^{13}C$ values are -12.3‰ and -12.2‰. No dental remains could be positively identified for either of the femurs representing the secondary interments so comparing these individuals must rely entirely on the collagen data. Based on these data it I feel that the primary individual probably ate slightly less maize than the two secondary individuals and possibly ate more freshwater fish, snails, and $C_3$ plants. The practice of burying an elite individual with secondary interments was common among the Maya, but explaining the tradition is difficult. It is possible that the secondary burials are sacrificial victims or ancestors of the primary individual. Leslie Shaw suggests that at Kichpanha the latter possibility is the most probable, that families contending for status within Kichpanha included deceased ancestors in burials as a way of exhibiting their history and importance in the community (Shaw 1995b). The $\delta^{13}C$ value for this individual's dental enamel is -9.9‰. Again, it is somewhat lower than the -9.0‰ average for the Preclassic time period, but not an outlier (the standard deviation is 1.57).

A second higher status burial (Operation 3003 burial 1) also dates to the Preclassic and includes a primary burial with 13 secondary interments, five of which had identifiable femora that were analyzed in this study.

Table 5.2 Stable Isotope Data for Femoral Collagen from Six Individuals from a Single Preclassic Burial (Operation 3003 burial 1) at Kichpanha

| | Primary Interment | Secondary Interment | Secondary Interment | Secondary Interment | Secondary Interment | Secondary Interment |
|---|---|---|---|---|---|---|
| Femoral Collagen $\delta^{13}C$ (‰) | -13.0 | -12.1 | -12.3 | -15.0 | -13.2 | -12.2 |

In this case the $\delta^{13}C$ value for the collagen of the primary burial is right at the average for the time period. Its $\delta^{13}C$ value is -13.0‰ which also places it right in the middle of the individuals included in the burial whose values range from -12.1‰ to -15.0‰ (the second lowest $\delta^{13}C$ value within this burial is -13.2‰). The fact that one of the secondary burials has a $\delta^{13}C$ value of -15.0‰ is interesting because it is not just the lowest $\delta^{13}C$ value in this burial, but the lowest value for any individual from the Preclassic population of Kichpanha and the fourth lowest of all of the individuals analyzed in this study. This suggests that this individual's diet was particularly high in protein derived from freshwater resources such as fish and snails, as well as terrestrial animals which fed on $C_3$ plants. This seems to support Shaw's assertion that the secondary interments were ancestors of the primary individual and not sacrificial victims. Unfortunately, dental data is available for only four of the secondary interments, and it cannot be determined which teeth go with which long bones due to poor preservation and the manner in which the secondary individuals were interred. That being said, the dental values for all those interred in this burial range from -7.5‰ to -8.7‰ with the primary burial again falling right in the middle with a value of -8.0‰. This range is slightly higher than the average for the Preclassic population as a whole suggesting that these individuals may have consumed a greater than average amount of maize, but an average

amount of protein (besides the one secondary individual with the particularly low collagen $\delta^{13}C$ signature).

Table 5.3 Stable Isotope Data for Dental Enamel Hydroxyapatite from Five Individuals from a Single Preclassic Burial (Operation 3003 burial 1) at Kichpanha

| | Primary Interment | Secondary Interment | Secondary Interment | Secondary Interment | Secondary Interment |
|---|---|---|---|---|---|
| Dental Enamel $\delta^{13}C$ (‰) | -8.0 | -8.7 | -8.6 | -7.6 | -7.5 |

While a sample of two individuals cannot be considered conclusive, these results suggest that the diet of high status individuals was the same or very similar to the rest of the population at Kichpanha.

Age

$\delta^{13}C$ values derived from bone collagen should not be compared directly to $\delta^{13}C$ values derived from dental enamel. This is because the $\delta^{13}C$ signature of bone collagen largely reflects protein in the diet, while the $\delta^{13}C$ signature of bioapatite in dental enamel closer is representative of an individual's diet as a whole. Therefore, anyone consuming maize will have a lower $\delta^{13}C$ bone collagen signature than $\delta^{13}C$ dental enamel signature because the carbohydrate portion of the diet shows up more pronounced in dental enamel than in bone collagen. However, these data are useful in that I can compare the trends in the two types of data. These trends can provide some insight into the difference between the diets of adults and children at Kichpanha. Also, to avoid overstating the difference between the data provided by the two material types it should be noted that changes in any part of the diet (protein, carbohydrate, or lipid) are reflected in the $\delta^{13}C$ values of

both bone collagen and enamel bioapatite, but changes in protein have a much greater effect on the $\delta^{13}C$ signature of bone collagen than do changes in carbohydrates and lipids. On the other hand, changes in carbohydrate, lipid, or protein sources seem to affect the $\delta^{13}C$ signature of the bioapatite in dental enamel equally (Ambrose and Norr 1993). This is because the carbonate in bioapatite is derived from $CO_2$ in the blood which is produced as a byproduct of cellular energy metabolism. Nearly all dietary macronutrients are used in energy metabolism; therefore, the $\delta^{13}C$ signature of bioapatite should reflect the overall $\delta^{13}C$ value of an individual's diet (Ambrose et al. 2003).

When looking at the trends over time for the $\delta^{13}C$ values from bone collagen and dental enamel from the sample from Kichpanha the trends from the Preclassic through the Late Classic are very similar. All values are fairly low suggesting that $C_4$ plants did not make up an overwhelming proportion of the diet. In both bone collagen and dental enamel, $\delta^{13}C$ values decline between the Preclassic and Early Classic, then increase during the Late Classic. A difference in the trends shows that during the Late Classic the $\delta^{13}C$ value for dental enamel exceeds that of the Preclassic, while the increase in the $\delta^{13}C$ value for bone collagen between the Early Classic and Late Classic is smaller than the decrease that occurred between the Preclassic and Early Classic. While the recovered Early Classic skeletal sample from Kichpanha is small and my sample of dental enamel is fairly small for the Late Classic, the fact that the values are so similar increases my confidence in drawing conclusions based on these data. What I believe these data suggest is that maize was more important in the diet of subadults at Kichpanha during the Preclassic and Late Classic than during Early Classic. Somewhat less certain, but possible, is that maize was more important in children's diets during the Late Classic than

the Early Classic. The bone collagen data suggest a similar trend, but because protein has a greater influence on the $\delta^{13}C$ values of bone collagen than carbohydrate, changes in carbohydrate consumption are tempered in their translation into bone collagen. While I am hesitant to draw any conclusions about the relative importance of maize in subadult and adult diets at Kichpanha, trends in maize consumption from the Preclassic through late Classic are very similar.

Interestingly, there is a divergence in the trends during the Terminal/Postclassic. During the Terminal/Postclassic, $\delta^{13}C$ values for dental enamel drop fairly sharply to their lowest level (-10.1‰), while $\delta^{13}C$ values for bone collagen rise slightly (from -13.5‰ during the Late Classic to -13.3‰ in the Terminal/ Postclassic) during this time period. These data could imply that maize consumption decreased for children during the Terminal/Postclassic, but may have remained steady for adults. This decrease in maize consumption in children may have been compensated for with an increase in protein consumption or in $C_3$ plant consumption. Determining which of these possibilities is more likely cannot be determined with the current data. Possibly testing nitrogen isotopes from the enamel could shed more light on this question; however, that is outside the scope of the present study.

Comparing Kichpanha to other Maya Sites

When comparing the $\delta^{13}C$ values from Kichpanha to the other published Mayan stable isotope studies it is immediately obvious that the diet at Kichpanha was significantly different from most of the other skeletal collections analyzed. Of the 16 sites included in this comparative data set only six (besides Kichpanha ) have, for any

time period, an average $\delta^{13}C$ for bone collagen below -12.0‰ and only two have an average $\delta^{13}C$ for any time period below -13.0‰ (Table 4.4 and Figure 4.4). Also, during the Late Classic and Terminal Classic, only Laminai has lower average $\delta^{13}C$ values than Kichpanha. What this indicates is that the residents of Kichpanha were probably consuming less maize than most other people in the Maya Empire. During the Preclassic time period, the sites with $\delta^{13}C$ values most similar to Kichpanha are Cuello, La Blanca, and Laminai. Kichpanha has the lowest $\delta^{13}C$ values of any of these sites, but the difference between Kichpanha and Cuello is very small, and Laminai and La Blanca are within 1‰ of the values shown for Kichpanha. This would suggest that the diet at Cuello and Kichpanha were very similar and there was little difference between those two sites and Lamanai and La Blanca. The only other sites where Preclassic populations were analyzed are Altar de Sacrificios and Seibal which have $\delta^{13}C$ values of -10.7‰ and -9.6‰ respectively. These values are both much higher than Kichpanha's average $\delta^{13}C$ value of -13.0‰.

During the Early Classic time period the average $\delta^{13}C$ for Kichpanha drops to -13.6‰ while Lamania's average $\delta^{13}C$ rises slightly from -12.4‰ to -12.3‰ (although the Early Classic sample at Laminai only includes two individuals). While many other Early Classic Mayan populations have been analyzed, no other site has values anywhere near as low as that found at Kichpanha. Unfortunately there are no data from Cuello or La Blanca for the Early Classic time period.

As I've stated previously, between the Early and Late Classic time periods the mean $\delta^{13}C$ of bone collagen rose slightly at Kichpanha from -13.6‰ to -13.5‰. Pacbitun, Altar de Sacrificios, Copan, and Homul also experienced changes in diet

resulting in an increase in average $\delta^{13}C$ from the Early to the Late Classic time period. However, all of those sites have $\delta^{13}C$ values much higher than that of Kichpanha and their increases in $\delta^{13}C$ are much greater. This would indicate that while the changes may have been similar, either an increase in C4 plant consumption or in animals that consumed C4 plants, their actual diets were very different. The sites with similar $\delta^{13}C$ values to Kichpanha for the Late Classic Time Period are Laminai, Chau Hiix, and Altun Ha, which also all happen to be in modern day Belize and are relatively close geographically. This suggests that the diets at these four sites were relatively similar during this time period. Interestingly, Laminai, Chau Hiix, and Altun Ha all had marked decreases in $\delta^{13}C$ between the Early and Late Classic, while the carbon isotope values at Kichpanha were relatively stable. In fact, all three of these sites appear to have had very volatile subsistence changes throughout their histories, while Kichpanha remained very stable.

When analyzing the data from Kichpanha I combined the Terminal and Post classic populations. I did this because both samples were small (two Terminal Classic individuals and four Postclassic individuals), there is no archaeological evidence that populations or lifestyles changed at Kichpanha during these time periods, and the isotopic data for both time periods is very similar.

When comparing this Terminal/Postclassic population to other Mayan sites there is no site with a similar $\delta^{13}C$ for either the Terminal Classic or Postclassic time period. Diet at Kichpanha again remained stable with only a very slight increase in $\delta^{13}C$ from -13.5‰ in the Late Classic to -13.3‰ in the Terminal/Postclassic. At Laminai the $\delta^{13}C$ values for bone collagen continue to drop off between the Late Classic and Terminal

Classic from -14.2‰ to -15.0‰. Then, during the Postclassic Laminai underwent an extreme change in diet which resulted in the $\delta^{13}C$ rising from -15.0‰ to -9.3‰. Chau Hiix also experienced a rather extreme change in diet between the Late Classic and Postclassic. From the Late Classic to Terminal Classic, Chau Hiix's average $\delta^{13}C$ rose from 13.3‰ to -12.1‰. Then, during the Postclassic, their average $\delta^{13}C$ rose again to -8.3‰ suggesting a large increase in maize consumption most likely associated with a decrease in protein and $C_3$ plant consumption. At Altun Ha, diet changes also resulted in rising $\delta^{13}C$ values; however the changes were much more modest than at either Laminai or Chau Hiix. At Altun Ha the average $\delta^{13}C$ rose from -12.3‰ during the Late Classic to -11.6‰ during the Terminal Classic. Then, during the Postclassic there was a slight decline in average $\delta^{13}C$, down to -11.8‰. I interpret the changes in average $\delta^{13}C$ during the Terminal and Postclassic time periods at Laminai, Chau Hiix, and Altun Ha as indicative of a decreased reliance on freshwater protein sources such as fish and snails, and likely an overall decrease of protein in the diet. This decrease in protein would have to be compensated for somehow, and I expect that maize made up for the loss of calories from their diet. While I previously stated that changes in carbohydrate consumption generally has a relatively small impact on the $\delta^{13}C$ of bone collagen, when protein makes up a very small proportion of the diet, changes in carbohydrate consumption is reflected to a greater extent in bone collagen (Ambrose and Norr 1993).

The only two sites with published dental data comparable to Kichpanha are Cuello and Chau Hiix. As in the comparison of $\delta^{13}C$ values from bone collagen for Kichpanha and Cuello, their average $\delta^{13}C$ values from dental enamel are very similar with Kichpanha having a slightly lower average $\delta^{13}C$ value then does Cuello. The

difference is only 0.3 ‰ (-9.0 ‰ for Kichpanha and -8.7 ‰ for Cuello) and therefore, support my previous conclusion that the diets at Kichpanha and Cuello were nearly identical during the Preclassic period. Chau Hiix has no published isotopic data for the Preclassic period.

From the Early Classic through the Terminal Classic the trend in enamel carbon isotope values at Cau Hiix is fairly similar to that seen at Kichpanha. At both sites there is an increase in the average $\delta^{13}C$ from the Early Classic to the Late Classic, then a decrease in the average $\delta^{13}C$ from the Late Classic to the Terminal Classic. However, while the trends are similar, the $\delta^{13}C$ values are not. The average enamel $\delta^{13}C$ values for all time periods are substantially lower at Kichpanha than at Chau Hiix. This indicates that $C_4$ plants, most likely maize, were much more important in the subadult diet at Chau Hiix than at Kichpanha. This is particularly interesting because during the Late Classic time period the average $\delta^{13}C$ values from bone collagen for Kichpanha and Chau Hiix are very similar, only 0.2 ‰ difference. The difference seen in their average $\delta^{13}C$ values from dental enamel for this time period is 2.8 ‰. This indicates that while the adult diets at Kichpanha and Chau Hiix were very similar during the Late Classic time period, particularly in regard to protein consumption, the childhood diets at the two sites were quite different. These values also support my previous assertion that maize was less important in the diet at Kichpanha then at other Maya sites. Unfortunately, there are not more sites with published $\delta^{13}C$ data from dental enamel comparable to Kichpanha.

# CHAPTER 6

# CONCLUSIONS REGARDING DIET AT KICHPANHA

What this study indicates is that the diet at Kichpanha was unusual among the Maya primarily due to its stability. No statistically significant difference was seen between the average $\delta^{13}C$ for either bone collagen or dental enamel bioapatite for any of the time periods represented in this study. Kichpanha also falls in the bottom of the range of $\delta^{13}C$ values for both bone collagen and dental enamel bioapatite for all Maya sites. This suggests that the inhabitants of Kichpanha ate less maize and more aquatic resources then the inhabitants of most other Maya sites through most time periods. Only Laminai had a lower average $\delta^{13}C$ value than Kichpanha for any contemporary time period (only during the Late Classic and Terminal Classic).

When considering both the long bone data and the dental data from Kichpanha it appears that the subadult and adult diets at Kichpanha were very similar. Both were relatively low in maize and high in $C_3$ sources such as $C_3$ plants and the terrestrial animals which consume them, and fresh water aquatic resources such as fish, snails, and crocodilians.

Social status also appears to have had little influence on an individual's diet. The two individuals who could reliably be identified as upper class individuals had $\delta^{13}C$ values very similar to the rest of the individuals from their time period. An interesting finding from this study is that diet appears to be most varied during the Late Classic and

Terminal/ Postclassic time periods. This is counter to what I had expected. I anticipated that the diet at Kichpanha would be most varied during the Late Preclassic and Early Classic when Kichpanha had a more obviously socially stratified population.

When considering the porotic hyperostosis and enamel hypoplasia data provided by Jansen (1995), it is surprising that the $\delta^{13}C$ values for Kichpanha are so low. The high prevalence of both porotic hyperostosis and enamel hypoplasias in the Kichpanha skeletal sample suggests a nutrient poor diet and is generally assumed in Maya populations to be indicative of a diet heavily reliant on maize. However, the low $\delta^{13}C$ values for the Kichpanha sample suggest that these general indicators of stress may be the result of childhood illness (such as intestinal parasites or infectious disease) instead of a nutrient poor diet.

The trend over time in the prevalence of dental carries in the skeletal sample from Kichpanha follows roughly the same v-shaped trend as the average $\delta^{13}C$ for bone collagen. The decrease in carries rates between the Late Preclassic and Early classic coincides with a decrease in the average $\delta^{13}C$ for bone collagen. Following the Early Classic both the carries rate and the average $\delta^{13}C$ values for Kichpanha increased. However, it should be noted that the increase in caries rates was far more substantial than the change in average $\delta^{13}C$ values. This difference may be the result of a relatively small increase in maize consumption at Kichpanha following the Early Classic associated with a finer processing of maize products which would explain the very high carries rates during the Late/ Terminal Classic and the steady increase in calculus that occurred at Kichpanha from the Protoclassic through the Late/ Terminal Classic (Magennis 1999: 141-145).

While this study has provided some valuable data and insight toward the understanding of the diet of the inhabitants of Kichpanha, there is still more research that can be done on the subject to further clarify the issue. A weakness of isotopic studies is that they are expensive, and each isotope from each type of skeletal material only provides a small piece of the puzzle. I chose to analyze $\delta^{13}C$ from bone collagen largely because it was the most common type of isotopic study carried out on Mayan populations and allowed me to compare Kichpanha to a large number of other Mayan sites. However, the weakness of bone collagen $\delta^{13}C$ analysis is that $\delta^{13}C$ is primarily used to provide information about maize consumption in the New World, but collagen is better suited to provide information about protein consumption and there are many dietary variables that can complicate the interpretation of this data. I also analyzed $\delta^{13}C$ from bioapatite in dental enamel because it provided data pertaining to the subadult diet at Kichpanha and because it represents the $\delta^{13}C$ value of the entire diet weighted equally. This helped to clear up some of the inherent ambiguity in the bone collagen data, but still leaves unanswered questions.

While I conclude that the diet at Kichpanha is high in freshwater protein sources and that maize was a less important staple food at Kichpanha than at other Maya sites, further research including analyzing $\delta^{13}C$ from bone bioapatite and $\delta^{15}N$ isotopic studies could be very beneficial to understanding the diet at Kichpanha.

These studies could help determine whether the low $\delta^{13}C$ values I derived from bone collagen are really the result of high freshwater animal consumption or are the result of a heavy reliance on $C_3$ plants such as chenopods, amaranth, and/or manioc. A more detailed study of the faunal remains at Kichpanha could also help to answer this question by providing direct evidence of the types and relative abundance of faunal resources consumed at the site.

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APPENDIX

KICHPANHA CARBON ISOTOPE DATA

| **Dental Enamel** | | | | | |
|---|---|---|---|---|---|
| **Op** | **Sub-op** | **feat/bur** | **indv. #** | **Time Period** | **$\delta^{13}C$** |
| 3001 | | 6 | | Preclassic | -11.68 |
| 3011 | | 24 | | Preclassic | -8.52 |
| 3011 | | 24 | ind B | Preclassic | -11.68 |
| 3003 | | 1 | bone T | Preclassic | -8.74 |
| 3003 | | 1 | bone K (P) | Preclassic | -8.02 |
| 3003 | | 1 | bone 9 | Preclassic | -8.63 |
| 3003 | | 4 | P | Preclassic | -9.86 |
| 3003 | | 1 | bone AA | Preclassic | -7.58 |
| 3003 | | 5 | | Preclassic | -7.84 |
| 3003 | | 1 | bone 2,3 | Preclassic | -7.47 |
| 3001 | | 42 | | Early Classic | -11.00 |
| 1001 | | 26 | | Early Classic | -8.31 |
| 2000/2 | | 2 | | Early Classic | -9.73 |
| 1001 | | 15 | | Late Classic | -7.02 |
| 1001 | | 10 | | Late Classic | -6.86 |
| 1001/I | I, J | 14 | | Late Classic | -12.89 |
| 1001 | | 16 | | Late Classic | -6.14 |
| 1001-C | C | 5 | | Terminal Classic | -8.26 |
| 1001/B | B | 6 | ind A | Terminal Classic | -10.61 |
| 1001/B | B | 2 | | Terminal Classic | -11.54 |

| Bone Collagen | | | | | |
|---|---|---|---|---|---|
| **Op** | **Sub-op** | **feat/bur** | **indv. #** | **Time Period** | **$\delta^{13}C$** |
| 3003 | | 5 | | Preclassic | -14.94 |
| 3003 | | 4 | p | Preclassic | -13.29 |
| 3003 | | 4 | s3 | Preclassic | -12.27 |
| 3003 | | 4 | s5 | Preclassic | -12.21 |
| 3003 | | 1 | s1 | Preclassic | -13.20 |
| 3003 | | 1 | s4 | Preclassic | -12.08 |
| 3003 | | 1 | s6 | Preclassic | -12.32 |
| 3003 | | 1 | 3 | Preclassic | -12.98 |
| 3003 | | 1 | s1 | Preclassic | -12.15 |
| 3003 | | 1 | s2 | Preclassic | -15.01 |
| 3003 | | 2 | | Preclassic | -13.11 |
| 3003 | | 3 | | Preclassic | -14.29 |
| 3011 | | 24 | | Preclassic | -11.98 |
| 1001/C | C | 9 | | Preclassic | -12.92 |
| 3001/30 | | 49 | | Preclassic | -11.91 |
| 3001/31 | | 73 | | Preclassic | -13.56 |
| 3003B | | 28 | 1 (A) | Preclassic | -11.33 |
| 3003B | | 28 | 2 (B) | Preclassic | -13.87 |
| 3005/2 | | 4 | | Preclassic | -13.48 |
| 3001/30 | | 41 | | Early Classic | -13.83 |
| 3001/30 | | 48 | | Early Classic | -13.90 |
| 2000/2 | | 2 | | Early Classic | -14.12 |
| 1001/J | J | 26 | | Early Classic | -12.63 |
| 2002/1 | | 3 | | Late Classic | -13.74 |
| 2000/1 | | 2 | | Late Classic | -16.13 |
| 3001/42 | | 54 | | Late Classic | -14.43 |
| 3001/42 | | 55 | | Late Classic | -14.13 |
| 3001/42 | | 53 | | Late Classic | -16.22 |
| 1001 | | 25 | | Late Classic | -13.51 |
| 1001/I | I | 10 | | Late Classic | -13.96 |
| 1001/I | I, J | 14 | | Late Classic | -12.26 |
| 1001 | I | 22 | | Late Classic | -11.86 |
| 1001 | | 3 | | Late Classic | -9.15 |
| 3005 | | 1 | | Late Classic | -14.02 |
| 1001/I | I | 16 | | Late Classic | -12.30 |
| 1001/J | I, J | 12 | | Late Classic | -12.43 |
| 2002 | | 1 | | Late Classic | -14.30 |
| 1001/C | C | 2 | | Terminal Classic | -14.20 |
| 1001 | C | 5 | | Terminal Classic | -10.10 |

| Bone Collagen | | | | | |
|---|---|---|---|---|---|
| **Op** | **Subop** | **feat/bur** | **indv. #** | **Time Period** | **$\delta^{13}C$** |
| 3001/11 | | 13 | 1 | Postclassic | -14.81 |
| 3001/11 | | 13 | 2 | Postclassic | -15.74 |
| 3001/14 | | 19 | | Postclassic | -10.65 |
| 3001/9 | | 8 | | Postclassic | -14.33 |