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Maize, Meat, and Migration: Stable Isotope Analysis at Chalcatzingo, Morelos, Mexico

A Thesis submitted in partial satisfaction of the requirements for the degree

Master of Arts

in

Anthropology

by

Samantha A. Streuli

Committee in charge:

Professor Margaret Schoeninger, Chair

Professor Geoffrey Braswell

Professor Paul Goldstein

2016

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University of California, San Diego

2016

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ABSTRACT OF THE THESIS

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by

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Master of Arts in Anthropology

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Professor Margaret Schoeninger, Chair

Human social inequality is known to impact health outcomes, often through socioeconomically linked nutritional disparities. Differential access to particular types and amounts of food has been demonstrated by archaeological examinations and stable isotope analyses throughout Classic Period Mesoamerica. The results of these studies have suggested that Mesoamerican elites were granted greater access to maize and meat relative to commoners during the Classic Period. Stable oxygen isotope studies have served to further elucidate issues of migration and social interaction in Classic Period

Mesoamerica by aiding in defining marriage patterns, understanding how migration relates to social status, and identifying the geographic origins of sacrifice victims. Few studies of Pre-Classic human remains from central Mexico have employed stable isotope analyses. The present study employs stable oxygen, carbon, and nitrogen isotopes in order to understand dietary behaviors, status differences, and migration patterns at the complex Formative Period site of Chalcatzingo in Morelos, Mexico. Stable carbon and nitrogen isotope results suggest that both elites and commoners consumed large amounts of maize and similar amounts of animal protein. There was no significant difference between commoners and elites in terms of dietary behaviors. Stable oxygen isotope results differed from previously reported values for central Mexico, potentially suggesting that Chalcatzingo was a community composed of a number of migrants. There was no statistically significant difference between elites and non-elites in terms of oxygen stable isotope values. The social stratification at this site evidently did not result in substantial differences in dietary behaviors or migration patterns between elites and commoners, suggesting that factors other than socioeconomic status and archaeological evidence must be taken into account when considering how such behaviors were mediated in the past.

INTRODUCTION

Contemporary studies of the widespread social inequality that is characteristic of modern life have overwhelmingly indicated that inequality leads to disparities in both physical and mental health (Gravlee, 2009; Marmot et al., 1991; Marmot, 2005; Murali and Oyebode, 2004). One way in which social inequality influences health outcomes is through its impact on dietary behaviors, with individuals from disadvantaged groups frequently lacking access to healthy foods, lacking the education to choose those foods, or maintaining cultural preferences that put them at greater risk for consuming less healthy types of food (Adler and Newman, 2002; Horowitz et al, 2004; Lynch et al., 1997; Satia, 2009). Far from being a modern phenomenon, socioeconomic inequality was a major factor in the social organization of complex societies in Formative Period Mesoamerica (Feinman, 1995). As in modern socially stratified societies, a relationship between social status and diet has been established for socially complex ancient Mesoamerican civilizations (Emery, 2003; Gumerman, 1997; Schoeninger, 1979; Turkon, 2004).

The Formative Period site of Chalcatzingo is situated in the Valley of Morelos in central Mexico and dates to 1150-450 BCE (Grove, 1987); (Figure 1). During the Middle Formative Period (700-500 BCE), there was a significant increase in social complexity at Chalcatzingo that is evidenced by clear status differences in human burials and the construction of monumental architecture with Olmec-style bas reliefs depicting high status individuals with specially reserved roles in governance and spiritual life (Grove, 1987; Merry De Morales, 1987). This rapid increase in social complexity has been interpreted by Hirth (1978) as a product of Chalcatzingo's central location along long-

distance trade routes. The Olmec-style iconography and pottery at Chalcatzingo represent interaction with the Gulf Coast Olmec culture. The significance of this interaction in the development of social complexity has been a topic of considerable debate. Some sources suggest that the Olmec culture began at the Gulf Coast and was brought to inland Mesoamerican sites by migrating Gulf Coast elites or missionaries (Coe, 1965; Grove, 1987). Others suggest that the presence of Olmec-style artifacts and artwork at numerous sites represents a culture that was produced through cooperation among autonomous communities (Flannery and Marcus, 2000; Plunket, 2012). Social stratification at Chalcatzingo has been shown not only through the aforementioned unequal distribution of status goods in burials (Merry De Morales, 1987) but also through an early analysis of Strontium (Sr) concentration in the human remains which has provided evidence that elites had greater access to animal protein relative to commoners (Schoeninger, 1979a; 1979b).

Bioarchaeologists frequently use studies of skeletal morphology, paleopathological analyses, and metric analyses to determine the biological profile, health status, and behaviors of ancient peoples (Larsen, 1997). At Chalcatzingo, traditional bioarchaeological interpretations of human remains have not been possible due to poor skeletal preservation. Stable isotope analysis offers a method of investigating fragmentary skeletal remains in order to help answer questions about the lives of archaeological populations. Stable isotope analysis has been widely used in Classic Period Mesoamerica to discuss paleodiet, migration patterns, and the development of agriculture (Farnsworth et al., 1985; Finucane et al., 2006; Price et al., 2008; Somerville et al., 2013; Warinner et al., 2013; White and Schwarcz, 1989; White and Spence, 1998).

However, few studies of Pre-Classic human remains in Mesoamerica have employed stable isotope analysis.

Stable carbon isotope values can be used to determine the contribution of particular plant foods to individual diets (DeNiro and Epstein, 1978), while stable nitrogen isotope values can be used to approximate the amount of animal protein consumed (DeNiro and Epstein, 1981). Stable oxygen isotope values in human remains can be used to examine migration patterns based on differences in $\delta^{18}\text{O}$ values in meteoric water in different environments (Longinelli, 1984; Luz et al., 1984; White and Spence, 1998). The following project discusses the use of stable carbon and nitrogen isotopes in determining the dietary composition of the archaeological population of Chalcatzingo and in evaluating dietary status differences among this stratified population. Additionally, stable oxygen isotope values in the Chalcatzingo remains will be used to address the potential Gulf Coast origins of elites.

Studies of the production, distribution, and consumption of various food items at archaeological sites can offer significant insight into social relations and can help researchers to develop a deeper understanding of past behavior (Gumerman, 1997). The use of stable isotope analysis to study diet, social status, and migration patterns at Chalcatzingo should provide a more robust understanding of life at this complex ancient site. Additionally, the results of this study can add valuable information to the existing dataset on diet and status in Mesoamerica, placing Chalcatzingo into a broader geographic and sociopolitical context.

SITE BACKGROUND

Physical setting and subsistence patterns

Chalcatzingo is situated in the Amatzinac Valley in the eastern portion of the modern-day state of Morelos, just south of the Valley of Mexico. Between the Valley of Mexico and Morelos is the Ajusco mountain range, which includes now dormant volcanoes that were active during the Formative Period (Grove, 1987). The site is located at the base of two mountains: Cerro Chalcatzingo and Cerro Delgado. David Grove (1999) has suggested that the site was placed in this specific area due to the fact that the ancient settlers believed the mountains to be sacred. At the northern portion of the site is the Barranquilla stream, which was likely an important water source for the population of Chalcatzingo (Grove, 1987). This stream has been used for fishing by contemporary populations, and likely provided fish to the Formative Period inhabitants as well (Bugé, 1987a).

A paleoecological reconstruction using plant microfossils and macrofossils has suggested that climatic conditions in the Amatzinac Valley were relatively dry during the initial settlement at Chalcatzingo, but became increasingly moist throughout the occupation of the site (Bugé, 1987a). Agricultural production was bolstered by the presence of highly fertile tierra negra soils, tierra amarilla soils which are productive in times of increased moisture, and a generally warm and humid climate (Bugé, 1987a, 1987b). Much of the agricultural activity took place on constructed terraces, and water-control systems were developed during the Formative Period in order to aid in agricultural production (Bugé, 1987b). Macrofossil evidence suggests that maize was the primary crop grown during the Formative Period, while contemporary agriculture in the

region includes the production of corn, squash, tomatoes, peanuts, and beans (Bugé, 1987a, 1987b). Macrofossil analysis suggests that the use of wild plants during the Formative Period was minimal, and that agriculture was the primary means of subsistence for the residents of Chalcatzingo (Bugé, 1987a).

Faunal analysis at the site has suggested that dogs, rabbits, and deer were the primary sources of animal protein at Chalcatzingo (Grove, 1987b). Due to the large quantity of dog remains, Grove (1987b) has suggested that dogs either represented a common, domesticated source of protein or a species that was frequently offered as a tribute or exchange item. In addition to being used as a food source, dogs have been suggested to have had particular ritual significance at this site due to the burial of a complete dog skeleton in conjunction with human burials at the T-25 altar (Grove, 1987b). Other species represented in the Chalcatzingo faunal remains include fox, turtle, bird, and gopher (Grove 1987b).

Human Burials

The climate of Morelos is sub-tropical with a high degree of rainfall and humidity (Grove, 1987). The tierra negra and tierra amarilla soils found at the site typically retain moisture very well in wet climates, with tierra amarilla soils desiccating during periods of dryness (Bugé, 1987b). The high temperature and moisture of soils at Chalcatzingo have resulted in human skeletal remains that are extremely fragmentary and very poorly preserved (Baxter, 2004; Merry De Morales, 1987). Because of poor preservation, morphological characteristics such as age, sex, and stature have been difficult to ascertain. Similarly, no information about potential skeletal pathologies or deformations

is available (Merry De Morales, 1987). Although traditional morphological and paleopathological examinations of these remains are not possible, preservation was adequate enough to enable Sr trace element analyses on very small bone fragments (Schoeninger, 1979a; 1979b). Because stable isotope analysis requires similarly small portions of bone, it has proven to be a useful technique for the examination of the fragmentary skeletal remains (Clementz, 2012).

Archaeological examinations of Mesoamerican burials have determined that access to status goods, elaborate interments, and burial near city centers are indicators of high social status (Gerry, 1997; Gillespie, 2011; Storey, 1991; White et al., 1993). Marcia Merry De Morales (1987) suggests that Chalcatzingo elites were buried in laboriously constructed graves near the city center with rare jade items or pottery, and that their burials were often stained with hematite. Scholars also argue that stone-associated burials may represent the most convincing indicator of high social status at this site because they are geographically restricted and more prominently represented in elite residences, while other potential status indicators (e.g. jade) are much less restricted in their distribution (Grove and Gillespie, 1992; Merry De Morales, 1987: 99).

Jade and other greenstone items held political and ideological significance for Mesoamerican peoples during the Middle Formative period due to the large amount of work and skill required to craft artifacts from these hard materials and due to the fact that Mesoamerican peoples associated the green-blue color with fertility and water (Tate, 1995: 50). Jade was found with many burials at Chalcatzingo; however, these items were not local to the site and would have been imported from external sources. Because of the ritual and ideological significance of jade items, and because they were difficult to

obtain, these artifacts were reserved for high status burials at Chalcatzingo and were only found in association with 17 interments (Merry De Morales, 1987).

Ceramic vessels are associated with many of the Chalcatzingo burials, though there is variation in number and type of vessels which may have some social significance. Multivariate analyses of status indicators in the Chalcatzingo burials have failed to reveal any significant association between ceramic type or form and social status (Schoeninger, 1979a; Schoeninger, 1979b; Merry De Morales, 1987). However, Merry De Morales (1987) proposes that peralta orange pottery and double loop censers may indicate elite status due to their rarity and association with more elaborate burials, while coarse grey pottery may be related to non-elite status as this pottery type is infrequently associated with other indicators of high social status (e.g. jade, stone-associated burials).

Studies at other Mesoamerican sites have provided evidence that elite burials were located in more public locations nearer to the city center than non-elite burials (Gerry, 1997; Storey, 1991; White et al., 1993). The burial pattern at Chalcatzingo seems to align with the general Mesoamerican trend, with individuals from high and low status categories being buried under the floors of the residences in which they lived, and high status individuals frequently being buried in more public spaces nearer to the city center (Merry De Morales, 1987). The PC-1 structure in Chalcatzingo's Plaza Central has been determined to be an elite residence based on its central location and the high concentration of burials whose grave goods and interment types imply high social status (Merry De Morales, 1987). The T-25 structure is presumed to have been a site of public ritual due to the presence of an altar and high-status burials (Gillespie, 2011; Merry De

Morales, 1987). For these reasons, burials at PC-1 and T-25 have been classified as elite burials within this study.

Rosemary Joyce (1999) suggests that the Chalcatzingo elite burials were adorned with similar jewelry to elite individuals buried at La Venta and that standardized sets of pottery were included in elite burials at both locations, potentially reflecting a vast network of elites with a shared sense of identity which “transcended the local sphere” (Joyce, 1999: 38). If Joyce’s assertion is accurate, this may support the idea that Chalcatzingo elites came from the Gulf Coast or that there was a significant Olmec influence on elite rulers at this site.

PRINCIPLES OF STABLE ISOTOPE ANALYSIS

Stable isotope analysis has been frequently used to understand the dietary behaviors of archaeological populations, and numerous excellent articles have been written which support the use of this method (DeNiro and Epstein, 1981; Katzenberg, 2008; Lee-Thorp, 2008; Schoeninger, 1995; Schwarcz et al., 1985; Schwarcz and Schoeninger, 1991; Schoeninger et al., 1983). While the isotopic composition of all bodily tissues can provide information about diet, bones and teeth are the most frequently preserved tissues and thus offer the best source of information on biochemical studies of the diets of archaeological populations. Bone is composed of an inorganic hydroxyapatite portion and an organic collagen portion, each of which can provide valuable information about diet composition.

Fractionation refers to the change in isotope ratios that takes place between product and substrate (Hoefs, 1997). It is necessary to be aware of fractionation as it is responsible for much of the variation in stable isotope ratios and results in an offset between the stable isotope values in bone and those values of the actual diet. The degree of fractionation between diet and human tissues is highly dependent upon the type of tissue sampled. In human bone, for example, the degree of fractionation for the mineral portion is controlled largely by reaction temperature (i.e. body temperature) (Schoeninger, 1995). The degree of fractionation for the collagen portion of bone is controlled by enzymes which are active during collagen production (Schoeninger, 1995).

Carbon

The use of stable carbon isotope analysis in paleodietary studies is based upon the principle that $\delta^{13}\text{C}$ ratios in human bone will reflect the $\delta^{13}\text{C}$ ratios of the plant foods that they consume. Additionally, $\delta^{13}\text{C}$ ratios in human bone reflect the $\delta^{13}\text{C}$ ratios of plants foods which were consumed by the animals that humans eat. Carbon stable isotope ratios will differ from plant to plant depending upon the photosynthetic pathway used by the plant (DeNiro and Epstein, 1978). Plants which use the C3 (Calvin Cycle) photosynthetic pathway include trees, shrubs, and some cool season grasses. C3 plants exhibit $\delta^{13}\text{C}$ values with a mean of approximately -27‰ (Kohn, 2010; O'Leary, 1988). Plants which use the C4 (Hatch-Slack) photosynthetic pathway are represented primarily by dry season grasses including food crops such as maize, sorghum, and millet. These plants typically have mean $\delta^{13}\text{C}$ values of approximately -14‰ (O'Leary, 1988). A third photosynthetic pathway is represented by CAM (Crassulacean acid metabolism) plants, which are often succulents adapted to life in arid regions. The $\delta^{13}\text{C}$ values of obligate CAM plants generally cluster around -11‰, but can fall between -11‰ and -27‰ in facultative CAM plants which fluctuate between using a CAM photosynthetic pathway and a C3 photosynthetic pathway (Nalborczyk et al., 1975; O'Leary 1981).

Although various dietary macronutrients contribute to the isotopic composition of bone collagen, roughly 60% of the carbon composition of bone collagen comes from dietary protein while about 40% of carbon found in bone collagen comes from other sources (Ambrose et al., 1997; Ambrose and Norr, 1993; Froehle et al., 2010). The isotopic composition of the hydroxyapatite portion of bone is strongly correlated with the isotopic composition of whole diet, and is not significantly biased toward any one

macronutrient (Froehle et al., 2010; Jim et al., 2004). Thus, analyses of carbon stable isotope values in both the collagen and hydroxyapatite portions of bone can provide a more robust picture of an individual's diet.

Nitrogen

Stable nitrogen isotope values in human bone collagen are reflective of dietary nitrogen which is derived from protein in plant and animal matter (DeNiro and Epstein, 1981; Koch, 2007). Nitrogen in plants comes primarily from soil and atmospheric nitrogen (Koch, 2007; Schoeninger, 1995). Plants such as legumes which fix nitrogen from the atmosphere tend to have $\delta^{15}\text{N}$ values of 0‰, while plants that derive nitrogen from the soil have more positive $\delta^{15}\text{N}$ values (Schoeninger, 1995). Additionally, plants growing in dry soils tend to have higher $\delta^{15}\text{N}$ values than plants growing in soils with more moisture (Koch, 2007).

Because nitrogen stable isotope levels are positively correlated with trophic level, individuals with diets high in animal protein have tissues that exhibit higher $\delta^{15}\text{N}$ values than those who consume less meat (O'Connell and Hedges, 1999; Schoeninger and DeNiro, 1984; Schoeninger, 1995). Nitrogen stable isotope values have also been used to distinguish between marine and terrestrial foods in human diets, with more positive $\delta^{15}\text{N}$ values in populations that exploit marine resources (Schoeninger et al., 1983).

Oxygen

Oxygen stable isotope ratios have been used to study migration in human populations based on the variation of $\delta^{18}\text{O}$ values in meteoric water in different

environments (White and Spence, 1998; White et al., 2007). The $\delta^{18}\text{O}$ values found in the bone phosphate, bone carbonate, and tooth enamel phosphate of mammals that are obligate drinkers reflects $\delta^{18}\text{O}$ values in body water (Longinelli, 1984; Luz et al., 1984). Due to fractionation, $\delta^{18}\text{O}$ values in body water tend to be more positive than the $\delta^{18}\text{O}$ values in ingested water (Luz et al., 1984).

$\delta^{18}\text{O}$ values of meteoric water can be affected by factors such as distance from the ocean, elevation, humidity, and latitude (Ayliffe and Chivas, 1990; Yurtsever and Gat, 1981). $\delta^{18}\text{O}$ values decrease with increasing elevation, increasing distance from the sea, and with decreasing temperature (Yurtsever and Gat, 1981). Additionally, meteoric water will exhibit increased $\delta^{18}\text{O}$ values in areas with low humidity due to preferential loss of $\delta^{16}\text{O}$ during evaporation (Ayliffe and Chivas, 1990). Because local stable oxygen isotope signatures are recorded in developing teeth during childhood and early adulthood, $\delta^{18}\text{O}$ values in enamel phosphate can provide information about the geographic origin of individuals who migrated in early life (Luz et al., 1984). Stable oxygen isotope values in ingested meteoric water are also reflected in human bone throughout life, and can help to elucidate migration patterns by comparing bone values to local meteoric water (Longinelli, 1984; Luz et al., 1984; White and Spence, 1998).

SOCIAL COMPLEXITY AND THE OLMEC INFLUENCE

The Formative Period in Mesoamerica was a time of increasing social complexity and social stratification signified by increasingly elaborate architecture, differential access to status goods, and increasing long-distance exchange of goods and ideas (Chase and Chase, 1992; Grove, 1976). Archaeological examinations of Formative Period sites have placed considerable emphasis on the widespread evidence of a shared Olmec artistic style throughout Mesoamerica (Grove et al., 1976; Plunket and Uruñuela, 2012). The Olmec culture developed along the Gulf Coast in ancient Mexico, and its definition and scope have been topics of significant debate within the archaeological community (Pool, 2007). Some scholars argue that the development of social complexity in Mesoamerica during the Formative Period was the result of the spread of Olmec culture, which was purportedly more sociopolitically advanced than the surrounding societies (Clark, 1997). This position is often referred to as the “Mother Culture” argument. Conversely, the “Sister Culture” argument suggests that the widespread use of “Olmec-style” iconography and the concomitant increase in social complexity in Mesoamerica were the result of a co-evolution of independent societies who all shared ancient history and experienced increasing cultural diffusion via trade and migration (Flannery and Marcus, 2000).

The Olmec influence at Chalcatzingo is especially apparent due to the fact that it is the only central Mexican highland site with documented Olmec-style monumental rock carvings (Grove et al., 1968). These bas-reliefs provide insight into the beliefs and cultural practices of the Chalcatzingo population. A number of carvings include iconography that indicates the importance of water and agricultural fertility, while other

carvings show individuals with distinctive social roles as shamans or elites (Grove, 1968). Archaeological evidence gathered by Grove and colleagues (1976) suggests that Chalcatzingo was a simple farming village prior to the Middle Formative Period when it reached its sociopolitical zenith and began to show evidence for social stratification and substantial interaction with the Gulf Coast Olmecs. It is still unclear if increasing social complexity and stratification at Chalcatzingo developed as a result of interaction with the Gulf Coast, or if social complexity developed independently at Chalcatzingo and drew the attention of Gulf Coast elites who sought trade partners (Grove et al., 1976). The desire of Olmec elites to obtain status goods has been proposed as a driving force behind increasing long-distance exchange in Formative Mesoamerica (Flannery, 1968). Hirth (1978) suggests that the central location of Chalcatzingo along long-distance exchange routes resulted in this site becoming an important gateway community for the surrounding sites.

Oxygen stable isotopes have proven to be useful in evaluating migration patterns of past populations (White and Spence, 1998; White et al., 2007). $\delta^{18}\text{O}$ values in the human remains at Chalcatzingo could help to answer questions about how Olmec culture and social complexity developed at this particular site. White et al. (2007) have performed a meta-analysis compiling stable oxygen isotope values in bone and enamel phosphate throughout Mesoamerica. The authors have determined that bone phosphate $\delta^{18}\text{O}$ values are between -7.7 to -5.7‰ (PDB; Table 5) in the central Mexican highlands. These isotope values can be compared to $\delta^{18}\text{O}$ values in bone carbonate in order to determine whether the inhabitants of Chalcatzingo were native to the region or migrated from other areas, and can also be used to look for differences in migration patterns

between elite and non-elite individuals. In analyzing migration patterns at Chalcatzingo, it is important to consider the fact that this site had significant interaction with sites in Western and Southern Mexico as well as the Gulf Coast (Grove, 1987). Thus, stable oxygen isotope values of individuals at this site may also reflect migration from regions other than the Gulf Coast.

SOCIAL STRATIFICATION AND DIET

The subsistence practices and nutritional statuses of individuals within any human population are inextricably tied to social relations and thus serve as excellent sites for the study of social status and inequality (Gumerman, 1997; Danforth, 1999). There is significant zooarchaeological and trace element concentration evidence to suggest that Classic Period Mesoamerican elites were granted disproportionate access to certain types of foods (Emery, 2003; Haller et al., 2006; Haviland and Moholy-Nagy, 1992; Seinfeld et al., 2009; Turkon, 2004). At El Palmillo in Oaxaca, Mexico, elites consumed higher quantities of meat than commoners, although social status had no effect on access to preferred food species (Haller et al., 2006). Zooarchaeological analysis suggests that elites in the Mayan region of Petexbatún in Guatemala had greater access to preferential food species than did individuals of lower social status, although the over-all quantity of meat consumed was not significantly different between elites and commoners (Emery, 2003). The varying distribution of meat across status categories may represent the use of particular animals as tributes to elites (Turkon, 2004) or the symbolic value of certain species in ritual contexts (Emery, 2003). Faunal remains at Chalcatzingo have been discovered in both elite and non-elite residence areas (Grove, 1987), which may suggest equal access to meat regardless of social status. This distribution of faunal remains could also suggest that commoners engaged in food preparation both in their own homes and in elite residences, or that Chalcatzingo elites outsourced food preparation to the homes of commoners (Turkon, 2004).

An early analysis of Strontium (Sr) concentration at Chalcatzingo found evidence that elites at this site were consuming more meat than non-elite individuals (Schoeninger,

1979). It has since been demonstrated that nitrogen stable isotope analyses can more accurately determine the relative contribution of meat to individual diets, with diets high in animal protein exhibiting higher $\delta^{15}\text{N}$ values than diets which are low in animal protein (Schoeninger, 1995). If high status individuals at Chalcatzingo exhibit higher $\delta^{15}\text{N}$ values, this may indicate greater consumption of animal protein.

Previous studies support the assumption that there was differential access to maize at some Mesoamerican sites during the Formative Period. For example, bulk stable carbon isotope analysis of ceramic residues at the Olmec site of San Andrés has revealed that $\delta^{13}\text{C}$ values of residues on luxury ceramic wares were consistent with C4 plant values. The authors propose that these stable isotope data indicate that maize was used to produce beverages that were consumed during ritual feasts which were reserved for elites, thus resulting in differential consumption of maize at San Andrés (Seinfeld et al., 2009). However, the authors did not perform stable isotope analysis on human remains from San Andrés, so patterns of actual consumption at this site are unclear. A stable isotope study of Maya dietary patterns throughout the southern lowlands during the Classic period shows great variation in the elite consumption of maize through time, while commoners' diets remained relatively consistent (Somerville et al., 2013). These results suggest that Mesoamerican elites not only had greater access to certain food items, but enjoyed more varied diets relative to commoners during this time period.

Various monuments at Chalcatzingo include Olmec-style carvings that highlight the association of maize with ritual, spirituality, and elite power which may indicate differential access to maize at this site (Taube, 1996). Prehistoric $\delta^{13}\text{C}$ values for maize fall between -8.7‰ and -12.6‰ (Tieszen and Fagre, 1993). Using this range of values,

stable carbon isotope analyses of the human remains from Chalcatzingo can uncover potential status differences in the consumption of maize.

MATERIALS AND METHODS

Samples

From the 161 burials uncovered at Chalcatzingo during the 1972-1974 field seasons (Merry De Morales, 1987), 60 bone fragments were available for the purposes of this study. Of these 60 fragments, 23 samples were chosen for stable isotope analysis based on their total weight after cleaning and their representation of varying status categories. Due to the fragmentary nature of the remains, the sex of each individual could not be reliably determined. Similarly, age could not be specified beyond the basic classification into adult and sub-adult categories. All samples tested within this study represent adult individuals with the exception of one sample (MS-0036) which was taken from an infant innominate bone. Apart from this infant innominate (n = 1), the bone samples represented within this study come primarily from long bone (n = 9) and rib (n = 6) fragments. Additional samples come from unidentifiable miscellaneous fragments (n = 5) or cranial fragments (n=2).

Determination of Social Status

Despite the presence of a detailed burial record at Chalcatzingo, it was not possible to associate each sample used within this study with its burial type or grave goods. Social status for 12 of the 23 samples was based on detailed burial records including burial location, type of interment, and grave goods (Merry De Morales, 1987; Table 1). As previously mentioned, Marcia Merry De Morales (1987) has noted that burial location and type of interment seem to be the most reliable indicators of high social status at Chalcatzingo. For this reason, stone-associated burials in elite residences or

public centers (e.g. PC-1; T-25) have been interpreted as elite individuals (Table 1). In situations where burial records provide limited information or potentially conflicting evidence of social status, burial type has been prioritized as the most important status indicator following Merry De Morales' (1987) argument that stone-associated burials were restricted to elite individuals.

Where possible, the association of burial type with at least one additional indicator of social status has been used to determine the ultimate status classification. For instance, sample number MS-0022 represents a stone-associated burial at location that has not been considered an elite residence or part of the city center (T-9B; Figure 6). However, this interment also contained peralta orange pottery which was rare at Chalcatzingo and may have been present only in elite burials (Merry De Morales, 1987). Thus the stone-associated burial in combination with the presence of rare pottery has been used to indicate that MS-0022 represents an elite individual (Table 1). Similarly, sample number MS-0024 was buried in a location that has been interpreted as non-elite (T-21); however, it is a stone associated burial which includes a large amount of pottery and hematite staining, and has thus been interpreted as an elite individual (Table 1).

While the remaining 11 samples could not be associated with burial records from the original excavation, their burial locations were known and these locations were used to infer social status based on previous work suggesting that elites at Chalcatzingo were buried at T-25 and PC-1 (Gillespie, 2011; Merry De Morales, 1987). Additionally, elites at other Mesoamerican sites were frequently buried nearer to city centers than were commoners (White et al., 1993; Gerry, 1997), thus providing further support for associating status with the spatial dimension of burials.

One limitation of this method of assigning social status is the unknown nature of burials at Terrace 25, which was a site of public ritual containing an altar. There is Olmec-style iconographic evidence at Chalcatzingo to support the idea that human sacrifice may have been a common practice at this site (Lambert, 1987). If this were the case, some individuals buried at T-25 may have been non-elite sacrifice victims. However, there is presently no way to differentiate between elite individuals and sacrifice victims at T-25, thus elite status has been assigned to all individuals found in this location based upon the idea that the location of the T-25 structure combined with the presence of a number of elite burials have marked it as a socially significant burial site (Gillespie, 2011; Merry De Morales, 1987).

It is important to note that the assignment of social status within the present study represents a simplification of what is known to have been a complex social system (Grove and Gillespie, 1992). While complex societies in ancient Mesoamerica almost certainly consisted of a status continuum rather than strictly dichotomous status designations of “elite” and “non-elite” (Gerry, 1997), the small sample size and limited information available for the present study made it difficult to determine the subtle variation that may have been associated with a more “middle class” status category.

Cleaning

All samples were cleaned in Margaret Schoeninger’s Paleodiet Laboratory at University of California, San Diego (UCSD). Cleaning was performed using a diamond point drill bit (#7144) attached to a Dremel rotating hand drill in order to remove surface contamination. During the cleaning process, particular emphasis was placed on the

removal of trabecular bone from each sample due to the fact that this type of bone is more easily contaminated by the burial environment than cortical bone (Jørkov et al., 2007). Following cleaning with the Dremel drill, samples were ultrasonically cleaned in a bath of double distilled water and subsequently dried overnight in the oven at 60°C. Because samples were fragmentary and poorly preserved, some bone was lost in the cleaning process. Only samples which yielded 1 gram of bone following cleaning were analyzed in order to ensure that the sample weight would be sufficient for testing both the collagen and hydroxyapatite portions of each bone fragment.

Hydroxyapatite

Following cleaning, all samples which were used for hydroxyapatite analysis of stable carbon and oxygen isotopes ($n = 23$) were weighed to at least 30 mg. Samples were then ground into a fine powder using an agate mortar and pestle and sifted through a micro sieve to ensure that the powder was homogenous. Subsequent to the powdering process, samples were weighed once again. The powdered bone samples were transferred to labeled microcentrifuge tubes for further chemical preparation.

In order to remove the organic collagen portion of bone, a 2% sodium hypochlorite solution was added to microcentrifuge tubes at a ratio of 0.04 mL of solution per 1 mg of bone powder following the procedure outlined by Koch et al. (1997). After 24 hours, the sodium hypochlorite solution was removed from the samples using a pipette and they were rinsed three times in double distilled water. Following this rinsing procedure, 1.0 M acetic acid was added to samples at the same ratio of 0.04mL/mg that was used for the sodium hypochlorite solution. Samples remained in the acetic acid

solution for 24 hours in order to remove diagenetic carbonates. The following day, the acetic acid was removed from the samples and they were once again rinsed three times in double distilled water. Samples were then placed into the oven at 60°C to dry overnight. Once dried, the prepared samples were kept under vacuum in a sealed bell jar until they could be brought to the mass spectrometry facility for analysis.

Stable carbon and oxygen isotope analysis of hydroxyapatite was performed at the Scripps Institute for Oceanography Stable Isotope Facility using a Gas Bench Thermo MAT 253 attached to a Thermo-Finnigan Delta XP Plus mass spectrometer. Replicates of an internally calibrated CO₃ standard were analyzed with collagen samples resulting in a reproducibility of ±0.2‰ for both δ¹³C and δ¹⁸O. Stable carbon and oxygen isotope data are presented relative to the Pee Dee Belemnite (PDB) International standard. Carbon stable isotope values were corrected by -1.0‰ in order to compensate for the depletion of ¹³CO₂ in the atmosphere as a result of the burning of fossil fuels (Keeling 1979).

In order to assess migration patterns at Chalcatzingo, δ¹⁸O values in bone carbonate (δ¹⁸O_c) were compared to δ¹⁸O values in bone and enamel phosphate (δ¹⁸O_p) which were reported by White and colleagues (Table 5). White et al. (2007) have compiled stable isotope values in human remains throughout Mesoamerica, showing some distinct differences in values between individuals from different regions. While stable oxygen isotope values presented by White et al. (2007) are largely from time periods later than the Middle Formative, these values can provide some estimation of regional values with which to compare individuals at Chalcatzingo. The formula used to translate the findings of White et al. (2007) to δ¹⁸O_c values was:

$$\delta^{18}\text{O}_c(\text{VSMOW}) = (8.5 + (\delta^{18}\text{O}_p)) / 0.98.$$

This formula was used because White et al. (2007) reported stable oxygen isotope values relative to the Vienna Standard Mean Ocean Water (VSMOW) standard. Following the use of the above formula, results were converted to the PDB international standard in order to better compare them to samples from Chalcatzingo using the formula:

$$\delta^{18}\text{O}(\text{PDB}) = (0.97002 \times \delta^{18}\text{O}(\text{VSMOW})) - 29.98$$

Collagen

Collagen samples were cleaned using the procedure outlined above and weighed prior to undergoing chemical preparations for stable isotope analysis. Each sample was placed into a 15 mL centrifuge tube and soaked in 13 mL of 0.25M hydrochloric acid (HCL) in order to facilitate demineralization. The HCL solution was poured out and changed every few days to ensure the continuation of the chemical reaction. Once fully demineralized, each sample was rinsed three times in double distilled water. Following this rinse, 13 mL of 0.125M sodium hydroxide (NaOH) was added to each centrifuge tube in order to remove humic acids which may have contaminated the bone in the burial environment (Ambrose, 1990). Samples remained in the NaOH solution for 24 hours and were subsequently rinsed another five times in double distilled water.

10 mL of a weak acid solution (0.25 M HCL mixed with water; pH=3) was added to each centrifuge tube along with bone samples, after which all samples were placed into the oven for 24 hours at 75°C. Schoeninger et al. (1989) propose that the use of a weak acid solution in conjunction with high temperatures allows for solubilization of collagen with minimal collagen degradation, leading to greater collagen yields in poorly preserved

archaeological bone. After 24 hours, samples were centrifuged and liquid was poured into labeled Teflon beakers. All remaining collagen samples remained in their centrifuge tubes and an additional 10 mL of pH3 water was added to each tube. This process was repeated until collagen samples were entirely solubilized and dried down in Teflon beakers. Solubilized collagen samples were transferred to pre-weighed glass vials and then lyophilized at -50°C . Finally, the glass vials full of collagen were weighed in order to calculate collagen yield. Seven samples (MS-0085, MS-0044, MS-0023, MS-0022, MS-0001, MS-0046, and MS-0090) failed to yield any collagen following chemical preparation, indicating poor skeletal preservation (Schoeninger et al., 1989; Van Klinken, 1999). The total number of samples which yielded adequate collagen for stable isotope analysis was 16.

Stable carbon and nitrogen isotope analyses of collagen were performed on a Costech 4010 EA attached to a Thermo-Finnigan Delta XP Plus mass spectrometer. Replicates of an internally calibrated standard were analyzed with collagen samples resulting in a reproducibility of $\pm 0.2\text{‰}$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Carbon isotope ratios are represented relative to the PDB international standard and nitrogen isotope ratios are presented relative to atmospheric $\delta^{15}\text{N}$ (AIR). As with the hydroxyapatite portion of bone, Carbon stable isotope values in collagen were corrected by -1.0‰ in order to compensate for the depletion of ^{13}C in the atmosphere as a result of the burning of fossil fuels (Keeling 1979).

Diagenesis

Diagenesis refers to physical and chemical changes in skeletal remains that take place due to interactions with the burial environment. It is necessary to test for diagenetic alterations in skeletal remains, as these alterations may significantly affect stable isotope values so that they no longer provide accurate information about the diet, lifestyle, or environment of the living individual. Fourier transform infrared (FTIR) spectroscopy is a technique that is frequently used to assess levels of diagenesis in archaeological human remains by measuring changes in the size and morphology of bone crystals which result from the interaction of bone with the burial environment (Berna et al., 2004). These changes in crystallinity are analyzed using IR-SF (infrared splitting factor). Previous studies on modern and archaeological bone in Dr. Margaret Schoeninger's Paleodiet Laboratory in conjunction with existing literature (Hollund et al., 2013; Smith et al., 2007) support the idea that archaeological remains are minimally altered by diagenesis if they present IR-SF values between 2.0 and 4.0. Another way in which FTIR determines the degree of diagenesis is by assessing the carbonate (CO_3) to phosphate (PO_4) ratio (C/P) of a bone sample (Wright and Schwarcz, 1996). The aforementioned Paleodiet Laboratory studies and existing literature (Hollund et al., 2013; Smith et al., 2007) suggest that unaltered bone will exhibit C/P values between 0.10 and 0.50.

FTIR was performed on powdered bone samples using attenuated total reflection (ATR) prior to mass spectrometry in order to assess potential diagenesis (Beasley et al., 2014; Wright and Schwarcz, 1996; Shemesh, 1990). Roughly 2-3 milligrams of apatite powder was placed onto the optic window of a Nicolet Magna 500 FTIR instrument with a ZnSe crystal and clamped down with the high pressure Smart iTR accessory to ensure

full sample contact with the crystal. Each sample was scanned 100 times, and the OMNIC (v7.0) software was used to analyze the spectra.

Other methods of testing for diagenesis consist of evaluating carbon to nitrogen (C/N) ratios in bone samples and determining collagen yields after preparing samples for stable isotope analysis. DeNiro (1985) suggests that skeletal remains with C/N ratios of 2.9-3.6 are not severely diagenetically altered and can be useful for determining past dietary behaviors. The C/N ratios of samples in this study were calculated and subsequently analyzed using DeNiro's (1985) baseline values. The use of collagen yield to help assess diagenesis is based upon the principle that poorly preserved bone will produce much lower percentages of collagen following preparation for isotope analysis (Schoeninger et al., 1989; Van Klinken, 1999). Collagen yield was calculated for each sample within this study, and samples yielding over 1% collagen were considered to be relatively well preserved following Ambrose (1990).

Statistical Methods

Statistical analyses of stable isotope differences between the elite and non-elite groups in this study were performed using two-tailed Mann-Whitney *U* tests. This particular type of non-parametric statistical test was chosen due to the non-normal distribution of dietary data and the small sample sizes within this study. Differences were determined to be statistically significant if P-values were less than or equal to 5% ($P \leq 0.05$). Due to small sample sizes and non-normal sample distributions, median values have been reported rather than mean values.

RESULTS

Diagenesis

FTIR (Table 2) revealed C/P values of less than 0.10 for three samples (MS-0046, MS-0084, and MS-0090), suggesting diagenetic alteration which may have affected stable isotope values. For this reason, the results of isotopic analyses of these samples were excluded from the following comparative analysis. The C/N ratio of sample MS-0084 was 4.84, falling outside the bounds of acceptable C/N ratios (2.9-3.6) which have been suggested by DeNiro (1985) and providing further evidence for diagenetic alteration. C/N ratios of all other samples fell within the acceptable range (Table 3).

Seven samples did not yield any collagen (MS-0085, MS-0044, MS-0023, MS-0022, MS-0001, MS-0046, and MS-0090), making it impossible to perform stable isotope analysis on the collagen portion of these remains. For all samples in which usable collagen was extracted, collagen yield was calculated (Table 3). All samples yielded over the 1% recommended for well-preserved bone, with the exception of MS-0084 which yielded exactly 1% collagen. Notably, the infant innominate (MS-0036) yielded 19.8% collagen.

Carbon Isotope Results

$\delta^{13}\text{C}$ values of hydroxyapatite for the entire Chalcatzingo population range from -5.7‰ to -2.8‰ with a median value of -4.2‰ (Figure 2- 3; Table 4). The $\delta^{13}\text{C}$ values for individuals designated as “elite” (n= 8) ranged from -5.0‰ and -3.7‰, with a median value of -4.4‰. Non-elite individuals (n = 12) had a range of $\delta^{13}\text{C}$ values between -5.7‰ and -2.8‰, with a median value of -4.1‰. While the median $\delta^{13}\text{C}$ value of each status

group is not significantly different from the median of the population as a whole, the range of $\delta^{13}\text{C}$ values is slightly larger for non-elite individuals (SD = 0.92) than for elite individuals (SD = 0.53). However, this difference is not statistically significant as per the results of a 2-tailed Mann Whitney U Test ($U = 35.5$, $p = 0.45$) and is likely an artifact of differences in sample size between elite ($n = 7$) and non-elite ($n = 13$) groups.

For collagen, $\delta^{13}\text{C}$ values of the entire population range from -10.2‰ to -7.6‰, with a median value of -9.0‰ (Figure 2; Table 3). $\delta^{13}\text{C}$ values of elite individuals ($n = 7$) range from -10.2‰ to -8.7‰, with a median value of -9.4‰. Non-elite individuals ($n = 8$) exhibit $\delta^{13}\text{C}$ values between -10.1‰ and -7.6‰, with a median value of -8.8‰. Results of a 2-tailed Mann Whitney U Test ($U = 17.5$, $p = 0.25$) have determined that the $\delta^{13}\text{C}$ values of elites and non-elites show no statistically significant difference, although non-elite $\delta^{13}\text{C}_{\text{collagen}}$ can be seen to cluster toward the slightly less negative values on a scatter plot relative to elite values (Figure 2). The sample with the least negative $\delta^{13}\text{C}$ values was MS-0036; this sample was an infant innominate bone and exhibited values of -7.6‰. Removal of this sample prior to statistical testing does not result in any significant difference between status categories ($U = 17.5$, $p = 0.41$).

Nitrogen Isotope Results

Stable nitrogen isotopes are only found in the collagen portion of bone, thus $\delta^{15}\text{N}$ values of collagen are reported in this section. $\delta^{15}\text{N}$ values of the entire population range from 6.7‰ to 10.4‰, with an median of 8.9‰ (Figure 4; Table 3). Elite ($n=7$) $\delta^{15}\text{N}$ values range from 8.1‰ to 10.4‰ with a median value of 9.2‰. Non-elite ($n = 8$) $\delta^{15}\text{N}$ values range from 6.7‰ to 9.2‰ with a median value of 8.8‰. The results of a Mann

Whitney U Test ($U = 16.5$, $P = 0.20$) have determined that the differences between elite and non-elite $\delta^{15}\text{N}$ values is not statistically significant. Nonetheless, some elite individuals (MS-0024 and MS-0083) did exhibit slightly higher $\delta^{15}\text{N}$ values in comparison to the rest of the population; while a single non-elite individual (MS-0071) has exhibited lower $\delta^{15}\text{N}$ values in comparison to the rest of the population. When this individual is removed prior to statistical testing, there is still no statistically significant difference between status categories ($U = 16.5$, $p=0.34$).

Oxygen Isotope Results

Stable oxygen isotope values are found in the hydroxyapatite portion of bone, thus values reported in this section reflect hydroxyapatite analysis. $\delta^{18}\text{O}$ values of the entire population range from -10.6‰ to -5.9‰ with a median value of -9.0‰ (Figure 3, Table 4). $\delta^{18}\text{O}$ values of elite individuals ($n = 8$) range from -10.6‰ to -8.5‰ with a median value of -9.5‰ . Non-elite individuals ($n = 12$) exhibit $\delta^{18}\text{O}$ values from -10.4‰ to -5.9‰ with a median value of -8.6‰ . The scatter plot of the data (Figure 3) shows all data points clustering around similar $\delta^{18}\text{O}$ values with only one individual (MS-0036) exhibiting particularly high values. Non-elites exhibit a wider range of variation in terms of $\delta^{18}\text{O}$ values in comparison to non-elite individuals; however, this difference may be due to the small sample size of elite individuals. A Mann Whitney U Test ($U = 24.5$, $p = 0.105$) has determined that there is no statistically significant difference between elite and non-elite $\delta^{18}\text{O}$ values. When the individual with high $\delta^{18}\text{O}$ values is removed prior to statistical testing, there is still no statistically significant difference between status groups ($U=23$, $p=0.091$).

According to White et al. (2007; Table 5) stable oxygen isotope values in the Central Mexican Highlands range from -7.7‰ to -5.7‰ . However, excluding the individual with extremely high values (MS-0036; see discussion), only one individual at Chalcatzingo (MS-0085) exhibited a $\delta^{18}\text{O}$ value which overlaps with those expected for individuals from the Central Mexican Highlands (-7.7‰). It is important to note that the stable oxygen isotope values presented by White and colleagues represent averages from the sites of Teotihuacan, Chapantongo, Xico, and Cholula; all of which are higher in elevation than Chalcatzingo (Teotihuacan = 2300 m; Chapantongo = 2135 m; Xico = 2346 m; Cholula = 2150 m; Chalcatzingo = 1350 m). Lower elevation results in higher $\delta^{18}\text{O}$ values (Yurtsever and Gat, 1981), which could help to explain why oxygen stable isotope values at Chalcatzingo are higher than the surrounding central Mexican sites. However, Grove (1987) has suggested that Chalcatzingo was a humid site, which would result in slightly lower $\delta^{18}\text{O}$ values (Ayliffe and Chivas, 1990; Luz et al., 1990). An alternative explanation for the Chalcatzingo oxygen stable isotope values in human remains would be the migration into Chalcatzingo from surrounding regions. The majority of the Chalcatzingo values align with White and colleagues' (2007) reported ranges for Western Mexico, the Valley of Oaxaca, Pacific Coast Guatemala, Sierra Madre Occidental, and Sierra Madre del Sur (-9.7‰ to -7.7‰).

DISCUSSION

Maize

Kellner and Schoeninger (2007) have developed a model in which stable carbon isotope values in collagen and apatite can be compared with parallel regression lines in order to determine whether dietary protein was derived from C3 or C4 sources. Additionally, this model can help to elucidate the sources of other dietary macronutrients such as lipids and carbohydrates, with C4 derived macronutrients falling at the upper end of the regression line and C3 derived macronutrients falling at the lower end of the regression line (Kellner and Schoeninger, 2007; 1122). When the Chalcatzingo values are plotted along the regression lines of this simple carbon model (Figure 5), all values fall along the C4 protein line and cluster at the upper end of the line, indicating a diet that was almost entirely composed of C4 plants or animals that consumed C4 plants. This conclusion is somewhat unsurprising given the fact that maize is a C4 plant, and maize agriculture is known to have been a central part of life at Chalcatzingo (Bugé, 1987a, 1987b; Grove, 1987). The median population value of $\delta^{13}\text{C}_{\text{collagen}}$ at Chalcatzingo was -9.0‰, which is close to the median $\delta^{13}\text{C}_{\text{collagen}}$ value of -9.3‰ that has been reported in adult remains at the nearby residential compound of Tlajinga 33 (White et al., 2004). Tlajinga 33 was part of the urban center of Teotihuacan and is known to have been a site of high maize consumption, further supporting the assertion that maize was a primary dietary component at Chalcatzingo.

Faunal remains at Chalcatzingo consist largely of deer, dogs, and rabbits (Grove, 1987b). While faunal remains from Chalcatzingo were not available for stable isotope comparison with the human remains, previous stable isotope studies support the idea that

deer in Mesoamerica are primarily C3 plant consumers that may occasionally graze on C4 plants where available (White et al., 2001; Whittington and Reed, 2006). Given the presence of deer remains at Chalcatzingo and the strong C4 signature of the human remains, it is likely that deer at this site were grazing in maize fields, being fed maize, or that deer meat was a relatively small portion of human diet at this site. Stable isotope analyses of the faunal remains from Chalcatzingo are necessary in order to fully answer this question.

Dogs are the most abundantly represented faunal remains at Chalcatzingo, which Grove (1987b) suggests may be an indicator of their domestication as a food source. Stable isotope evidence suggests that dogs who have been domesticated as food sources or ritual sacrifices at other Mesoamerican sites were often fed diets that consisted almost entirely of maize (White et al., 2001), which would support a strong C4 signal both in the animals and in the humans who consumed them. Therefore, it is possible that dogs at Chalcatzingo were fed maize and subsequently consumed by humans. Without stable isotope data for the fauna at Chalcatzingo, it is impossible to know for sure whether these animals were being purposefully fed maize; however, the stable carbon isotope values of human remains at the site in combination with the large concentration of dog remains suggest that this is a strong possibility.

As previously mentioned, there is evidence for status based differences in maize consumption at other Mesoamerican sites (Gerry, 1997; Seinfeld et al., 2009; Somerville et al., 2013); however, no existing studies discuss dietary disparities and differential access to maize during the Formative Period in the central Mexican highlands specifically. Monumental carvings depicting maize as a spiritually significant crop which

was linked to ideas of agricultural fertility can be found at both Chalcatzingo and the highland Mexican site of Teopantecuanitlan (Taube, 1996). Nonetheless, the spiritual and ritual significance of maize evidently did not result in differential maize consumption between elites and commoners at Chalcatzingo. There are a number of potential explanations for the lack of status-based differences in maize consumption including elite control and distribution of food resources that did not result in differential consumption patterns. For instance, in pre-Hispanic central Peru, archaeologists discovered more maize in elite residences, but stable isotope analysis of the human remains failed to uncover any significant differences between elites and commoners in terms of maize consumption (Costin and Earle, 1989: 698). Costin and Earle (1989) suggest that the lack of association between maize abundance and actual consumption patterns was due to elite provisioning of commoners through feasting. It is possible that a similar pattern of maize provisioning could have been in effect at Chalcatzingo. However, unless feasting was a daily event, it is unlikely that this factor alone would have resulted in the relative homogeneity of $\delta^{13}\text{C}$ values across status categories at Chalcatzingo.

Taube (1996) proposes that maize iconography is representative of an intentional Olmec exportation of “subsistence ideology” in order to support their own economic interests and trade with other Formative period sites. If this were indeed the case, maize iconography at Chalcatzingo may be linked to legitimation of power, economic ties, or recognition of the importance of agriculture rather than ascribing any particular social or spiritual value to maize itself. This may provide another explanation for why maize was not differentially distributed despite iconographic evidence which positions it as a spiritually important food item.

The fragmentary nature of the skeletal remains at Chalcatzingo has made sex determination incredibly difficult (Merry de Morales, 1987). Thus, it was not possible to assess potential sex-based differences in maize consumption. However, sex-based differences in maize consumption have been observed in other regions including the Mantaro Valley of Peru. Hastorf (1991) proposes that sex-based differences in maize consumption in this region were due primarily to Inca political control over the distribution of maize and played an important role in the construction of gender roles. Ambrose and colleagues (2003) have also identified sex-based stable isotope differences at Cahokia in central Illinois, where low-status females were eating approximately 60% more maize than high status individuals. However, it is unclear whether these dietary differences are due primarily to social status, sex, or an intersection of the two. The lack of information on the biological sex of specimens at Chalcatzingo makes it similarly difficult to understand potential relationships between sex, social status, and dietary behaviors at this site.

The tissues of breastfeeding infants typically show a 1‰ enrichment in $\delta^{13}\text{C}$ values over the tissues of their mothers. However, when solid weaning foods are introduced into infants' diets, their $\delta^{13}\text{C}$ values show a sudden decrease in comparison to the values of their mothers (Fuller et al., 2006). MS-0036 represents a sample from an infant innominate at Chalcatzingo. This particular sample exhibited the least negative $\delta^{13}\text{C}$ values of the entire population (-7.6‰), which was likely the result of a nursing signal.

Meat

Nitrogen stable isotope values of the human remains at Chalcatzingo were relatively homogenous, suggesting no significant status-based differences in consumption of animal protein. This lack of status-based differences in $\delta^{15}\text{N}$ values could be due to issues with the assignment of social status within this study or the lack of information on sex in the Chalcatzingo population. Sex differences in consumption of meat have been documented in other archaeological populations (Ambrose et al., 2003; White, 2005), and more information about sex at Chalcatzingo would help to define status and dietary patterns at this site. However, the results of the present analysis align well with the lack of zooarchaeological evidence for differential access to animal protein at Chalcatzingo (Grove, 1987; Grove, 1987b). Two high status individuals (MS-0024 and MS-0083) exhibited slightly higher $\delta^{15}\text{N}$ values relative to other members of the population; however, these values were within 1.5‰ of the population median value and the non-elite median value (9.0‰ and 8.9‰, respectively). Average stable nitrogen isotope values of the entire population at Chalcatzingo are in agreement with previous stable isotope studies of individuals in Mesoamerica who were known to rely heavily on maize for sustenance and to supplement their diets with meat (Gerry, 1997).

A single non-elite individual (MS-0071) exhibited slightly lower $\delta^{15}\text{N}$ values (6.7‰) which were roughly 2.2‰ lower than both the median population value (9.0‰) and the median non-elite value (8.9‰). Notably, MS-0071 was one of a small number of individuals ($n = 7$) at Chalcatzingo who were buried in caves outside of the city (Merry de Morales, 1987). Susan Gillespie (2011) argues that burial practices at Chalcatzingo were acts which deliberately represented social interaction and identity within the sphere

of this particular site. Thus a burial which deviated from the typical sub-floor interment and was placed in a geographic location outside of the city may have represented an individual who was an “outsider,” a migrant, or someone of particularly low social status. The $\delta^{18}\text{O}$ value of MS-0071 (-9.9‰) does not deviate significantly from the population median (-9.0‰). If $\delta^{18}\text{O}$ values at Chalcatzingo signify migration from other sites, the close match between MS-0071 and the rest of the population may suggest that this individual migrated with others. Therefore, the unique $\delta^{15}\text{N}$ value combined with the burial location may be more indicative of an “outsider” identity or low social status than migration from a significantly different community or geographic region.

Migration

The oxygen stable isotope values at Chalcatzingo are higher than values reported for the surrounding central Mexican sites (White et al., 2007). These values may reflect a local Chalcatzingo signal which is unique due to its elevation or climate, or they may support the idea that the community was composed of a number of migrants. If Chalcatzingo represents a population of migrants, the lack of status-based differences in $\delta^{18}\text{O}$ values may represent similar migration patterns across status groups. Additionally, it is uncertain whether the stable oxygen isotope values support the idea that elites may have migrated from the Gulf Coast, as no stable oxygen isotope values of Gulf Coast individuals were available for comparison. Further studies including strontium (Sr) isotope analysis could help to further elucidate these migration patterns, as there are presently no studies establishing baseline $\delta^{18}\text{O}$ values at Chalcatzingo.

MS-0036 exhibited the highest $\delta^{18}\text{O}$ values at 24.8‰. As previously mentioned, this particular sample was taken from an infant innominate bone. A recent study performed by Britton et al. (2015) has proposed that high $\delta^{18}\text{O}$ values in infants in archaeological populations can be indicative of a nursing signal, which is likely the case in terms of this particular sample. White et al. (1998) have found evidence for sex-based differences in $\delta^{18}\text{O}$ values in the Valley of Oaxaca and the Valley of Mexico; however, this factor cannot be reliably examined at Chalcatzingo due the fragmentary nature of the remains. The authors assert that stable oxygen isotope differences can be used to assess the maintenance of ethnicity and marriage patterns in ancient societies. If sex data was available for the Chalcatzingo population, we could more easily determine the importance of these patterns at this particular site.

CONCLUSIONS

While Formative Period Chalcatzingo represents an archaeological site with substantial evidence for social inequality, stable isotope evidence does not support the assumption that elites were granted greater access to certain food resources. Furthermore, stable isotope analysis has shown different results in terms of status-based differences in animal protein consumption at Chalcatzingo than earlier Sr concentration analyses (Schoeninger, 1979a; Schoeninger 1979b). These differing results confirm that stable isotope analysis provides an updated methodology with which to reevaluate previous conclusions about archaeological populations.

As with many other Mesoamerican sites, maize was a staple crop of the population at Chalcatzingo. However, unlike other Mesoamerican sites where status-based differences in maize consumption have been demonstrated (Gerry, 1997; Seinfeld et al., 2009; Somerville et al., 2013), the stable isotope results presented in this study suggest that this important food resource was consumed equally by high and low status individuals. The majority of Mesoamerican populations in which differential access to food has been demonstrated isotopically have been from Classic Period Mayan sites. It is possible that despite the presence of status markers in the Chalcatzingo residences and burials, the increasing social complexity at this Formative Period site simply had not yet led to status-based dietary differences.

While the present study lacks certain data such as osteological indicators of age and sex which would help to elucidate dietary differences, it does not appear that socioeconomic status played a significant role in dietary behaviors. A deeper understanding of all factors affecting status and identity would help to strengthen this

conclusion. Individuals whose burial locations and status indicators were somewhat anomalous did present slightly unusual stable isotope values. For instance, the individual who was buried in a cave (MS-0071) exhibited a lower $\delta^{15}\text{N}$ value than the population median. If the conclusions of Susan Gillespie (2011) are correct and these unusual burials outside of the city center represent something significant about individual identity, then the stable isotope data may support differential dietary behaviors according to social identity rather than simply socioeconomic status.

Oxygen stable isotope values at Chalcatzingo do not align with previously determined values in human remains from central Mexico (White et al., 2007). These results could be a product of differences in climate and elevation between Chalcatzingo and previously studied sites, or could represent a number of migrants living at Chalcatzingo. The question of the potential Gulf Coast origin of elites remains unanswered by the stable isotope data due to a lack of comparative oxygen stable isotope data in human remains from the Gulf Coast region.

The social complexity of Chalcatzingo, its location along long-distance exchange routes, and the presence of monumental architecture with Olmec-style carvings clearly situate it as an important and fascinating Formative Period site. Although there is evidence of significant interaction with the surrounding Mesoamerican sites and possible migration from the surrounding regions, it does not appear that socioeconomic inequality at Chalcatzingo resulted in the same patterns of differential access to food as at other Mesoamerican sites. It is conceivable that differences in distribution and consumption of food items may have increased through time with increasing social complexity, and a diachronic study of diet would provide significant insight into this possibility.

Additionally, stable isotope analyses of zooarchaeological remains and a greater number of human samples which can be more accurately associated with the burial record could help to elucidate social status patterns.

A single factor such as socioeconomic status cannot be used to adequately understand differences in human diet without a deeper understanding of the intersections between social status, identity, biology, and social interaction that affect human dietary behaviors. Stable isotope studies of ancient populations can continue to provide valuable insight into general dietary patterns and offer new information about individual variation when analyzed in conjunction with sociocultural and archaeological evidence. The results of stable isotope analyses within this study have supported some archaeological assumptions about Formative Period Chalcatzingo while questioning others, showing that using combined methods in our analyses is extremely useful for developing a more robust understanding of the past.

APPENDIX

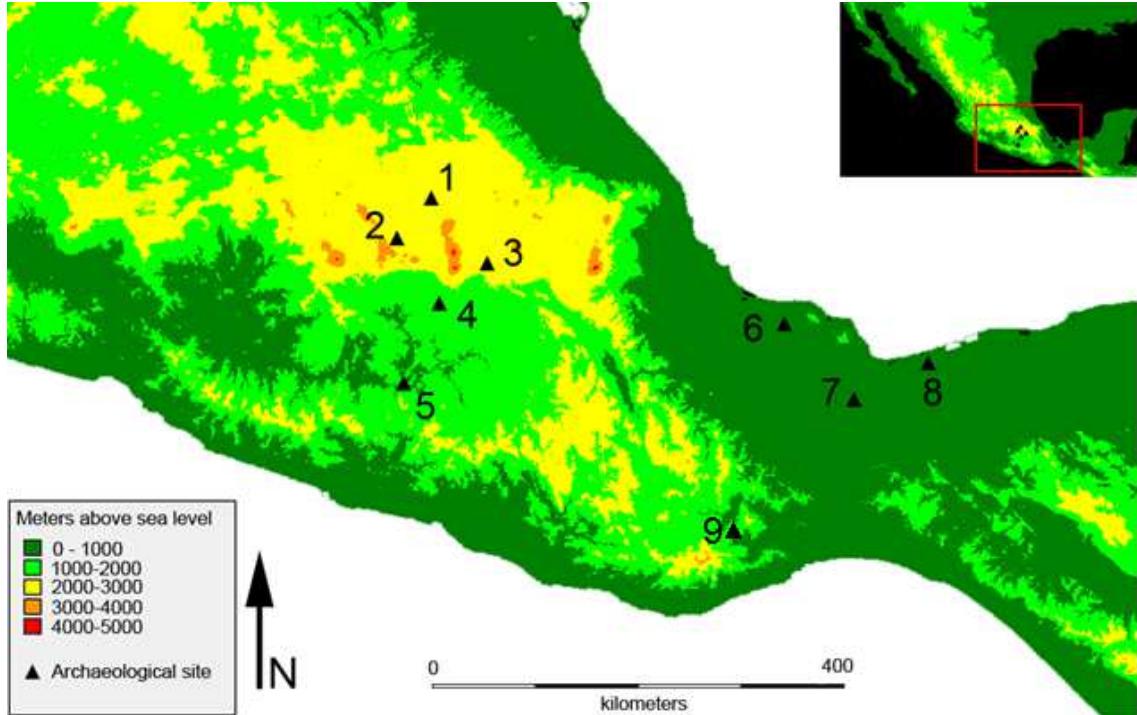


Figure 1. Map of Chalcatzingo (4) in relation to surrounding sites. Key: (1) Teotihuacan (2) Cuicuilco (3) Cholula (4) Chalcatzingo (5) Teopantecuanitlan (6) Tres Zapotes (7) San Lorenzo (8) La Venta (9) El Palmillo. Created by Andrew Somerville.

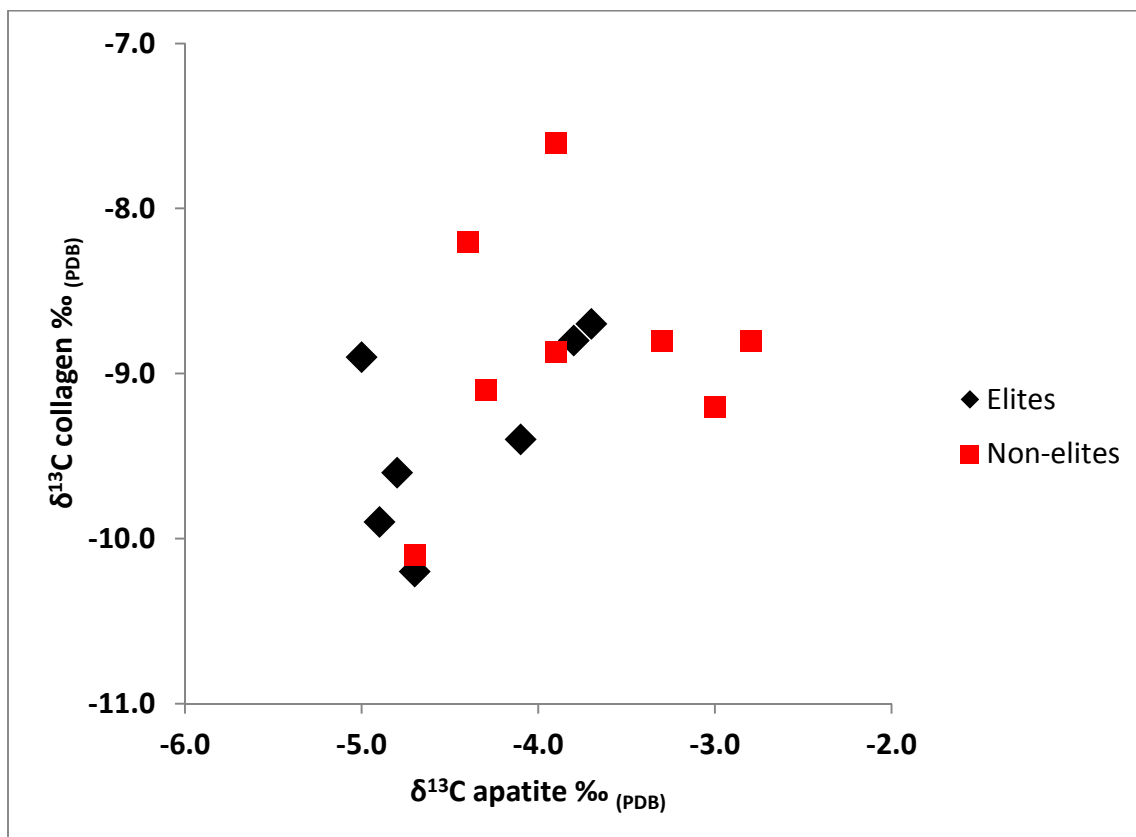


Figure 2. Scatterplot of $\delta^{13}\text{C}$ collagen and $\delta^{13}\text{C}$ apatite comparing elites to non-elites.

$\delta^{13}\text{C}$ values corrected by -1.0 ‰ to account for changes in atmospheric CO_2 .

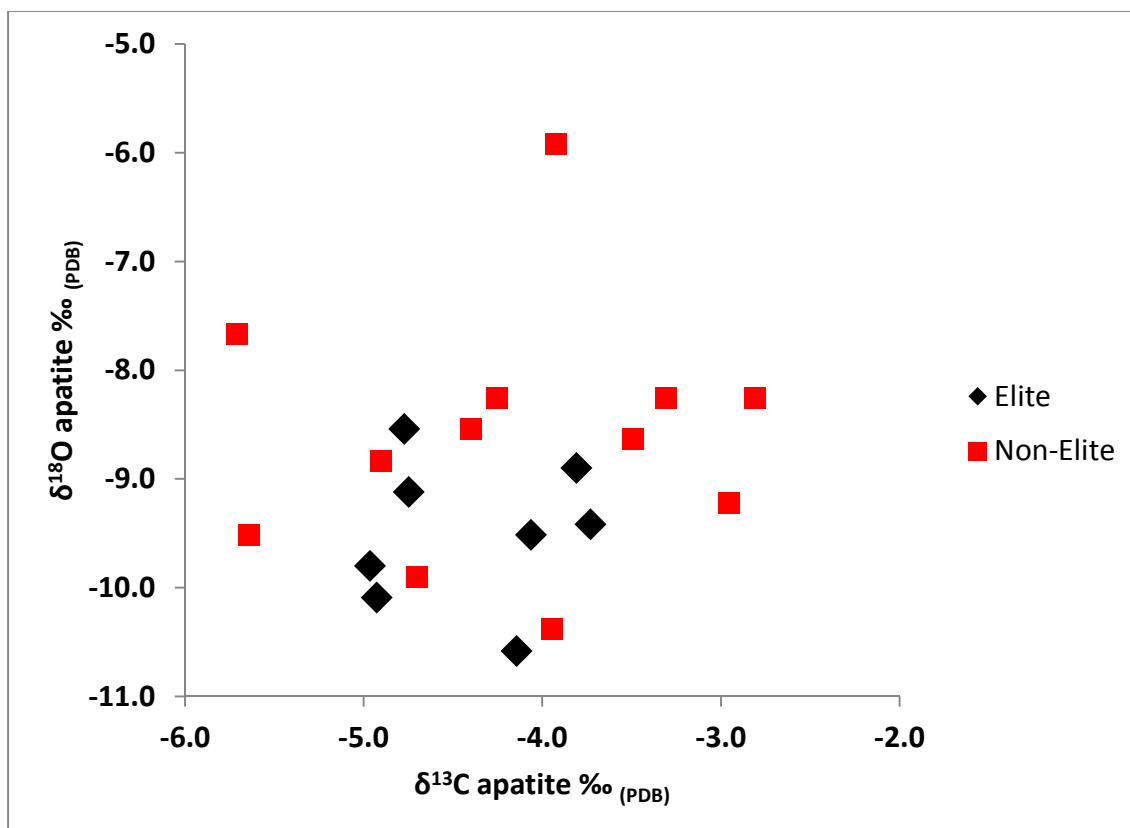


Figure3. Scatterplot of $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values in apatite comparing elite and non-elite values. $\delta^{13}\text{C}$ values corrected by -1.0 ‰ to account for changes in atmospheric CO_2 .

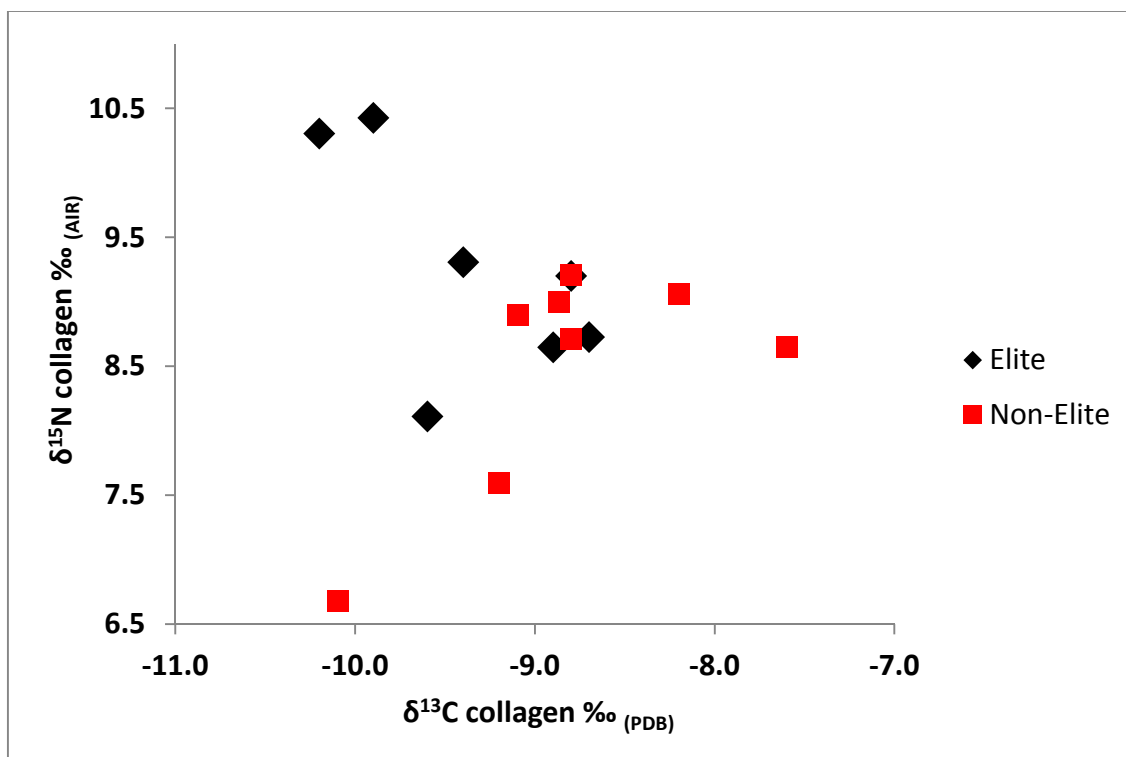


Figure 4. Scatterplot of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values in collagen comparing elite and non-elite values. $\delta^{13}\text{C}$ values corrected by -1.0 ‰ to account for changes in atmospheric CO_2 .

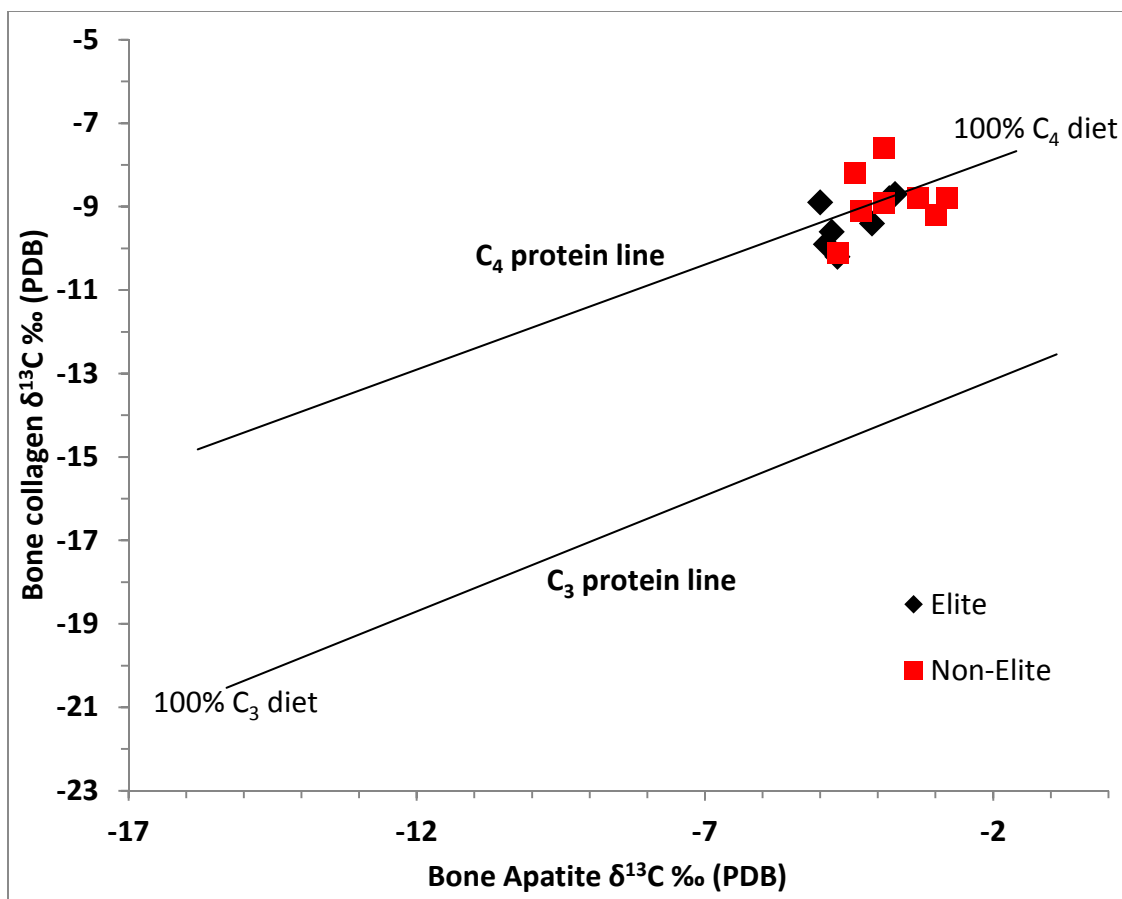


Figure 5. Scatterplot of $\delta^{13}\text{C}$ values in collagen and apatite comparing elite and non-elite values in relation to regression lines from a simple carbon model of diet. Adapted with permission from Somerville et al., 2013.

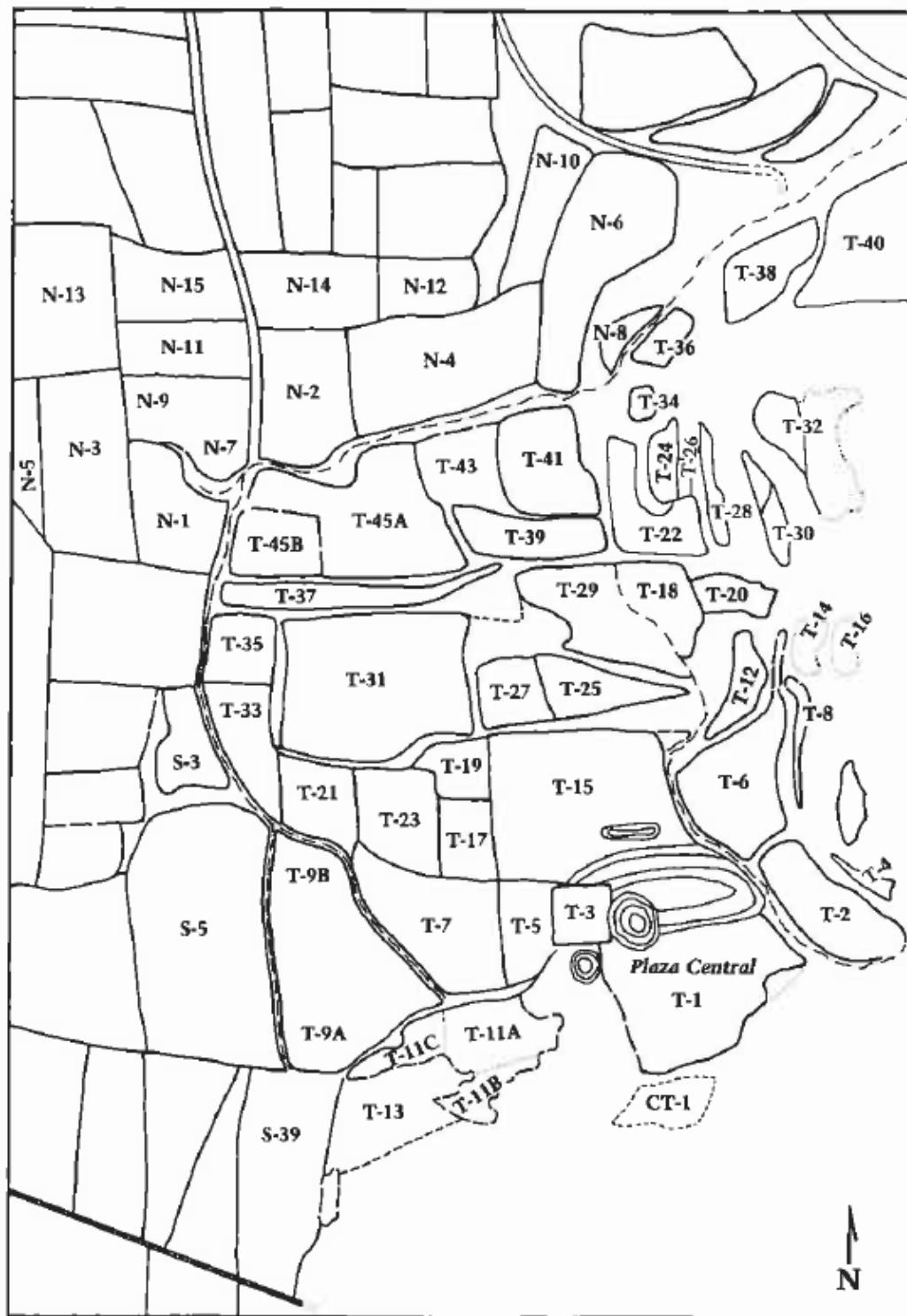


Figure 6. Map of project numbering for terraces and fields at Chalcatzingo. Adapted from Grove (1987).

Table 1. Status Determination.

Sample	Age	Sex	Location	Burial Type	Grave Goods	Status
MS-0001	Adult	-	Area A	-	-	NE
MS-0020	Adult	-	T-25	-	-	E
MS-0022	Adult	-	T-9B	Stone-associated	Peralta orange small olla	E
MS-0023	Adult	-	Field N-5	Direct	Fragment of perforated iron ore disc	NE
MS-0024	Adult	-	T-21	Stone-associated	1) Atoyac unslipped polished I small bowl with lip lugs 2) Eroded shallow bowl 3) Atoyac unslipped polished small bowl 4) Peralta orange composite silhouette bowl 5) Atoyac unslipped polished small bowl 6) Atoyac unslipped polished small bowl with interior hematite stains	E
MS-0036	Infant	-	T-11	Direct	None	NE
MS-0039	Adult	-	T-20	-	-	NE
MS-0041	Adult	-	T-23	-	-	NE
MS-0044	Adult	-	Cave 4	-	-	NE
MS-0046	Adult	-	T-25	-	-	E
MS-0047	Adult	-	T-25	-	-	E
MS-0067	Adult	-	T-25	-	-	E
MS-0071	Adult	-	Cave 1	-	-	NE
MS-0077	Adult	-	T-11	Direct	1) Amatzinac white pseudo-grater bottom bowl 2) Amatzinac white hemispherical bowl with exterior incising 3) Ground stone mano	NE
MS-0080	Adult	-	Field S39	-	-	NE
MS-0081	Adult	-	T-25	Stone-associated	1) Carrales coarse grey bowl, highly polished 2) Carrales coarse grey composite bowl with out-flaring rim and four evenly spaced rim lugs 3) Santa clara orange hemispherical bowl	E
MS-0084	Adult	-	Cave 4	-	-	NE
MS-0085	Adult	-	Field N-2	Direct	Eroded cantarito fragments at feet	NE
MS-0090	Adult	-	PC-1	Direct	Tubular jade bead	E
MS-0093	Adult	-	T-9A	Direct	None	NE
MS-0100	Adult	-	T-20	-	-	NE
MS-0102	Adult	-	PC-1	Direct	2 Amatzinac white shallow bowls	E

E = elite, NE = non-elite. Empty categories indicate missing information.

Table 2. FTIR results.

Sample Number	c/p	ir-sf
MS-0001	0.16	2.90
MS-0020	0.11	3.09
MS-0022	0.14	3.02
MS-0023	0.19	2.98
MS-0024	0.16	2.94
MS-0036	0.36	2.73
MS-0039	0.10	3.17
MS-0041	0.13	3.06
MS-0044	0.10	3.34
MS-0046	*0.07	3.21
MS-0047	0.12	3.03
MS-0067	0.19	2.86
MS-0072	0.17	3.21
MS-0077	0.27	2.94
MS-0080	0.21	2.93
MS-0081	0.14	3.08
MS-0083	0.17	3.21
MS-0084	*0.09	3.17
MS-0085	0.19	3.20
MS-0090	*0.07	3.34
MS-0093	0.10	3.10
MS-0100	0.11	3.14
MS-0102	0.14	3.16

* = values indicate diagenetic alteration and samples were excluded from comparative analysis.

Table 3. Collagen data.

Sample	Element	Status	C/N Ratio	Collagen Yield (%)	$\delta^{13}\text{C}$ (PDB)	$\delta^{15}\text{N}$ (AIR)
MS-0020	Long bone	E	3.43	2.6	-9.4	9.3
MS-0024	Misc.	E	3.38	2.1	-10.2	10.3
MS-0036	Innominate (infant)	NE	3.35	19.8	-7.6	8.6
MS-0039	Misc.	NE	3.375	2.2	-9.1	8.9
MS-0041	Long bone	NE	3.41	3.8	-8.8	9.2
MS-0047	Misc.	E	3.32	2.5	-9.6	8.1
MS-0067	Rib	E	3.32	3.9	-8.9	8.6
MS-0071	Long bone	NE	3.31	4.5	-10.1	6.7
MS-0077	Rib	NE	2.86	7.6	-8.2	9.1
MS-0080	Rib	NE	3.31	6.9	-8.8	8.7
MS-0081	Long bone	E	3.325	3.1	-8.8	9.2
MS-0083	Rib	E	3.35	4.1	-9.9	10.4
MS-0084*	Long bone	NE	4.84	1.0	-16.7	9.5
MS-0093	Cranial	NE	3.36	2.4	-8.9	9.0
MS-0100	Rib	E	3.37	3.1	-9.2	7.6
MS-0102	Cranial	E	3.32	2.1	-8.7	8.7

E = elite, NE = non-elite. $\delta^{13}\text{C}$ values corrected by -1.0‰ to account for changes in atmospheric CO_2 .

* = sample excluded due to diagenetic alteration.

Table 4. Hydroxyapatite data.

Sample	Element	Status	$\delta^{13}\text{C}$ (PDB)	$\delta^{18}\text{O}$ (SMOW)
MS-0001	Misc.	NE	-3.5	-8.6
MS-0020	Long bone	E	-4.1	-10.6
MS-0022	Long bone	NE	-4.1	-9.5
MS-0023	Rib	NE	-5.6	-9.5
MS-0024	Misc.	E	-4.7	-9.1
MS-0036	Innominate (infant)	NE	-3.9	-5.9
MS-0039	Misc.	NE	-4.3	-8.3
MS-0041	Long bone	NE	-2.8	-8.3
MS-0044	Misc.	NE	-4.9	-8.8
MS-0046*	Long bone	E	-4.1	-8.3
MS-0047	Misc.	E	-4.8	-8.5
MS-0067	Rib	E	-5.0	-9.8
MS-0071	Long bone	NE	-4.7	-9.9
MS-0077	Rib	NE	-4.4	-8.5
MS-0080	Rib	NE	-3.3	-8.3
MS-0081	Long bone	E	-3.8	-8.9
MS-0083	Rib	E	-4.9	-10.1
MS-0084*	Long bone	NE	-6.0	-7.1
MS-0085	Long bone	NE	-5.7	-7.7
MS-0090*	Long bone	E	-4.5	-8.8
MS-0093	Cranial	NE	-3.9	-10.4
MS-0100	Rib	E	-3.0	-9.2
MS-0102	Cranial	E	-3.7	-9.4

E = elite, NE = non-elite. $\delta^{13}\text{C}$ values corrected by -1.0 ‰ to account for changes in atmospheric CO_2 .

* = sample excluded due to diagenetic alteration.

Table 5. Stable Oxygen Isotope Values of Mesoamerican Regions. Adapted from White et. Al (2007).

Region	$\delta^{18}\text{O}$ phosphate (PDB)	$\delta^{18}\text{O}$ carbonate (PDB)
Central Highlands/Basin of Mexico	-16.4 to -14.5	-7.7 to -5.7
Western Mexico	-18.3 to -16.4	-9.7 to -7.7
Valley of Oaxaca	-18.3 to -16.4	-9.7 to -7.7
Pacific Coast Guatemala	-18.3 to -16.4	-9.7 to -7.7
Southern Highlands	-15.4 to -12.5	-6.7 to -3.8
Northern Lowlands (Yucatan)	-12.5 to -5.7	-3.8 to -3.2
Southern/Central Lowlands	-12.5 to -10.6	-3.8 to -1.8
Sierra Madre Occidental	-18.3 to -16.4	-9.7 to -7.7
Sierra Madre Oriental	-16.4 to -14.5	-7.7 to -5.7
Sierra Madre del Sur	-18.3 to -16.4	-9.7 to -7.7
Altiplano	-16.4 to -14.5	-7.7 to -5.7

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