ISOTOPIC INVESTIGATIONS OF ARCHAIC PERIOD SUBSISTENCE AND SETTLEMENT IN THE ST. JOHNS RIVER DRAINAGE, FLORIDA

By

BRYAN DUANE TUCKER

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2009

© 2009 Bryan Duane Tucker

To my family and friends

ACKNOWLEDGMENTS

I'd like to thank my committee for the guidance they have provided. John Krigbaum and Ken Sassaman provided invaluable assistance in the course of this research. This work would not have been possible without the technical wizardry of Jason Curtis, and I appreciate his willingness to get data to me on short notice. Paul Thacker and Rebecca Saunders have each read drafts of various parts of this research and their ongoing support throughout this process is greatly appreciated. I thank John Bloch and Ross Secord, for allowing me the freedom to finish this research while still maintaining financial stability. My wife Megan has been patient and supporting through this process and my daughter Eavan has reminded me to stop and have some fun on the way. Last, I would like to acknowledge the late Bob Blakely, for helping to develop the field of bioarchaeology and for introducing me to it.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS 4

LIST OF TABLES 8

LIST OF FIGURES 9

ABSTRACT 11

CHAPTER

1 INTRODUCTION 14

Archaeological Models of Mobility 19
Dissertation Outline 25
Variation in Burial Treatment 26
Variation in Diet 27
Variation in Stable Isotope Ratios Recorded in Human Tooth Enamel 29
Variation in Diet by Season at Harris Creek and Windover 30
Conclusion 31

2 ISOTOPIC INVESTIGATIONS OF MIDDLE ARCHAIC MORTUARY PRACTICES AT THE HARRIS CREEK SITE, TICK ISLAND, FLORIDA 34

Introduction 34
Mortuary Theory in Archaeology 35
Status or Rank 35
Group Mobility, Settlement Patterns and Mortuary Practices 36
Beyond Saxe-Binford 38
Harris Creek Burial Mound 38
Previous Investigations at the Site 39
Burial Form 40
Body Positioning 40
Stable Isotope Analysis 41
Carbon Isotopes 41
Oxygen Isotopes 42
Nitrogen Isotopes 43
Materials and Methods 43
Results 45
Accelerator Mass Spectrometry Dates 45
Stable Isotopic Values of Faunal Bone Apatite and Local Water 46
Stable Isotopic Values of Tooth Enamel 47
Discussion 48
Rank and Status 48
Settlement and Mobility 49

Function of Mounds 51
Conclusion 52

3 DIETARY CONTINUITY AND CHANGE DURING THE FLORIDA ARCHAIC 63

Introduction 63
Background 65
Stable Isotopes and Dietary Reconstruction 65
Apatite to Collagen Spacing and Diet 66
Previous Isotopic Studies of Harris Creek and Windover 67
Site Descriptions 68
The Windover site (8BR246) 68
The Harris Creek/Tick Island site (8VO24) 69
Materials 70
Methods 70
Results 71
Discussion 72
Conclusion 77

4 EVALUATING A SERIAL SAMPLING METHODOLOGY 83

Introduction 83
Environmental Buffering and Isotopic Attenuation 84
Tooth and Enamel Development 86
Maturation and Mineralization Waves 86
Carbonate Substitutions in Enamel 87
Striae of Retzius and Perikymata and Crown Formation Times 90
Materials and Methods 91
Sample selection 91
Site Descriptions 91
External Sampling—Dental Drill 92
Internal Sampling—Micromill 92
Pretreatment 93
Results 93
Discussion 94
Effects of Secondary Mineralization 94
Source of Isotopic Variation 95
Conclusion 97

5 PIERCING THE SEASONAL ROUND: USING STABLE ISOTOPES TO RECONSTRUCT HUMAN DIET BY SEASON AT WINDOVER AND HARRIS CREEK 109

Introduction 109
Background 114
Site Descriptions 114
Windover (8BR246) 114

Harris Creek (8VO24) 115
Previous Studies of Paleodiet at Windover and Harris Creek 116
Season of Site Occupation 116
Serial Sampling 119
Methods 121
Results 121
Discussion 122
Conclusion 125

6 CONCLUSION 140

APPENDIX

LIST OF REFERENCES 148

BIOGRAPHICAL SKETCH 164

LIST OF TABLES

Table		page
2-1	All individuals from the Harris Creek site (8VO24) sampled in this research.	53
2-2	Conventional and AMS radiocarbon dates from Harris Creek.	54
2-3	Harris Creek faunal bone and enamel isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW).	55
2-4	All Harris Creek human burials and dental isotopic $\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$ values	56
2-5	Harris Creek local human burials and dental isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW).	57
2-6	Harris Creek non-local (southern) human burials and dental isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW).	58
3-1	Windover and Harris Creek/Tick Island $\delta^{13}C$ and $\delta^{15}N$ ratios	79
3-2	Isotopic endpoints for the Isosource linear mixing model.	79
3-3	Results of Isosource remixing model for Harris Creek and Tick Island	79
4-1	Summary statistics for individuals sampled in this research.	99
5-1	Conventional and AMS radiocarbon dates from Harris Creek.	126
5-2	Season of site occupation of Archaic sites in the St. Johns Region	127
5-3	Summary statistics from Windover (8BR246) and Harris Creek (8VO24)	128
5-4	Perikymata counts for selected human molars from Harris Creek.	129

LIST OF FIGURES

Figure		page
1-1	Map of Florida with selected Archaic Period sites.	33
2-1	Location of the Harris Creek site.	59
2-2	A plot of $\delta^{18}O$ and $\delta^{13}C$ ratios of humans and fauna from Harris Creek.	60
2-3	Estimated $\delta^{18}O$ isopatches of river water for the state of Florida.	61
2-4	Distribution of local and non-local burials sampled in this research and the location of AMS dated individuals.	62
3-1	Adjusted $\delta^{13}C$ and $\delta^{15}N$ ratios of bone collagen and apatite from Windover and Harris Creek.	80
3-2	Difference in mean $\delta^{13}C$ ratios between apatite and collagen from Windover and Harris Creek.	81
3-3	Regressions of protein $\delta^{13}C$ ratios.	82
4-1	Serial sampling methods employed in this study.	102
4-2	Appositional nature of enamel formation.	103
4-3	Picture of tooth microstructure showing perikymata, enamel prisms and Striae of Retzius.	104
4-4	Difference in $\delta^{18}O$ ratios recovered from modern and prehistoric human molars.	105
4-5	Difference in $\delta^{13}C$ ratios recovered from modern and prehistoric human molars.	106
4-6	Distribution of $\delta^{18}O$ ratios for Western Europe and the Eastern US.	107
4-7	Series of $\delta^{18}O$ ratios from each sampling method for the modern teeth.	108
5-1	Milanich and Fairbank's (1980) model of movement between the river and coast	130
5-2	Russo and Ste. Claire's (1992) model of movement up and down the river and coast by separate ethnic groups.	131
5-3	The location of Windover (8BR246), Harris Creek (8VO24) and other Archaic Period sites in the region.	132
5-4	The $\delta^{13}C$ ratios of bone collagen from selected prehistoric sites	133
5-5	Appositional nature of enamel formation.	134

5-6 Picture of tooth microstructure showing perikymata, enamel prisms and Striae of Retzius. 135

5-7 Sampling tracks on a human molar.....136

5-7 Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Windover. 137

5-8 Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Harris Creek—individuals 4, 8, 35, 36, 38, 46, 91, 100/101. 138

5-9 Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Harris Creek—individuals 108, 128, 132, 153, 141, 147/148, 170. 139

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

ISOTOPIC INVESTIGATIONS OF ARCHAIC PERIOD SUBSISTENCE AND SETTLEMENT IN THE ST JOHNS RIVER DRAINAGE, FLORIDA

By

Bryan Duane Tucker

August 2009

Chair: John Krigbaum
Major: Anthropology

This research uses stable isotopic analysis and models of human mobility to examine three common themes in archaeological studies of hunter-gatherers; egalitarianism, subsistence, and settlement patterns. Specifically, $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ ratios from human bone and teeth are used to evaluate human mobility and identify variability in patterns of social organization, diet, and settlement during the Archaic Period in the St Johns region of Florida. Two Archaic Period sites, the Windover site (8BR246) and Harris Creek (8VO24), are assayed in this research.

First, mortuary variation at Harris Creek is evaluated as the result of differences in social status or as an outcome of the group's mobility strategy. Two competing hypotheses which explain differences between burials at Harris Creek are evaluated with $\delta^{13}C$ and $\delta^{18}O$ ratios from tooth enamel. The results of the isotopic assay suggest the differences in mortuary treatment are not the result of mobility strategies or social status, rather the different burials may show different religious or ethnic preferences exhibited by immigrants to the region.

Next, $\delta^{13}C$ and $\delta^{15}N$ ratios from human bone are used to assess the contribution of freshwater and marine resources to diet at Windover and Harris Creek. Culture historical models suggest a broad scale subsistence change occurred in the St Johns region between the Early and

Middle Archaic Periods when populations began to consume large amounts of riverine resources (Milanich & Fairbanks, 1980). Based on the isotopic data, there is no evidence of a new and intense use of riverine resources; both populations relied on moderate amounts of riverine resources as component of their total diet. The results also suggest a marine dietary component was present at both sites which suggests a seasonal occupation of the coast.

A serial sampling methodology is developed, tested and employed to determine the season of coastal occupation. Serial sampling studies are frequently employed to recover isotopic time series data from tooth enamel. However, concerns over isotopic attenuation caused by secondary mineralization have remained (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005). Fifteen human molars from four modern and eleven prehistoric individuals were assayed to develop a sampling methodology and to assess the effects of secondary mineralization. The results suggest that sampling the visible growth structures recovers the most isotopic variation and that secondary mineralization is not a major source of isotopic attenuation for researchers sampling enamel carbonate.

The sampling methodology suggested developed in the pilot study is used to sample molars from Windover and Harris Creek. Two settlement models have been suggested for Archaic Period in the St Johns region. The first suggests population occupied the St Johns River basin the warm months and moved to the coast or central highlands during the colder months (Milanich & Fairbanks, 1980). An alternative model suggests separate groups occupied the riverine and coastal zones year-round (Russo et al., 1992; Russo & Ste. Claire, 1992). The isotopic data suggest neither model is correct. Based on the $\delta^{13}C$ and $\delta^{18}O$ ratios and data from floral and faunal studies of the seasonal of site occupation, a new scenario is proposed suggesting a summer/fall occupation of the coast.

Finally, these results are considered as a whole and their implications for archaeological models of the region are discussed. The data suggest a dietary regime which included a summer use of coastal foods was in place as early as ca. 8000 BP and changed little over the next 5000 years. Despite the presence of large freshwater shell mounds, freshwater shellfish did not constitute a large portion of the annual diet which suggests the appearance of shell mounds during the Middle Archaic was not a result of a dietary shift. Furthermore, the presence of extra local individuals in these mounds suggests the mounds were not territorial markers for local groups of isolated hunter-gatherers; rather the mounds provided a place for contact between different groups in a wider network of socially connected groups.

CHAPTER 1
INTRODUCTION

This study contributes to broad-scale research within anthropology where issues of individual and group mobility are addressed within the framework of hunter-gatherer anthropology. Mobility is a universal property of all humans (Close, 2000) and specific types of mobility may have played a significant role in human evolution (Brantingham, 1998). This research uses stable isotopes to examine hunter-gatherer mobility at different geographic and temporal scales during the Archaic Period in the St. Johns region of Florida. Specifically, stable isotope ratio analyses are used to evaluate human mobility by identifying variability in patterns of social organization, subsistence, and settlement patterns. The St. Johns River basin and the adjacent Atlantic coast have been the subject of archaeological study for over a century. The area is rich in prehistoric remains with sites ranging from the Paleoindian to the Mission Period (Milanich, 1998). Despite long-term study, many aspects of hunter-gather life during the Archaic Period remain unclear including the degree of mobility required to maintain social networks, harvest natural resources, or construct massive freshwater shell mounds found along the river. Advances in stable isotope geochemistry provide a novel means to interpret mobility in the past and offer fresh perspectives of old ideas in hunter-gatherer research and the Archaic prehistory of the Southeastern United States.

Though hunter-gatherers have been the subject of anthropological study since the advent of the discipline, modern hunter-gatherer studies began in the 1960s with projects like the Harvard Kalahari Project (Lee & De Vore, 1968). Such projects were designed to study modern hunter-gatherers to model the behavior of our human ancestors. These projects approached the study of hunter-gatherers from an ahistorical evolutionary-ecological perspective which presumed these groups remained isolated and thus provided a glimpse of the human past (Stiles,

1992). Under this model, traits that make up the hunter-gatherer "package" such as residential mobility, seasonal population aggregation, egalitarianism, food sharing, and simple technology were human adaptations to an unpredictable environment.

During the late 1980s and throughout the 1990s, the growing post-modern movement introduced a historical perspective into hunter-gatherers studies (Lewin, 1988). This revisionist perspective was accompanied by an explicit recognition that hunting and gathering groups, like all humans, had a long and rich history that shaped the group's current behaviors. The revisionist scholars argued that the San, an African hunter-gatherer group, were not prehistoric relics shaped by the environment, rather their lifeway had been formed by their history of political conflict and European colonialism (Schrire, 1980; Wilmsen, 1983). Under this historical model, many of the traits used to define hunter-gatherers are viewed as a reaction to the dominant culture of aggressive neighbors rather than the result of environmental constraints. Hunter-gatherers of the ethnographic present are best understood as components rather than antecedents of complex societies (Sassaman, 2004).

The revisionist critique suggests ethnographically documented populations are unsuitable analogs for prehistoric groups. These scholars recognize that recent hunter-gatherers are a subset of those that existed before the advent of farming and that social organizations not present today may have been common in the past (Deetz, 1968; Hodder, 1986; Schrire, 1984; Sealy, 2006; Wobst, 1978; Woodburn, 1980). Archaeological studies of complex hunter-gatherers have demonstrated that many of the defining traits traditionally associated with modern hunter-gatherers, like small group size, egalitarianism and residential mobility were not present in all hunter-gatherer groups in prehistory (Chapman, 2003; Price & Brown, 1985; Sassaman, 2004). In fact, a subsistence economy based on wild food resources is no longer directly associated with

any particular form of social organization, level of technology, labor relations, intergroup relations, or ideology (Sassaman, 2004). The dissolution of the hunter-gatherer package of traits has called the category of "hunter-gatherers" into question with some advocating the abandonment of the category altogether (eg.Burch, 1998:211). Considering the diversity present in modern and prehistoric groups, hunter-gatherers can be defined simply as people who acquire the majority of their food through hunting, fishing, and gathering, with no *a priori* assumptions about other aspects of their social system (after Sassaman, 2004).

Long histories of interaction with neighboring societies coupled with reduced diversity among modern hunter-gatherers suggest they are poor analogs for Pleistocene groups. In the absence of modern analogs, the only way to study hunter-gatherers in a world of hunter-gatherers, before animal husbandry or agriculture, is through the study of archaeological remains. Though movement is ephemeral and seldom leaves any material trace in the archaeological record, archaeologists have developed several techniques to reconstruct human movement in prehistory (Close, 2000). These reconstructions are frequently based on the source of raw materials used for stone artifacts (e.g. Amick, 1996) ceramics (e.g. Simms et al., 1997), lithic refit studies (Close, 2000), the frequencies of plant remains (Bonzani, 1997), or the types of houses and storage (Smith, 2003). These techniques are seldom able to clarify the movement of individuals, though a few exceptions occur under extraordinary circumstances such as Close's (2000) refitting study and the footprints at Laetoli (Leakey & Hay, 1979). Most archaeological studies of mobility avoid the individual and study broad scale patterns of mobility or they assess mobility in terms of its relationship to the organization of technology (Close, 2000).

The archaeological study of mobility is further complicated by the imperfect relationship between movement and material culture (Kelly, 1992:21). Artifacts may be decoupled from the

individual rendering the movement of material goods independent from the movement of the individual. As a result, the materials goods may be cached for later use or traded down-the-line.

Indicators of mobility in an individual's biological remains are not subject to the problems which complicate archaeological studies based on material culture. Unlike artifacts, biological markers of mobility cannot be decoupled from the individual. Studies of mobility using human remains have focused on two areas of research; biomechanical markers and stable isotope analysis. Bone is a living tissue which reacts to stresses from habitual activities and thus records evidence of the activity in its morphology. Repeated activity can affect bones throughout the human skeletal system and the markers left by these forces can provide information about the life history of the individual (Carlson et al., 2007; Larsen et al., 1991; Merbs, 1983; Wanner et al., 2007). For instance, Larsen and Ruff (1994) assert that a general reduction in the size of the femoral midshaft in Contact Period populations from the Georgia Bight is a result of a decrease in individual mobility related to a new focus on farming introduced by the Europeans.

Stable isotopes are often employed in the study of prehistoric mobility. Light stable carbon and oxygen isotopes distinguish dissimilar environmental regions and, unlike the analysis of artifacts, flora or fauna, and settlement patterns, stable isotopes provide direct evidence for mobility at the individual level of analysis (e.g. Montgomery et al., 2005; Price et al., 2000; White et al., 1998). Throughout this research, stable isotope abundances are reported in delta (δ) notation which expresses the ratio of heavy to light isotopes in a sample compared to a standard measure in parts per thousand (per mil or ‰) (Faure, 1986). Ratios of $\delta^{13}C$ vary between terrestrial and marine systems and, in the absence of C_4 plant consumption, reliably assess the amount of marine foods in the diet. In terms of $\delta^{18}O$ ratios, environmentally similar regions have

similar seasonal $\delta^{18}O$ averages which fractionate in a predictable fashion according to latitude, altitude, and distance from the sea. The $\delta^{18}O$ values of precipitation are incorporated into the surface water of lakes and rivers and eventually into the biological tissues, including the bones and teeth, of animals and humans (Longinelli, 1984; Luz et al., 1984). Therefore, ratios of $\delta^{13}C$ and $\delta^{18}O$ recovered from these tissues ultimately reflect the isotopic profile of the environment where the tissue formed and differences in these ratios inform studies of mobility (Balasse et al., 2002; Bentley and Knipper, 2005; Evans et al. 2006; Hoogewerff et al., 2001; Prowse et al., 2003; Turner et al., 2005; White et al., 1998, 2001).

The independent data produced by the isotopic study of teeth are not subject to the same problems of equifinality as are archaeological studies of mobility based on material culture or subsistence remains. Stable isotope ratios are locked in tooth enamel and, when combined with paleodemographic profiles, can identify variations in individual and group mobility caused by cultural factors such as post-marital changes in residence. Isotopic data have been used to inform and strengthen archaeological models based on material culture. White et al. (1998), for instance, demonstrate the presence of ethnic enclaves at Teotihuacan using oxygen isotopes. Additionally, stable isotopes have been able to demonstrate the diversity of past hunter-gatherers compared to modern hunter-gatherer groups. Sealy (2006) found prehistoric settlement systems very different from those documented ethnographically in the same region. Isotopic data from prehistoric coastal hunter-gatherers in the southern Cape of Africa, demonstrate the Cape was divided into territories occupied by separate hunter-gatherer groups (Sealy, 2006). These groups appear to have practiced an economic or perimeter defense (from Cashdan, 1983) rather than the social boundary defense which applies to most ethnographically documented societies in the region (Sealy, 2006).

Archaeological Models of Mobility

This research uses stable isotopes to evaluate human mobility during the Early and Middle Archaic Periods in the St. Johns River region of Florida. The concept of mobility is central to any archaeological or ethnoarchaeological research that studies people who move(d) at a detectable rate (Close, 2000). Mobility is an important topic because changes in mobility are often accompanied by changes in food storage, trade, territoriality, social and gender inequality, sexual division of labor, subsistence and demography, as well as cultural notions of material wealth, privacy, individuality, cooperation, and competition (Kelly, 1992). Furthermore, mobility is critical for a more nuanced understanding of the variation and patterning found in the archaeological record (Binford, 1980).

As Close (2000:50) points out, there are few definitions of "mobility." Kelly (1992:44) believes "mobility is a property of individuals, who may move in many different ways: alone or in groups, frequently or infrequently, over long or short distances." Close (2000:50) cites Jochim (1976:24) who defines mobility as "the potential distance necessary to travel per capture." However, mobility is typically associated with the act of moving rather than the potential to move (Kelly, 1992:44). Therefore, Bamforth's (1988:20) definition may be more appropriate, although referring to bison, he equates the "degree of mobility" with "the frequency of movements, the distance of movements, or the speed of movements."

The concept of sedentism is related to and often confused with mobility. Historically, anthropologists considered sedentism and mobility at opposite ends of a continuum with typological categories ranging from nomadic to fully sedentary (e.g. Murdock, 1967). This continuum was often broken into 4 groups:(1) fully migratory or nomadic bands, (2) seminomadic communities whose members wander in bands for at least half of the year but occupy a fixed settlement during some season or seasons, (3) semisedentary communities whose

members shift from one fixed settlement to another seasonally or who occupy a single settlement and a substantial portion of the population departs from seasonally to occupy shifting camps, and (4) relatively permanent settlements (Murdock, 1967:159). When sedentism is conceptualized as a point on a continuum of residential mobility, or as a category in opposition to a more mobile state, archaeologists collapse the different dimensions of mobility (Kelly, 1983). As Kelly (1992:52) points out, sedentism may not reduce mobility; in fact logistical mobility is likely to increase as a group becomes more sedentary (Binford, 1980). It may be more productive to consider sedentism a threshold phenomenon defined by all segments of a population using facilities within a settlement during all seasons of a year (Plog, 1990) or when a portion of the population remains in a residential settlement throughout the year (Rafferty, 1985).

The juxtaposition of mobility and sedentism obscures the fact that mobility is universal, variable, and multi-dimensional (Kelly, 1992; Smith, 2003). The concept of mobility includes several dimensions: (1) individual mobility, or the movement of individuals independent of one another, (2) group mobility, or the coordinated movements of individuals, and (3) the frequency and magnitude of movement (Kelly, 1983; 1992). Movement is not equal for all individuals. Some individuals may move more than others (e.g. men vs. woman, young vs. old), and movement also occurs on daily, seasonal, and annual scales (Kelly, 1992). Differences in mobility provide different options for dealing with specific foraging dilemmas; some foraging tasks are better accomplished by individuals, others may require group action (Brantingham, 1998). Of the multiple dimensions of mobility, residential and logistical are the most often discussed (Binford, 1980; Kelly, 1983; 1995).

Binford's (1980) foraging and collecting model remains highly influential in archaeological discussions of mobility. Most studies of mobility are based on or in reaction to

Binford 's mobility types—foraging/residential and collecting/logistical. Binford (1980:10) describes two types of mobility strategies; a forager strategy where a group "maps onto" resources through residential moves and adjustments in group size, and logistically organized collectors who acquire specific resources with specifically organized task groups. His foraging model shows seasonal residential moves among a series of resource patches. In addition to areas with patches, this model is applicable to areas with relatively even resource distributions such as tropical rainforests or other equatorial settings. (Binford, 1980). In a foraging system, foragers range out daily gathering food on an "encounter basis" and return to their residential bases each afternoon or evening (Binford, 1980:5). Binford (1980) allows for considerable variability in the size of the mobile group and in the number of residential moves that are made by the group in the course of an annual cycle.

In terms of archaeological residues, a forager system is expected to produce two basic spatial contexts: a residential base and a location. A residential base is the hub of subsistence activities where foraging parties originate and where processing, manufacturing, and maintenance occur (Binford, 1980). A location is a place where resources are procured or where "extractive tasks" are performed (Binford, 1980:9). In settings with limited resources, patterns of residential mobility may be limited to a series of very restricted locations such as water holes, increasing the year to year redundancy in the use of particular residential camps (Binford, 1980). In general, foragers have high residential mobility and daily food procurement strategies.

Residential mobility is divided into a number of dimensions including demography, scheduling, frequency, stability, range and length/duration (Ames, 1991; Chatters, 1987; Kelly, 1983). The demography of a group is highly variable and may change in response to the patchiness of resources. When resources become scarce, members of a group may not all move

at the same time or to the same new location (Yellen, 1977). Scheduling involves the organization of mobility patterns to deal with scarceness by adjusting to seasonal distributions of resources (Binford, 1983). Frequency refers to the number of residential moves in a year and the duration of each occupation. Stability is the permanence of a mobility pattern from year to year and results in the redundant use of the landscape over several years (Binford, 1983). Range involves the total distance covered in a year and the average distance traveled for each residential move (Binford, 1983). According to Kelly (1992; 1995), the length of occupation of a residential site is determined by weighing the cost and benefit of staying compared to the cost and benefit of moving. The duration of residential site occupation varies, ranging from short-term occupation to year-round use of a location. The duration of site occupation also varies by season, often long-term occupations and limited group movement occur during one season (e.g. winter/summer or rainy/dry) with high group mobility during other times of the year. Hunter-gatherers are expected to move more frequently in marginal environments when resource productivity is low, unless sufficient stores are available (Smith, 2003).

In the collector or logistical mobility model, collectors organize task groups to leave the residential base for overnight forays to procure a specific type of resource. Unlike a foraging based system, collectors maintain stores of food for a portion of each year (Binford, 1980). In addition to residential bases and locations, collectors generate three additional types of sites: field camps, stations and caches. A field camp is a temporary base for a task group where the group sleeps, eats, and maintains itself while away from the residential base (Binford, 1980). A station is a site where task groups gather information, such as observing the movement of game or other humans (Binford, 1980). Caches are necessary for collectors because procurement of resources by small groups for relatively large groups requires storage (Binford, 1980).

Binford's (1980) categories of residential (forager) and logistical mobility (collector) have proven to be useful heuristic tools, but they should not be employed as dichotomous categories (Binford, 1980). Binford (1980) views the categories as a graded series from simple to complex and suggests that logistical and residential variability be viewed as organizational alternatives which are employed in various combinations. Most groups practice a complex blend of settlement strategies rather than occupying the poles of a continuum or a single category between sedentary and mobile (Binford, 1980; Lightfoot & Jewett, 1986; Pauketat, 1989; Varien, 1999; Warrick, 1988).

Under most models, mobility is related to the quality, quantity and distribution of resources (Binford, 2001; Donald & Mitchell, 1994; Hitchcock, 1982; Kelly, 1983). Mobility allows hunter-gatherers to reduce risk by "averaging over" variability and simply moving away from scarcity (Cashdan, 1992:237; Halstead & O'Shea, 1989; Kelly, 1983; 1992). However, factors other than the distribution and collection of resources can affect mobility. For instance, the depletion of water and fuel and the accumulation of trash, debris, and vermin can influence when and how often a group moves (Smith & McNees, 1999; Wandsnider, 1992).

In addition to physical and economic demands, social dimensions also affect mobility. Mobility can be influenced by a need to seek spouses, allies, shamans, or move in response to sorcery, death, and political concerns (Griffin, 1989; Vickers, 1989). Kelly (1990) points out that residential mobility itself may be culturally valued. Formerly mobile hunter-gatherers often regret their sedentary nature and "express a desire to move around in order to visit friends, to see what is happening elsewhere, or to relieve boredom" (Kelly, 1992:48).

Though social complexity and mobility are no longer directly correlated, changes in behavior and social organizational associated with agriculture and political complexity often

correlate with relatively sedentary societies. Evaluating sedentism at different social and temporal scales allows models of the adoption of agriculture and/or the emergence of political complexity to be assessed (Gallivan, 2002). Traditionally, increasing sedentism and social/political complexity have been associated with the emergence of agriculture (Christenson, 1980:52-53; Cohen, 1977; Rindos, 1983). However, studies of complex hunter-gatherers suggest areas with a rich supply of food resources can support relatively sedentary societies with large populations and complex political and social systems (Erlandson, 2001; Moseley, 1992).

Many complex hunter-gatherer societies subsist on aquatic resources (Erlandson, 2001; Moseley, 1975; 1992; Rick et al., 2001; Russo, 1996). Abundant marine and freshwater resources are capable of supporting large sedentary populations (Binford, 1968:332-333; Moseley, 1975; Sealy, 2006) and their richness and availability may obviate many of the shortages that necessitate residential mobility (Bailey & Milner, 2002; Bailey & Parkington, 1988; Binford, 1968; Cohen, 1977). Binford (1990:137) reports that terrestrial hunters moved more frequently over longer distances than did aquatic hunter-gatherers. Aquatic foods are excellent sources of protein and can be harvested by members of the population who are often excluded from subsistence procurement (children and seniors) (Russo et al., 1992).

Coastal and riverine environments, like those of the St. Johns region, can support a variety of societies with levels of mobility and sedentism ranging from seasonally mobile to fully sedentary settlements with complex social and political organizations (Perlman, 1983:293; Widmer, 1988). Two models of settlement have been suggested for the St. Johns region during the Middle to Late Period. Milanich and Fairbanks (1980) suggest that people spent their summers along the St. Johns River and dispersed to the coast and/or the interior during the colder months. Russo and colleagues (1992) critique this model demonstrating that it is a synthetic

treatment of flawed data originating with researchers in the late 19th century. Russo and Ste. Claire (1992) propose an alternative scenario in which separate populations occupied the coast and river valley year-round. These groups may have been sedentary or may have practiced some form of residential mobility in their respective riverine or coastal zone.

Delineating the types of mobility and the relative level of sedentism practiced by groups in the St. Johns region through time permits the discursive relationship between settlement pattern and social/political complexity to be examined. A better understanding of this relationship could indicate how and why social complexity arose and what social and/or environmental conditions lead to the high levels of social complexity common today.

Dissertation Outline

This research reconstructs subsistence and settlement patterns as proxies to evaluate human mobility and identify variability in patterns of social organization, subsistence, and settlement during the Archaic Period in the St. Johns region of Florida. Two well known Archaic Period sites in the St. Johns region of Florida are assayed in this research: Windover (8BR246) and Harris Creek (8VO24). The Windover site is an Early Archaic cemetery located near Titusville, Florida where at least 168 human skeletons were recovered from the shallow but persistent pond **(**Figure 1-1**)** (Doran 2002). Radiocarbon dates on human skeletal material indicate the interments occurred between 7,100 and 7,330 rcybp (Doran 2002). The Harris Creek-Tick Island site is a Mt. Taylor Period mortuary mound on Tick Island in the St. Johns River. Recent AMS dates on four of the 175 burials recovered from the site indicate the mortuary layers date to between cal. BP 6793 to 7179 [0.96] (X-9110) and 6482 to 6758 [0.98] (X-9111A), a range of cal BP 697 to 35 radiocarbon years (two sigma).

First, isotopic and mortuary variation in burials at Harris Creek is evaluated as the result of differences in social status or as an outcome of the group's mobility strategy. Settlement

patterns are reconstructed at the micro and macro level. The micro level analysis examines movement up and down the St. Johns River and between the river and the Atlantic coast. Macro level patterns are evaluated by quantifying the number of extra-local immigrants present in the populations. Then stable isotopes are used to identify and quantify the amount of freshwater and marine resources consumed during the Archaic Period, both in terms of annual diet at the level of the individual and on a temporally broader scale by determining when human populations in the region began to make use of marine resources. After the presence of a marine component in the diet is established, a serial sampling methodology is used to evaluate the season of consumption. Finally, the results of these studies are combined to assess culture historical models of the Archaic Period in the St. Johns region.

Variation in Burial Treatment

Differences in burial treatment are often interpreted to reflect identity or social status of the deceased (e.g. Binford, 1971; Saxe, 1970) or temporal/geo-spatial considerations of corpse disposal (e.g. Buikstra & Charles, 1999; Hofman, 1985). Both of these interpretations are particularly relevant for the population interred at the Harris Creek site. Excavations recovered more than 175 burials which were divided into two groups; tightly flexed secondary burials and loosely flexed primary burials (Jahn & Bullen, 1978). The difference between primary and secondary burials at Harris Creek has been interpreted as the earliest evidence for social differentiation among hunter-gatherers in North America (Aten, 1999:179). Alternatively, secondary burials are often interpreted as individuals who died while away from a preferred burial site and were processed and stored until an appropriate time and place for burial (e.g. Buikstra & Charles, 1999; Hofman, 1985).

Stable isotopes can be used to test if the differences in burials at Harris Creek reflect social differentiation or temporal/geospatial aspects of corpse disposal. Individuals of different

social status often have different diets which may be recorded in different isotope ratios between burial types (Ambrose et al., 2003; White et al., 2001). Individuals with higher rank or status, evidenced by secondary burials, may have experienced greater access to protein sources, such as meat or seafood, than more loosely flexed burials possibly resulting in enriched $\delta^{15}N$ or $\delta^{13}C$ values. Differences in $\delta^{18}O$ values, which are derived primarily from drinking water are not expected if the differences between the burial types are rank or status-related. Alternatively, if the differences in secondary and primary burials are the result of a need for curation and transport, then no differences would be expected in the isotope ratios of the two burial types. These hypotheses are tested with data derived from human molars from the Harris Creek site.

The results of the isotopic assay indicate the majority of sampled burials at Harris Creek belong to two groups of people, one local to the site and one (or more) non-local group that grew up further south on the Florida peninsula. The entire local group received post-mortem processing as indicated by their secondary (tightly flexed) burial. In comparison, only a portion of the non-local 'southern' group received similar burial treatment. The presence of primary and secondary burials at Harris Creek does not appear to be related to curation or transportation of the dead. Instead the differences probably result from different customs practiced by the different groups who came together at Harris Creek.

Variation in Diet

Stable isotopes are also used to reconstruct the diet of the people interred at Windover and Harris Creek. The use of $\delta^{13}C$ and $\delta^{15}N$ ratios from human bone to reconstruct diet is now a common method of bioarchaeological investigation (Ambrose et al., 2003; Buikstra & Milner, 1991; Hutchinson et al., 2000; Katzenberg & Saunders, 2000; Katzenberg et al., 1995; Newsome et al., 2004; Prowse et al., 2004; Richards et al., 2005; Schoeninger, 1989; Schoeninger & Schurr, 1998; Schwarcz et al., 2005; Turner et al., 2005; White & Schwarcz, 1989). Differences

in these values can indicate a reliance on marine foods or maize and differentiate between the relative trophic positions of the animals consumed. Though both Windover and Harris Creek are mortuary sites not habitation sites, neither is located on the coast and no evidence of marine food has been found at inland sites in the St. Johns region. Therefore, any evidence of marine food in the diets of the people interred at either site would represent some level and type of mobility between the river valley and the coast.

In addition to issues of diet and mobility, stable isotopes can provide evidence to evaluate the presence of monumental architecture in the St. Johns region. Many researchers suggest Middle Archaic shell mounds middens resulting from a new and intensive use of riverine resources (e.g. Milanich 1994). Other researches assert these mounds are examples of monumental architecture which may or may not be composed of food remains (Randall & Sassaman 2005b). Using the human dietary data, the assertion that mound construction is related to a shift in subsistence economy is addressed.

Isotopic ratios of $\delta^{13}C$ and $\delta^{15}N$ from Windover and Harris Creek/Tick Island suggest a minor shift in diet between the Early Archaic and Middle Archaic Periods. The results from Harris Creek suggest Mt. Taylor populations were not consuming large numbers of freshwater snails. Based on their $\delta^{13}C$ and $\delta^{15}N$ ratios and the estimated isotopic end member values of potential food resources in the region, people at Harris Creek and Windover consumed large amounts of marine/estuarine fish. Since no major shift in subsistence accompanies the introduction of shell mounds in the region, the appearance of shell mounds in the region does not seem to be related to a shift in diet and other explanations for mound construction should be sought.

Variation in Stable Isotope Ratios Recorded in Human Tooth Enamel

Most isotopic studies of dentition use a bulk sampling methodology to assess an average isotopic value for the period of enamel formation. A serial sampling or isotopic zoning (Kohn & Cerling, 2002) approach samples discrete units of enamel representing different periods of time. Multiple samples in a sequence collected from a single individual provide time series data which allow isotopic variability to be studied.

Secondary mineralization is a major concern in serial sampling studies (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005). Enamel is only partially mineralized at deposition and secondary mineralization occurs during the maturation phase as the mineral content of the tooth increases until the enamel is fully mineralized. This process extends the period of time over which minerals and isotopes are incorporated into a unit of enamel. Despite this concern, serial sampling methodologies have been successfully employed in many isotopic studies of faunal dentition (Balasse et al., 2005; Fricke & O'Neil, 1996 ; Gadbury et al., 2000; MacFadden et al., 2004; Wiedemann et al., 1999; Zazzo et al., 2005). However, this serial sampling methodology has not been frequently applied to human remains (but see Fuller et al., 2003; Sponheimer et al., 2006).

Before this technique can be used to reconstruct the seasonal round for the inhabitants of Windover and Harris Creek, the effects of secondary mineralization on the serial sampling of human dentition must be determined. I must also establish that the isotopic variation recovered from human dentition reflects environmental inputs and is not the result of internal biological rhythms. To this end, a sample of 15 human molars from various contexts is assayed. Four of the fifteen molars are modern, two from Gainesville, Florida and two from New Castle-on-Tyne, United Kingdom. The remaining eleven teeth are from four different prehistoric contexts, Harris Creek (Florida), the West Mouth of Niah Cave, (Sarawak, Malaysia), Lobang Jeragan, (Sarawak,

Malaysia), and Gua Cha, (Kelantan, Malaysia). Each molar was sampled using two methods; a micomill was used to sample the inner enamel along the project path of mineralization and a dental drill was used to remove samples from the surface of the tooth parallel to the growth structures (perikymata). The results of each method are compared to evaluate the effects of secondary mineralization and to evaluate which sampling method recovers more isotopic variation. The results of this study suggest serially sampling dentition from Harris Creek and Windover parallel to the growth structures will provide reliable dietary data with sub-annular resolution.

Sampling the visible growth structures recovers more isotopic variation than sampling parallel to the enamel prisms. These results do not suggest secondary mineralization is a significant source of isotopic attenuation in stable isotopic studies of tooth enamel carbonate. Based on the comparison of the modern and prehistoric teeth, no variation is caused by an internal biological rhythm; rather the prehistoric teeth reflect an attenuated record of seasonal variation apparent in $\delta^{18}O$ values.

Variation in Diet by Season at Harris Creek and Windover

Serial sampling techniques developed in the previous section are applied to human molars from Windover and Harris Creek to assess the relative amount and timing of marine food consumption. These data allow for the reconstruction of the seasonal round and provide a means to evaluate mobility at the individual level of analysis.

Isotopic samples from Windover and Harris Creek provide a diachronic view of dietary change in the St. Johns region during the Early and Middle Archaic. This diachronic view of dietary change and seasonal scheduling can provide information about mobility patterns through time in the region. Changes in mobility and resource use may be correlated with changes in settlement patterns and the construction of shell mounds and ridges.

Data recovered from Windover and Harris Creek indicate these populations consumed more marine food during warm months than during the cold months. These data support the bone isotope studies which indicated a marine component in the diet of people from Windover and Harris Creek. Based on these results and the distance of these sites from the sea, it is likely these hunter-gatherer groups were residentially mobile and occupied the coast or an estuarine environment for at least a portion of each summer

Conclusion

This research approaches three themes common in the archaeological study of hunter-gatherers to evaluate hunter-gatherer mobility: egalitarianism, subsistence, and settlement models. Though each chapter functions as an independent module, they are united by an isotopic methodology and the use of mobility as an explanation for the variability observed. In addition to the three main themes, other issues are addressed including ethnicity, monumentality, and technical issues of tooth enamel mineralization and development.

Taken as a whole, this research provides a significant new source of data to evaluate models of mobility, social differentiation, subsistence and settlement in the St. Johns region of Florida. An isotopic approach is well suited to evaluate mobility at the level of the individual and avoid many issues of equifinality present in archaeological studies. Additionally, the serial sampling methods developed here demonstrate that serial sampling human molars provides reliable data which show dietary and environmental change over a period of months rather than years. This increased resolution allows the seasonal round of hunter-gatherers to be assessed isotopically. This technique could be applied to questions in contexts far removed from the Southeastern United States. For instance, this technique can be used to clarify the long standing debate over the amount and timing of marine foods in human diets during the Mesolithic/Neolithic transition of Europe (Hedges, 2004; Lidén et al., 2004; Milner et al., 2004;

Richards & Hedges, 1999; Richards et al., 2003). In addition to marine resources, $\delta^{13}C$ ratios from serially sampled human teeth could reveal the seasons in which significant amounts of maize were consumed. Detailed information on the seasonality of maize consumption correlated with evidence for long term storage facilities could provide new insights into the Woodland/Mississippian transition in the Eastern Woodlands.

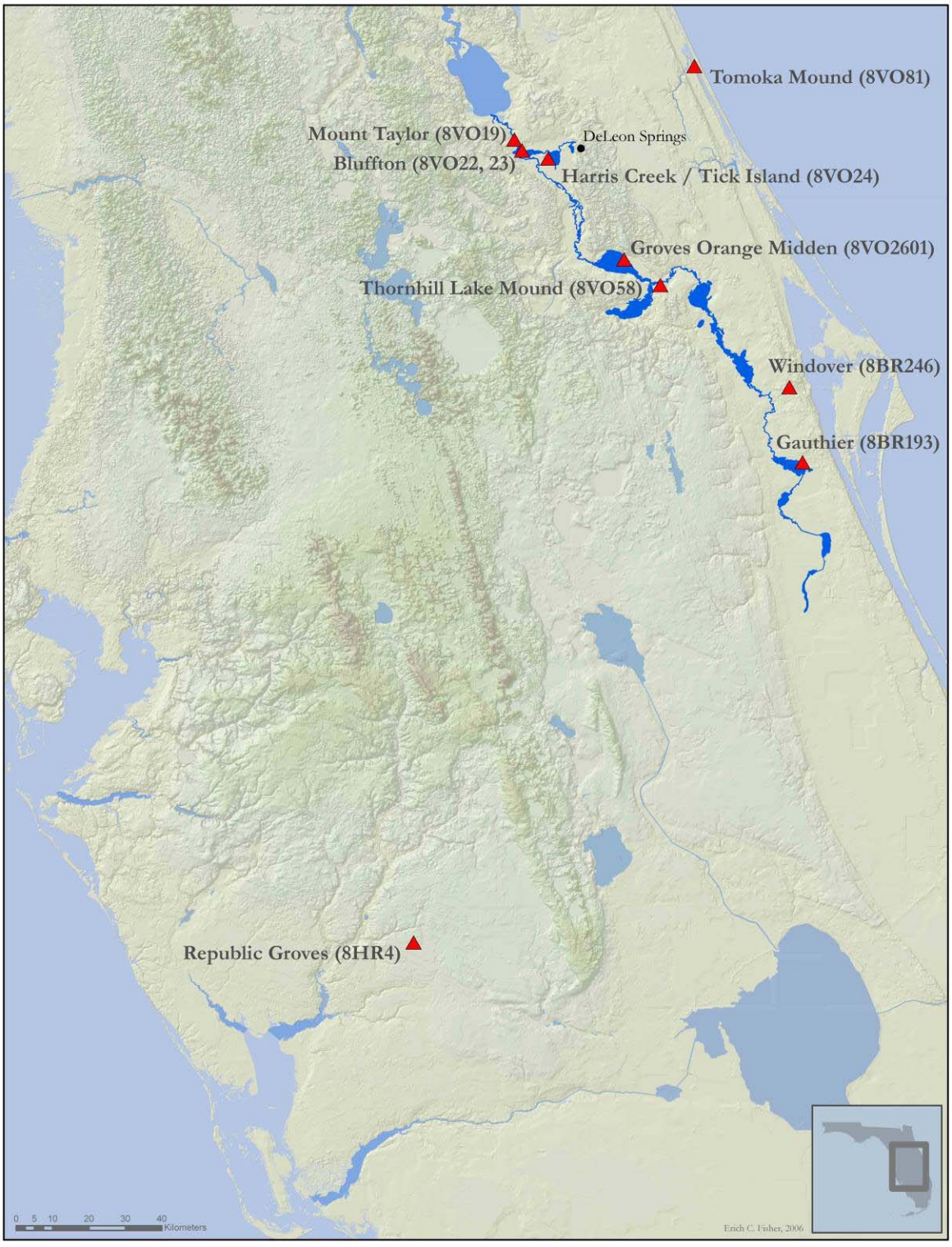


Figure 1-1. Map of Florida with selected Archaic Period sites.

CHAPTER 2
[1]ISOTOPIC INVESTIGATIONS OF MIDDLE ARCHAIC MORTUARY PRACTICES AT THE HARRIS CREEK SITE, TICK ISLAND, FLORIDA[1]

Introduction

The rituals and customs surrounding death and burial are some of the oldest areas of study in anthropology and archaeology (e.g. Gluckman, 1937; Kroeber, 1927) and remain of interest today (Garazhain & Yazdi, 2008 e.g. ; Horsley, 2008 ; Komar, 2008 ; Semple & Williams, 2007). Information about the participants, both living and dead, are encoded in the mortuary event, which has been interpreted to reflect a fashion-like phenomena (e.g. Cannon, 2005 ; Kroeber, 1927), the identity of the deceased (e.g. Binford, 1971; Saxe, 1970), the identity of the living participants (e.g. Parker-Pearson, 1999), or temporal/geo-spatial considerations of corpse disposal (e.g. Buikstra & Charles, 1999; Hofman, 1985). Human remains also contain information about the life history of the individual, which can be recovered through a variety of macroscopic, microscopic, genetic and chemical analyses (Larsen, 1997). When integrated, aspects of the mortuary event and the life history of the deceased can combine for more complete and holistic analyses (see Goldstein, 2006 for a discussion).

In this study, we examine mortuary variation at an Archaic period mortuary site in present-day Florida. Stable isotopes provide an ecological and geographical life history of the deceased, which may be integrated with mortuary data to produce a more nuanced understanding of burial practice. Specifically, we examine a suite of isotopic data to evaluate previous interpretations of Archaic mortuary variation at the Harris Creek site on Tick Island. Harris Creek (8VO24) is a Middle Archaic freshwater shell mound in the St. Johns River basin of

[1] This chapter is an early version of a manuscript in preparation for publication as: Tucker, B., Krigbaum, J. and Quinn, R. 2009. Isotopic Investigations of Mortuary Practice at the Harris Creek Site, Harris Creek, Florida. Submitted to American Antiquity.

northeastern Florida (Figure 2-1). Excavations during the 1960s by Bullen and co-workers recovered more than 175 burials before shell mining destroyed the site (Jahn & Bullen, 1978). Differences among the burials have been interpreted as some of the earliest evidence for social differentiation among hunter-gatherers in North America (Aten, 1999).

Stable isotopes bound in human tooth enamel provide an individual life history, including information about childhood residence and diet. Isotopic data can be framed into broader environmental context allowing for multi-scalar analyses not possible with conventional archaeological data. Isotopic ratios of $\delta^{13}C$ and $\delta^{18}O$ from human tooth enamel and $\delta^{15}N$ ratios from human dentin are used to investigate differences in diet, status/rank, residence and settlement pattern at Harris Creek. Finally, the functional correlates of mound use are examined for the Archaic people of present-day north-central Florida.

Mortuary Theory in Archaeology

Mortuary theory allows inferences about the living to be drawn from the burial of the dead. These inferences include evaluations of social status (heterarchical vs. hierarchical) as well as mobility and settlement patterns. Additionally, mortuary theory allows a more nuanced understanding of the role of the mortuary events for the living and the dead.

Status or Rank

The Saxe-Binford approach remains an important interpretive framework used to identify evidence of social status or social rank in mortuary data (Rakita & Buikstra, 2005). This approach assumes a relatively direct relationship between the social status of the deceased and the energy or wealth expended in the burial of the individual (Binford, 1971; Tainter, 1978). Elements of mortuary ritual such as complexity of body treatment, construction/placement of interment facility, extent/duration of mortuary ritual, material contributions to ritual, and evidence for human sacrifice are frequently associated with social rank (Tainter, 1975). The

amount of corporate involvement and the degree of disruption the community experiences during the death of one of its members may correlate with the amount of labor or energy used in subsequent funerary rites (Tainter, 1973 ; Tainter, 1978). Binford (1971) suggests that the number of social identities ritualized at death varies according to the social position enjoyed in life and that funerary treatment varies with elements of the social persona. For instance, biological sex could be distinguished by grave orientation or associated grave goods. Biological age is often expressed by variations in method of disposal, grave characteristics, patterning of the body, and/or placement of the grave.

Group Mobility, Settlement Patterns and Mortuary Practices

Differences between individuals within a burial population may represent more than facets of an individual's social persona or identity. For instance, in seasonally mobile groups, death might occur a considerable distance from a preferred burial site; in such cases, the deceased could be buried where she/he died (i.e. away from the preferred site) or curated and transported back to a preferred site at a time of group aggregation. Indeed, Hofman (1985) and Buikstra and Charles (1999) contend that differences between primary and secondary burial reflect the circumstances of the group at the time of an individual's death, specifically the group's distance from its preferred burial site. In their respective studies, evidence from two Archaic sites, the Ervin site in Tennessee and the Bullseye site in the Illinois River Valley, suggests that individuals who died afar were bundled and transported back to the site as a part of each group's seasonal round. If timing and logistics were important factors influencing burial, then variation in burial treatment and frequency of secondary burial could be informative about group organization, group mobility, and territory size (Buikstra and Charles, 1999; Hofman, 1985). In addition to issues of distance and timing, the deceased's social persona could affect the group's decision to curate and transport the remains only a subset of individuals might deserve or require

curation. In this model, cemeteries and mortuary mounds may act as seasonal aggregation sites, which serve economic, political, social, and ideological functions for seasonally mobile hunter-gatherers (Hofman, 1985). Burial rites may have played an important role in constituting and/or unifying many of these functions (Hofman, 1985).

Mortuary practices also reflect aspects of circumscription and territoriality. Saxe (1970) suggested that formal disposal areas for burial of the dead are maintained by corporate groups who use descent to legitimize their rights over crucial but restricted resources. Goldstein (1976) evaluated Saxe's hypothesis using data culled from thirty ethnographic studies. She concurs that the maintenance of a permanent, specialized and bounded disposal area is a means by which a corporate group might seek to legitimize its right to control and claim resources. However, in what has become referred to as the Saxe-Goldstein hypothesis, Goldstein adds that groups might symbolize this relationship in different ways—the absence of a formal cemetery does not preclude the existence of a lineal descent group (Goldstein, 1976).

The Saxe-Goldstein hypothesis was re-evaluated by Schroeder (2001), who addressed the issue of secondary disposal/burials using data from the Standard Cross-Cultural Sample of Murdock and White (1969). Schroeder's sample consisted of 186 well-documented societies which were linguistically and culturally distinct. With regard to the Saxe-Goldstein hypothesis, Schroeder found that there is a relationship between crucial (probably fixed) resources and lineal descent groups. Schroeder (2001:90) notes that "when this relationship is legitimated by lineal ties to ancestors, it may be reinforced by the maintenance of formal disposal areas exclusively used for dead". However, the exact relationship between crucial resources, lineal descent groups, and secondary disposal has yet to be elucidated (Schroeder, 2001).

Beyond Saxe-Binford

That physical and circumstantial factors affect mortuary practices seems clear; however many researchers argue that these are secondary to, and independent from, ideological and social factors (e.g. Carr, 1995; Hodder, 1984; Kroeber, 1927; Parker-Pearson, 1999). Rather than simply reflecting the identity of the deceased, these (and other) researchers believe that mortuary behavior is fluid and manipulated by the living to meet their own needs (Parker-Pearson, 1999). Some have reconfigured aspects of the Saxe-Binford approach, or have defined new approaches altogether (Barrett, 1990; Brown, 1995 ; Chapman, 1995 ; Härke, 2002; Lull, 2000 ; Morris, 1991 ; Parker-Pearson, 1993). New approaches include: the study of personhood (Gillespie, 2001), gender (Arnold & Wicker, 2001 ; Crown & Fish, 1996; Howell, 1995; Sullivan, 2001), and practice/agency theory (Barrett, 1990). Nevertheless, despite these critiques and reassessments, most researchers agree that the Saxe-Binford approach provides a starting point for analyses and does not exclude other symbolic or ideological aspects of mortuary investigation.

Harris Creek Burial Mound

Mortuary practices at Harris Creek, which include mound burial with differences in complexity of body treatment and extent/duration of mortuary ritual, have typically been associated with status or rank (Tainter, 1975). However, it is also possible that the freshwater shell mound constituted a formal burial area used by a descent group to legitimate their rights to specific resources, as proposed by Goldstein (1976) and Saxe (1970). In this project, we use stable isotope ratios to ascertain the relative importance of social ranking and/or circumscription of resources by Middle Archaic groups at Harris Creek.

Previous Investigations at the Site

Prior to its destruction, Harris Creek (8VO24) was composed of a series of shell middens and ridges, along with a substantial, bean-shaped platform mound constructed of freshwater shell, estimated to have been 5.5 to 10.7 m above ground level (Aten, 1999). The site has a long history of investigation, starting with Moore in 1891, followed by Bullen in 1961. Bullen conducted salvage excavations of the northeastern slope of the mortuary mound. Although more than 175 burial features were recovered, firsthand accounts from people involved in the shell mining operations indicate that hundreds of burials were destroyed by mining activities prior to Bullen's mitigation (Aten, 1999). This suggests the original number of interments at the site greatly exceeded those recovered by Bullen (Aten, 1999).

Aten (1999) identified ten stratigraphic layers within the mound; the lowest layer was designated Layer 1. The majority of the burials were in layers 3 and 4. Layer 3, the "white sand zone," was the earliest mortuary layer and contained two types of mortuary-related deposits: areas of white sand with burials and lenses of white sand with evidence of fires built atop them. Layer 3 also contained the "black zone," a zone of dark, organic, charcoal-impregnated soil with associated postholes. Following Jahn and Bullen (1978), Aten (1999) suggests that this zone represents the remains of a charnel house. The "black zone" in layer 3 is overlain by a more homogeneous Layer 4, constructed of freshwater snail shell (primarily *Viviparus* sp.) and a dark brown sandy matrix.

Jahn and Bullen (1978) reported four conventional radiocarbon dates from samples taken from his Harris Creek excavations. Two of these bracket the mortuary levels, one at the base of level 3 and one well above the mortuary layers in layer 8 (Aten, 1999). Charcoal at the base of layer 3 produced a radiocarbon date of 5450±300 rcybp (M-1264) and charcoal from layer 8 produced a date of 5320±200 rcybp (M-1265) (Aten, 1999). Based on these dates, the use range

of the two mortuary components could have been as great as 630 radiocarbon years or as short as 30 radiocarbon years (based on 1σ deviations). Once calibrated (CALIB 5.0.1, 2σ) (Stuiver & Reimer, 1993), Bullen's dates range between 6912 and 5112 years BP suggesting mound use could have exceeded 1800 years.

Burial Form

Deceased individuals at Harris Creek were primarily interred in layers 3 and 4 of the shell mound. Burial features typically contained one to three individuals, although one mass grave included at least 11 individuals (Aten, 1999). Aten (1999) identified three variations of burial treatment. Some burials were placed on a small fire in the bottom of the pit before the grave was filled with white sand; the aforementioned burial of 11+ individuals was in this category. Postholes in and around this grave suggest it was surrounded by a fence or structure of some kind. Other burials involved sand with no evidence of fire, the interred body being covered with a layer of white sand and shell midden. Finally, some burials were simply placed in a pit and covered with shell midden.

Body Positioning

The majority of the burials (98%) recovered from Harris Creek were flexed and consisted of two types—loosely flexed, in which the individual was lying on his or her side, and tightly flexed, in which the individual was interred in a vertical or seated position (Aten, 1999). Aten proposed that the loosely flexed burials were interred shortly after death (primary burials) and that the tightly flexed vertical burials were interred after an extended period of exposure above ground (secondary burials). The tightness of the vertically flexed burials suggests they were partially defleshed prior to burial. Additionally, some bones in tightly flexed burials were associated with the remains of small fires and some bones show evidence of charring, indicating that these bodies were desiccated and partially decomposed prior to burial (Aten, 1999).

Stable Isotope Analysis

Stable isotopes are commonly used to investigate the diet and movement of animals and humans (e.g. Ambrose et al., 2003; Balasse et al., 2002; Buikstra & Milner, 1991; DeNiro & Epstein, 1978; Dupras & Schwarcz, 2001; Hutchinson et al., 2000; Katzenberg & Saunders, 2000; Lee-Thorp, 1989; Montgomery et al., 2005; Price et al., 2002; Price et al., 2000; Richards et al., 2001; Schoeninger & Moore, 1992; van der Merwe, 1982; White et al., 1998). Following convention, the abundance of stable isotopes are reported in delta (δ) notation, which expresses the ratio of heavy to light isotopes in a sample compared to that of a known standard, measured in parts per thousand (per mil or ‰) (Faure, 1986) using the formula:

$\delta = [(R_{sample}/R_{standard}) - 1] \times 1000$ where $R = {}^{13}C/{}^{12}C$, ${}^{18}O/{}^{16}O$, ${}^{15}N/{}^{14}N$

The standard employed for carbon ($\delta\ {}^{13}C$) and oxygen ($\delta\ {}^{18}O$) is Pee Dee Belemnite (PDB) or its modern equivalent (NIST 19), and for nitrogen ($\delta\ {}^{15}N$) the standard is AIR.

Carbon Isotopes

In terrestrial systems, stable carbon isotopes vary by photosynthetic pathway, C_3, C_4, and CAM. C_3 plants have $\delta^{13}C$ ratios from –35 to –20‰ (avg = –26.5‰) and C_4 plants have $\delta^{13}C$ values that range from –15 to –7‰ (avg = –12.5‰) (Smith, 1972; Smith & Epstein, 1971). Edible CAM plants have a range of $\delta^{13}C$ values that partially overlap those of C_3 and C_4 plants. CAM plants are not a substantial concern in the diet of prehistoric inhabitants in eastern North America, although some prickly pear has been recovered from Archaic sites in Florida (Doran, 2002; Newsom, 1994; Tuross et al., 1994). Stable carbon isotopes also discriminate between terrestrial C_3 biota ($\delta^{13}C$ values between –35 to –20‰) and marine systems ($\delta^{13}C$ values between –19 to –9‰) (Schoeninger & DeNiro, 1984; Smith, 1972). In the absence of significant C_4 or CAM resources, i,e. in the Archaic southeastern United States, $\delta^{13}C$ values can be used to differentiate terrestrial and marine diets and the values have been employed in numerous

paleodiet studies (Ambrose & DeNiro, 1986; Drucker & Bocherens, 2004; Dupras et al., 2001; Hutchinson, 2002; Katzenberg et al., 1995; Keenleyside et al., 2006; Richards et al., 2002; Schoeninger & Schurr, 1998; Schwarcz et al., 2005; Tuross et al., 1994; Vogel & Van de Merwe, 1977; White et al., 1998; Wright & Schwarcz, 1998).

Oxygen Isotopes

The $\delta^{18}O$ of surface water are determined in large part by temperature, precipitation, and evaporation. The $\delta^{18}O$ of precipitation is determined by the ambient temperature and the amount of precipitation. Generally, warmer weather results in enriched $\delta^{18}O$ values and cooler weather in decreased $\delta^{18}O$ values (Bryant & Froelich, 1996). In temperate regions, which have relatively constant rainfall paired with varied temperatures throughout the year, $\delta^{18}O$ values are enriched during the summer months (Gonfiantini, 1985). In tropical regions, which have varied rainfall and more constant annual temperatures, $\delta^{18}O$ values track the amount of rainfall (Njitchoua et al., 1999).

Environmentally similar regions have similar seasonal $\delta^{18}O$ averages which fractionate in a predictable fashion according to latitude, altitude, and distance from the sea. The $\delta^{18}O$ values of precipitation are incorporated into the surface water of lakes and rivers and eventually into the biological tissues of the animals and humans (Longinelli, 1984; Luz et al., 1984). When significant differences in $\delta^{18}O$ ratios exist between regions, these differences can be used to assess migration and immigration in archaeological contexts (Balasse et al., 2002; Bentley & Knipper, 2005; Evans et al., 2006; Hoogewerff et al., 2001; Prowse et al., 2003; Turner et al., 2005; White et al., 2001; White et al., 1998); for example, White et al. (1998) use $\delta^{18}O$ values to identify and delineate immigrant ethnic enclaves at Teotihuacan.

Nitrogen Isotopes

Protein consumption and relative trophic level of the species consumed is commonly measured in archaeological assemblages with $\delta^{15}N$ values of collagen extracted from bone and dentin. The lighter isotope is more easily incorporated into metabolic processes such as ammonia excretion, resulting in loss of ^{14}N and enrichment of organism tissue in ^{15}N. At the base of the trophic pyramid, nitrogen-fixing flora such as legumes are typically lower in $\delta^{15}N$ values and may approach 0‰ (Shearer & Kohl, 1986). These and other primary producers supply herbivores with low $\delta^{15}N$ values. As enrichment ensues with excretion, and primary and secondary carnivores consume herbivores, they take on the enriched ^{15}N resulting in a stepwise function up trophic level (Koch et al., 1994). Additional trophic spaces in marine ecosystems result in higher $\delta^{15}N$ values relative to terrestrial and freshwater ecosystems (Schoeninger & DeNiro, 1984; Schoeninger et al., 1983). Marine plant's $\delta^{15}N$ ratios are approximately 4‰ enriched relative to terrestrial plants.

Materials and Methods

We utilized a subset of Harris Creek burials previously analyzed for $\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$ from tooth enamel and dentine (n = 39; Quinn et al., 2008). We choose burials with the most complete mortuary information and provenience data available (n = 21; Quinn, 1999). We did not include four individuals previously interpreted as immigrants from coastal and northern regions because these extreme outliers obscured variation present in the remaining sample (Quinn et al., 2008); rather, we focused on individuals believed to reside within the St Johns River valley. We enhanced the dataset with additional carbon and oxygen isotopic analysis of tooth enamel from 9 burials, yielding a total of 48 individuals. We denoted vertically flexed burials as 'Secondary' and loosely flexed burials as 'Primary,' reflecting their delayed or relatively rapid interment after death, respectively. Table 2-1 lists the burials with associated

mortuary information. The combined sample consists of 36 (75%) secondary burials and 12 (25%) primary burials. These ratios approximate the ratios of burial types recovered from the site: ca. 60% tightly flexed (secondary) and ca. 38% loosely flexed (primary) burials (Aten, 1999).

To establish a local isotopic baseline, bone apatite from 6 deer and enamel from 1 raccoon from the Harris Creek site were assayed for $\delta^{13}C$ and $\delta^{18}O$. Additionally, in an attempt to gain better chronological control over the mortuary layers at Harris Creek, four human bone collagen samples were AMS dated. Two individuals were sampled from layer 3 and two from layer 4.

For this study, enamel and dentin were preferred over bone for several reasons. First, tooth enamel is less likely to suffer diagenetic alteration than bone apatite (Koch et al., 1997; Nielson-Marsh & Hedges, 2000). In addition, enamel and primary dentin are not remodeled during an individual's lifetime. Finally, sampling dentin and enamel from the same tooth provides information on different aspects of the diet at the same point in time in an individual's life. The $\delta^{13}C$ ratios in enamel record whole diet, while $\delta^{13}C$ ratios in dentin preferentially reflect the protein component of the diet (Ambrose & Norr, 1993).

Each tooth records the diet consumed during the period of enamel formation. Mineralization and crown formation in human molars has been estimated by Smith (1991): first molar (0.1 to 2.5 years after birth), the second molar (3.8 to 6.8 years after birth), and the third molar (9.5 years to 12.4 years after birth). Bulk samples taken from the surface of the tooth do not encompass the entire period of crown formation. Due to the incremental nature of tooth growth, a portion of the enamel growth layers are enveloped in the appositional zone under the cusps and do not reach the surface (Dean & Benyon, 1991). Therefore, though crown formation

spans a period of ca. 2.5-3 years, each bulk sample contains only an average of around one to two years of growth, depending on the amount of tooth wear and which molar is sampled.

For stable isotopic analysis, the nine additional tooth samples were ultrasonically cleaned in distilled water and air-dried. Tooth surfaces were inspected under magnification and lightly abraded to remove remaining debris using a low speed dental drill (Brasseler UG12) outfitted with a carbide bit (Brasseler #170). Under magnification, a single sample (ca. 1.0 mg) per tooth was taken along the axis of growth. Sample powders were not chemically pretreated. Enamel was analyzed using a Micromass PRISM mass spectrometer interfaced with a multiprep device. Analytical precision is estimated at better than 0.05‰ for $\delta^{13}C$ and 0.1‰ for $\delta^{18}O$. Repeat analyses of three samples from Quinn et al. (2008) showed insignificant differences in both isotopes (e.g. Passey et al., 2002).

We report $\delta^{13}C$ values of enamel relative to PDB. These values are enriched compared to the diet $\delta^{13}C$ values by approximately 9-14 per mil (Lee-Thorp, 1989). The $\delta^{15}N$ values of collagen from dentin are reported relative to air and are enriched by 1-5 per mil relative to diet $\delta^{15}N$ values (Ambrose & DeNiro, 1986; DeNiro, 1985). We included only $\delta^{15}N$ values from collagen that yielded C:N values between 2.9-3.6 (Ambrose, 1990). We converted $\delta^{18}O_{PDB}$ values to Standard Mean Ocean Water (SMOW) after Coplen et al. (1983) and then converted $\delta^{18}O_{SMOW}$ values to $\delta^{18}O$ of ingested water ($\delta^{18}O_{IW}$) (after equations derived by Cormie et al., 1994; Iacumin et al., 1996; Luz & Kolodny, 1985; Luz et al., 1984). The $\delta^{18}O_{IW}$ values from the faunal sample were used to define a range of local values for the vicinity of Harris Creek.

Results

Accelerator Mass Spectrometry Dates

New accelerator mass spectrometry (AMS) data for four human burials from Harris Creek are reported in Table 2-2. Two individuals from layer 3 produced calibrated (CALIB 5.01) 2

sigma dates of cal BP 6793 to 7179 [0.96] (X-9110) and cal BP 6742 to 7030 [0.90] (X-9112RA). Two individuals from layer 4 are slightly younger in age at cal BP 6598 to 6891 [0.97] (X-9109A) and cal BP 6482 to 6758 [0.98] (X-9111A). These new AMS dates are uniformly earlier than dates reported by Bullen (Crane & Griffin, 1965). Based on these new dates, Harris Creek mortuary layers 3 and 4 span a time range of cal BP 697 to 35 radiocarbon years (2σ).

Stable Isotopic Values of Faunal Bone Apatite and Local Water

Bone from seven deer (*Odocoileus virginianus*) and tooth enamel from one raccoon (*Procyon lotor*) was sampled to establish the range of $\delta^{18}O$ values for local water. Bone apatite returned $\delta^{18}O_{PDB}$ values ranging from -3.1 to -0.3‰, with an average of -2.0 ± 0.8‰. Once converted to ingested water (IW) values, the $\delta^{18}O_{IW}$ values range from -4.5 to -0.8‰ with an average of -3.0 ± 1.1‰ (Table 2-3). One deer outlier is considerably enriched ($\delta^{18}O_{IW}$ = -0.8‰) compared to the remaining samples and is likely non-local in origin. With the outlier removed, the average $\delta^{18}O_{IW}$ value for deer bone apatite is -3.0% ± 0.7.

Deer are browsers and their $\delta^{18}O_{IW}$ values are often enriched relative to local water sources because deer derive a large amount of their water from consumed leaves, which are enriched relative to local water sources due to evapotransporation (Luz et al., 1990). However, this effect is most pronounced in areas of low relative humidity where isotopic enrichment of $\delta^{18}O$ can be as high as 9.7‰. Florida has high relative humidity and thus low evapotransporation minimizing $\delta^{18}O$ enrichment in leaves (Luz et al., 1990). The omnivorous raccoon is an obligate drinker and typically consumes surface water while drinking and eating. Its $\delta^{18}O_{IW}$ value therefore should constitute a robust measure of local water values. The raccoon has a $\delta^{18}O_{IW}$ value of -3.6‰, which is 0.2‰ depleted compared to the average deer $\delta^{18}O_{IW}$ values of -3.0‰, supporting

minimal enrichment in deer. Based on the faunal values, and the likelihood of a slight enrichment in the deer's $\delta^{18}O_{IW}$ values, we estimate the range of $\delta^{18}O$ values for local water sources in the vicinity of Harris Creek to be -2.5 to -4.0‰.

Quinn et al. (2008) modeled $\delta^{18}O$ values for Florida rivers adjusting modern $\delta^{18}O$ values by -1‰ to account for a 5°C higher average summer temperatures in the mid-Holocene (Jones et al., 2005). However, despite the evidence for increased summer temperature and increased seasonality, the mean faunal $\delta^{18}O_{IW}$ from Harris Creek suggest average yearly temperature stabilized in the region as early as 6,000 rcybp. Accordingly, in this work we use modern $\delta^{18}O$ isopatches rather than the -1‰ adjustment reported in Quinn et al. (2008).

Stable Isotopic Values of Tooth Enamel

A total of 48 human enamel samples returned results for $\delta^{13}C$ and $\delta^{18}O_{IW}$ analyses (Table 2-4). $\delta^{13}C$ values ranged from -8.7 to -12.8‰ with an average of -11.1±1.0‰. The $\delta^{18}O_{IW}$ ranged from -0.3 to -4.2‰ with an average of -2.2 ±0.9‰. Twenty-three dentine samples were assayed for $\delta^{15}N$ with values ranging from 15.3‰ to 10.8% and an average of 13.4 ±1.1 ‰.

Based on the range of local water $\delta^{18}O$ values estimated from the faunal samples reported above, we define two groups, one local and one non-local (Figure 2-2). The local group encompasses 18 individuals and the non-local group included the remaining 30 individuals. The local group (n=18) has a $\delta^{18}O_{IW}$ value range from -2.5 to -4.1‰ with an average of -3.1 ± 0.5‰ (Table 2-5). The $\delta^{18}O_{IW}$ values of the non-local group (n=30) range from -0.3 to -2.5‰ with an average of -1.7± 0.7‰ (Table 2-6). The $\delta^{18}O$ values of the designated groups are significantly different (ANOVA, p=.0001). The enriched $\delta^{18}O_{IW}$ values of the non-local group, based on Florida geography and modeled $\delta^{18}O$ distribution of Florida waters (Dutton et al., 2005)

suggests a more southern origin, perhaps near the head waters of the St. Johns River (Figure 2-3).

The $\delta^{13}C$ values for the local group range from –10.1 to –12.5‰ and average –11.7 ±0.6‰ (Table 2-5). The $\delta^{13}C$ values of the non-local group are more enriched, ranging from -8.7 to -12.8‰ with an average of -10.7±1.0‰ (Table 2-6). The two groups are significantly different in their $\delta^{13}C$ values (ANOVA, p=.0005).

In terms of tooth dentine, the local group (n=8) has $\delta^{15}N$ values that range from 15.2 to 10.8‰ and an average of 13.6 ± 1.4‰ (Table 2-5). The non-local group (n=15) has $\delta^{15}N$ values that range from 15.3 to 12.0‰ and an average of 13.2 ± 0.9% (Table 2-6). The two groups are not significantly different in $\delta^{15}N$ values (ANOVA, p=.5774). We found no statistical differences in any of the three isotopic systems when separated by burial layer (Figure 2-4).

Discussion

Rank and Status

Aten (1999) suggested differences in burials at Harris Creek may reflect difference in social rank. In many societies, elite individuals enjoy access to privileged foods; therefore we hypothesized that differences in diet between higher and lower status individuals in the Harris Creek mound might be manifested in varying isotope ratios (Ambrose et al., 2003; White et al., 2001). Individuals with higher rank or status, evidenced by extended mortuary resulting in tightly flexed burials, may have experienced differential access to protein sources, such as meat and marrow, than the more loosely flexed burials. This would result in higher $\delta^{15}N$ values. In addition, high status access to traded food resources from non-local environments such as coastal regions might yield less negative $\delta^{13}C$ values. Because $\delta^{18}O$ values are derived primarily from

drinking water, rank or status-related differences are not manifested in $\delta^{18}O_{IW}$ values of tooth enamel.

Significant differences in $\delta^{13}C$ values (ANOVA, $p = 0.04$) and $\delta^{18}O_{IW}$ values (ANOVA, $p = 0.01$) between primary and secondary burials at Harris Creek suggest these individuals consumed food and water from different sources. Differences in $\delta^{18}O$ of drinking water are not consistent with rank related dietary differences. Instead, significant differences in $\delta^{18}O_{IW}$ ratios from human molars suggest different areas of childhood residence.

All primary (loosely flexed) burials fall within the non-local range of $\delta^{18}O_{IW}$ values, suggesting these individuals spent their childhood south of the Harris Creek site (see Figure 2-2). The local group is composed entirely of secondary burials. There are no statistically significant differences in $\delta^{13}C$, $\delta^{15}N$, or $\delta^{18}O_{IW}$ values between primary and secondary burials within the non-local group, suggesting no significant dietary differences between the burial types when place of origin is controlled for.

Additionally, though there are significant differences in $\delta^{13}C$ values between the local and non-local groups, there are no significant differences in $\delta^{15}N$ values, suggesting that there is no significant difference in the trophic level of the dietary protein between groups. We propose that the isotopic evidence does not support status or rank related differences in diet between the primary and secondary burials, rather the differences are related to region of childhood residence. A more detailed study of differences in burial treatment at Harris Creek within the non-local 'southern' group will be possible after ongoing detailed demographic work on the assemblage is completed.

Settlement and Mobility

Isotopic evidence reported above suggests the population interred at Harris Creek includes people who were born into at least two different groups, one local and one non-local, perhaps

from southern portions of the Florida peninsula. The local group seems to have been fairly sedentary, since their $\delta^{18}O_{(IW)}$ values correlate with $\delta^{18}O_{(IW)}$ values of local fauna, and they have a more limited range of $\delta^{13}C$ values indicating a more restricted range of food resources. The non-local 'southern' group, in contrast, shows a broad range of $\delta^{18}O_{(IW)}$ values, which based on modeled $\delta^{18}O_{(IW)}$ ratios of river water are inferred to range south of Harris Creek to the Lake Okeechobee area (Figure 2-3). The southern group exhibits a wider range of $\delta^{13}C$ values compared to the local group, which may reflect variations in foraging across a large area that could have included the upper (southern) St. Johns River, the Lake Okeechobee area, and the Atlantic coast.

The isotopic and burial data presented for Harris Creek do not support the contention that different burial types at a mortuary site reflect differential aspects of group mobility, as argued for other Archaic groups by Hofman (1985) and Buikstra and Charles (1999). According to such a scenario, groups who spend more time away from the mound would have more secondary burials than groups who spent more time near the mound. Instead, at Harris Creek, the difference in primary and secondary burials suggests differences in social and ideological factors rather than energetic/physical factors of curation and transportation. We suggest the local group spent their childhood in the vicinity of Harris Creek and were interred as adults and we assume they lived in the local area throughout their lives. If primary and secondary burials were a function of the seasonal round and distance from the mound at time of death, more primary burials would be represented in this group. Instead, all cases of primary burial occur within individuals in the non-local 'southern' group. For primary burial to have occurred, these people must have been near the mound when they died as adults. Therefore, it is more likely these people joined the local group as adults. However, not all non-local individuals were primary

burials; many received the same extended mortuary processing as the local people. One interpretation is that local individuals enjoy a higher status due to their proximity to the mound, and only some southern individuals had or were able to gain such status prior to burial. An alternative explanation is that a portion of the southern group retained alternative religious beliefs and did not require the same type of mortuary treatment as the local population or religiously/ethnically converted non-locals.

Spatial analysis of the Harris Creek burials does not reveal any patterning in terms of burial treatment, burial layer, $\delta^{18}O_{IW}$, $\delta^{13}C$, or $\delta^{15}N$ values (Figure 2-4). Lack of apparent patterning supports an interpretation of a single burial population including people from different childhood origins who joined the local group as adults but retained different ethnic/religious beliefs.

Function of Mounds

Mounds are frequently cited as gathering places for seasonally mobile groups, where ceremony and ritual reinforce alliances and a shared sense of identity or common ancestry (e.g. Gibson, 2006; Hofman, 1985; Russo, 1994; Saunders, 1994). The act of mound construction and maintenance constitutes shared ritual by a community that could play a key role in maintaining the identity of these groups. Reinforcing or creating a shared sense of identity may be important when large numbers of immigrants are present. In addition to the non-local 'southern' group, there are other immigrants from coastal and more northerly regions identified at Harris Creek (these were not included in the present study) (Quinn et al., 2008)[1]. Based on $\delta^{18}O_{IW}$ values and $^{87}Sr/^{86}Sr$ ratios, at least 8% of the burials tested at Harris Creek contained individuals who were not from the local or non-local 'southern' group (Quinn et al., 2008). This percentage represents the minimum number of immigrants in the population, since some immigrants may not be isotopically distinct. If large numbers of immigrants are present in the population, then

communal acts that reinforce group identity such as mound building, feasting, or burial rights, could be an important means of maintaining group unity and integrating immigrants into the local population.

Conclusion

The majority of the burials at Harris Creek belong to two groups of people, one local to the site and one (or more) we suggest grew up further south on the Florida peninsula, perhaps as far south as the Lake Okeechobee area. Interestingly, all people who spent their childhood in the vicinity of Harris Creek were subjected to post-mortem processing as indicated by their secondary (tightly flexed) burial. In comparison, only a portion of the non-local 'southern' group received similar secondary treatment. The differences in burial treatment among the non-local 'southern' group may be evidence of rank or status among the burials, but this is not supported by isotopic differences in diet. In contrast to the models proposed by Hofman (1985) and Buikstra and Charles (1999), the presence of primary and secondary burials at Harris Creek does not appear to be related to curation or transportation of the dead. Instead the differences may be evidence of multiple ethnicities or religions among those people who join the local population during adulthood. Finally, the large number of non-local people interred at the site suggests an important function of mortuary mounds may be to create and reinforce a shared sense of identity or common ancestry though communal actions and efforts.

Table 2-1. All individuals from the Harris Creek site (8VO24) sampled in this research. Burial Modes: F/V= Flexed Vertical, F/R or F/L = Flexed on Right or Left side, E/B = Extended on Back.

Burial No.	Tooth	Burial Layer	Body Position	Primary vs. Secondary
4	LM^3	3	F/V	Secondary
6	LM_3	3	F/V	Secondary
8	LM_2	3	F/R	Primary
11, 4	LM_3	3	F/R?	Primary
16, 23	LM_3	4	F/R	Primary
19	RM_3	3	E/B	Primary
25	RM_3	5	F/V	Secondary
29	LM^3	5	F/V	Secondary
35	RM^3	4	F/V	Secondary
36	LM^3	4?	F/R	Primary
38	RM^3	4	F/R	Primary
46	RM^3	4	F/V	Secondary
49	LM_3	?	?/S	Secondary
65,66,68	LM_3	3/4	F/V	Secondary
67	RM_3	4?	F/V	Secondary
70	RM_3	4	F/V?	Secondary
74,75,76	LM_3	4	F/V	Secondary
83	RM_3	3	F/R	Primary
88	LM_3	3	F/V?	Secondary
89	LM_3	3	F/V?	Secondary
90	LM_3	4	F/V?	Secondary
91	RM_3	4	F/V	Secondary
92	RM_2	4	F/V	Secondary
93	LM_3	5	F/L	Primary
95	LM^2	3	F/R	Primary
102,103	LM_3	3	F/V?	Secondary
105,106,107	RM_3	3	F/V	Secondary
108	LM_3	3	F/L	Primary
111	LM_3	?	F/V	Secondary
113	LM^3	4?	F/V?	Secondary
114,117a	RM^3	4?	F/V	Secondary
114,117b	LM^3	4?	F/V	Secondary
115	LM^3	4?	F/V	Secondary
123	RM^3	3	F/R	Primary
132	RM_3	3	F/V	Secondary
134	RM_3	?	F/V	Secondary
135	LM_1	3?	F/V	Secondary
137	LM^3	?	F/V	Secondary
139,140b	LM_3	3	F/V	Secondary
141	RM_2	4	F/V	Secondary
143	RM^3	4	F/V	Secondary
147,148	LM^3	4/5?	F/V	Secondary
154,155,156	LM_3	3	F/RorL	Primary
158	LM_3	4	F/V	Secondary
159	RM_3	4	F/V	Secondary
165,166,167	RM_3	3/4?	F/V	Secondary
170a	RM^3	3?	F/V	Secondary
170b	RM_3	3?	F/V	Secondary

Table 2-2. Conventional and AMS radiocarbon dates from Harris Creek. New AMS dates are calibrated with CALIB 5.0.1 (Stuiver & Reimer, 1993).

Lab No.	Layer	Sample	Uncorrected 14C years B.P.	Corrected 14C years B.P.	Calibrated Dates, 2 sigma BP	Reference
M1264	3	charcoal	5450±300		[5590 BP:6912 BP] 0.999 [6921 BP:6929 BP] 0.001	Aten 1999
M1265	8	charcoal	5320±200		[5645 BP:6494 BP] 1.00	Aten 1999
M1268	3	charcoal	5450±180		[5767 BP:5806 BP] 0.01 [5890 BP:6652 BP] 0.99	Aten 1999
M1270	7 or 8	marine shell	5030±20	5430	[5081 BP:5095 BP] 0.02 [5112 BP:5587 BP] 0.98	Aten 1999
X9110	3	human bone (Burial 7)	6125±83		[6793 BP:7179 BP] 0.96 [7195 BP:7244 BP] 0.04	New date, this paper
X9112RA	3	human bone (Burial 31)	6053±65		[6742 BP:7030 BP] 0.90 [7043 BP:7069 BP] 0.02 [7077 BP:7086 BP] 0.01 [7096 BP:7156 BP] 0.07	New date, this paper
X9109A	4	human bone (Burial 3)	5904±62		[6563 BP:6592 BP] 0.03 [6598 BP:6891 BP] 0.97	New date, this paper
X9111A	4	human bone (Burial 9)	5825±62		[6482 BP:6758 BP] 0.98 [6761 BP:6782 BP] 0.02	New date, this paper

Table 2-3. Harris Creek faunal bone and enamel isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW).

Species	Sample material	$\delta^{13}C_{PDB}$	$\delta^{18}O_{PDB}$	$\delta^{18}O_{SMOW}$	$\delta^{18}O_{IW}$
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-9.7	-3.1	27.7	-4.5
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-11.1	-2.6	28.2	-3.9
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-11.0	-2.1	28.8	-3.2
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-13.4	-1.8	29.1	-2.8
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-10.7	-1.8	29.1	-2.8
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-10.6	-1.7	29.1	-2.7
White-tailed deer (*Odocoileus virginianus*)	bone apatite	-9.6	-0.3	30.7	-0.8
Raccoon (*Procyon lotor*)	enamel	-9.9	-2.4	28.4	-3.6
	Mean	-10.7	-2.0	28.9	-3.0
	Std. dev.	1.2	0.8	0.9	1.1

Table 2-4. All Harris Creek human burials and dental isotopic $\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$ values

Burial No.	Primary vs. Secondary	$\delta^{13}C_{PDB}$	$\delta^{18}O_{PDB}$	$\delta^{15}N_{AIR}$
4	Secondary	-10.5	-1.2	12.8
6	Secondary	-10.1	-1.5	14.9
8	Primary	-10.2	-0.9	13.1
11, 4	Primary	-11.3	-0.7	13.0
16, 23	Primary	-11.7	-1.5	12.6
19	Primary	-10.5	-1.6	12.8
25	Secondary	-12.4	-2.2	
29	Secondary	-10.9	-1.2	
35	Secondary	-11.0	-1.7	
36	Primary	-10.4	-0.5	
38	Primary	-8.9	-0.4	
46	Secondary	-11.8	-2.1	
49	Secondary	-12.1	-1.8	13.8
65,66,68	Secondary	-12.2	-2.3	
67	Secondary	-11.7	-1.6	15.2
70	Secondary	-11.9	-1.8	12.3
74,75,76	Secondary	-12.2	-2.5	
83	Primary	-9.9	-1.2	13.6
88	Secondary	-11.9	-1.8	
89	Secondary	-11.5	-2.3	
90	Secondary	-12.5	-2.0	
91	Secondary	-10.6	-1.6	14.2
92	Secondary	-10.5	0.1	
93	Primary	-10.4	-1.2	12.8
95	Primary	-11.7	-0.8	13.0
102,103	Secondary	-12.8	-1.2	15.3
105,106,107	Secondary	-10.2	-1.0	12.0
108	Primary	-10.6	-0.7	
111	Secondary	-12.5	-1.4	12.3
113	Secondary	-10.1	-1.6	13.7
114,117a	Secondary	-11.5	-1.4	
114,117b	Secondary	-12.4	-2.8	
115	Secondary	-11.5	-1.7	14.3
123	Primary	-9.6	-0.5	
132	Secondary	-11.8	-1.9	13.8
134	Secondary	-11.6	-1.5	13.9
135	Secondary	-11.5	-0.8	
137	Secondary	-10.5	-0.9	
139,140b	Secondary	-10.7	-1.5	
141	Secondary	-10.7	-0.1	
143	Secondary	-9.6	-1.5	
147,148	Secondary	-8.7	-0.1	
154,155,156	Primary	-11.9	-1.4	
158	Secondary	-11.7	-2.5	10.8
159	Secondary	-10.2	-1.5	14.4
165,166,167	Secondary	-11.5	-1.9	14.7
170a	Secondary	-12.2	-1.4	13.3
170b	Secondary	-10.1	-0.1	
Mean		-11.1	-1.4	13.4
Std. Deviation		1.0	0.7	1.1

Table 2-5. Harris Creek local human burials and dental isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW). Burial Modes: F/V= Flexed Vertical, ?/S = recorded as Secondary burial.

Burial No.	Tooth	Burial Layer	Burial Mode	$\delta^{13}C_{PDB}$	$\delta^{18}O_{PDB}$	$\delta^{18}O_{SMOW}$	$\delta^{18}O_{IW}$	$\delta^{15}N_{AIR}$
25	RM_3	5	F/V	-12.4	-2.2	28.6	-3.4	
35	RM_3	4	F/V	-11.0	-1.7	29.2	-2.6	
46	RM_3	4	F/V	-11.8	-2.1	28.8	-3.2	
49	LM_3	?	?/S	-12.1	-1.8	29.1	-2.8	13.8
65,66,68	LM_3	3/4	F/V	-12.2	-2.3	28.6	-3.4	
67	RM_3	4?	F/V	-11.7	-1.6	29.3	-2.5	15.2
70	RM_3	4	F/V?	-11.9	-1.8	29.1	-2.8	12.3
74,75,76	LM_3	4	F/V	-12.2	-2.5	28.3	-3.8	
88	LM_3	3	F/V?	-11.9	-1.8	29.1	-2.7	
89	LM_3	3	F/V?	-11.5	-2.3	28.6	-3.4	
90	LM^3	4	F/V?	-12.5	-2.0	28.8	-3.1	
91	RM_3	4	F/V	-10.6	-1.6	29.2	-2.6	14.2
113	LM^3	4?	F/V?	-10.1	-1.6	29.3	-2.5	13.7
114,117b	LM^3	4?	F/V	-12.4	-2.8	28.0	-4.1	
115	LM^3	4?	F/V	-11.5	-1.7	29.2	-2.7	14.3
132	RM_3	3	F/V	-11.8	-1.9	29.0	-2.9	13.8
158	LM_3	4	F/V	-11.7	-2.5	28.3	-3.7	10.8
165,166,167	LM^2	3/4?	F/V	-11.5	-1.9	28.9	-3.0	14.7
Mean				-11.7	-2.0	28.9	-3.1	13.6
Standard deviation				0.6	0.4	0.4	0.5	1.3

Table 2-6. Harris Creek non-local (southern) human burials and dental isotopic ($\delta^{13}C_{PDB}$, $\delta^{18}O_{PDB}$, $\delta^{15}N_{AIR}$) values (per mil, ‰) and converted $\delta^{18}O$-Standard Mean Ocean Water (SMOW) and $\delta^{18}O$-Ingested Water (IW). Burial Modes: F/V= Flexed Vertical, F/R or F/L = Flexed on Right or Left side, E/B = Extended on Back.

Burial No.	Tooth	Burial Layer	Burial Mode	$\delta^{13}C_{PDB}$	$\delta^{18}O_{PDB}$	$\delta^{18}O_{SMOW}$	$\delta^{18}O_{IW}$	$\delta^{15}N_{AIR}$
4	LM^3	3	F/V	-10.5	-1.2	29.7	-2.0	12.8
6	LM_3	3	F/V	-10.1	-1.5	29.4	-2.4	14.9
8	LM^2	3	F/R	-10.2	-0.9	30.0	-1.7	13.1
11, 4	LM_3	3	F/R?	-11.3	-0.7	30.3	-1.3	13.0
16, 23	LM_3	4	F/R	-11.7	-1.5	29.4	-2.4	12.6
19	RM_3	3	E/B	-10.5	-1.6	29.3	-2.5	12.8
29	LM^3	5	F/V	-10.9	-1.2	29.7	-2.0	
36	LM_3	4?	F/R	-10.4	-0.5	30.4	-1.1	
38	RM_3	4	F/R	-8.9	-0.4	30.5	-0.9	
83	RM_3	3	F/R	-9.9	-1.2	29.7	-2.0	13.6
92	RM_2	4	F/V	-10.5	0.1	31.0	-0.3	
93	LM_3	5	F/L	-10.4	-1.2	29.7	-2.0	12.8
95	LM^2	3	F/R	-11.7	-0.8	30.1	-1.5	13.0
108	LM_3	3	F/L	-10.6	-0.7	30.2	-1.4	
111	LM_3	?	F/V	-12.5	-1.4	29.5	-2.3	12.3
123	RM_3	3	F/R	-9.6	-0.5	30.5	-1.0	
134	RM_3	?	F/V	-11.6	-1.5	29.4	-2.4	13.9
135	LM_1	3?	F/V	-11.5	-0.8	30.1	-1.4	
137	LM^3	?	F/V	-10.5	-1.0	29.9	-1.7	
141	RM^2	4	F/V	-10.7	-0.1	30.8	-0.6	
143	RM^3	4	F/V	-9.6	-1.5	29.4	-2.4	
159	RM_3	4	F/V	-10.2	-1.5	29.4	-2.4	14.4
102,103	LM_3	3	F/V?	-12.8	-1.2	29.7	-2.0	15.3
105,106,107	RM_3	3	F/V	-10.2	-1.0	29.9	-1.8	12.0
114,117a	RM^3	4?	F/V	-11.5	-1.4	29.5	-2.3	
139,140b	LM_3	3	F/V	-10.7	-1.5	29.4	-2.4	
147,148	LM^3	4/5?	F/V	-8.7	-0.1	30.9	-0.5	
154,155,156	LM_3	3	F/RorL	-11.9	-1.4	29.5	-2.4	
170a	RM_3	3?	F/V	-12.2	-1.4	29.5	-2.2	13.3
170b	RM^3	3?	F/V	-10.1	-0.1	30.9	-0.5	
		Mean		-10.7	-1.0	29.9	-1.7	13.3
		Standard deviation		1.0	0.5	0.5	0.7	0.9

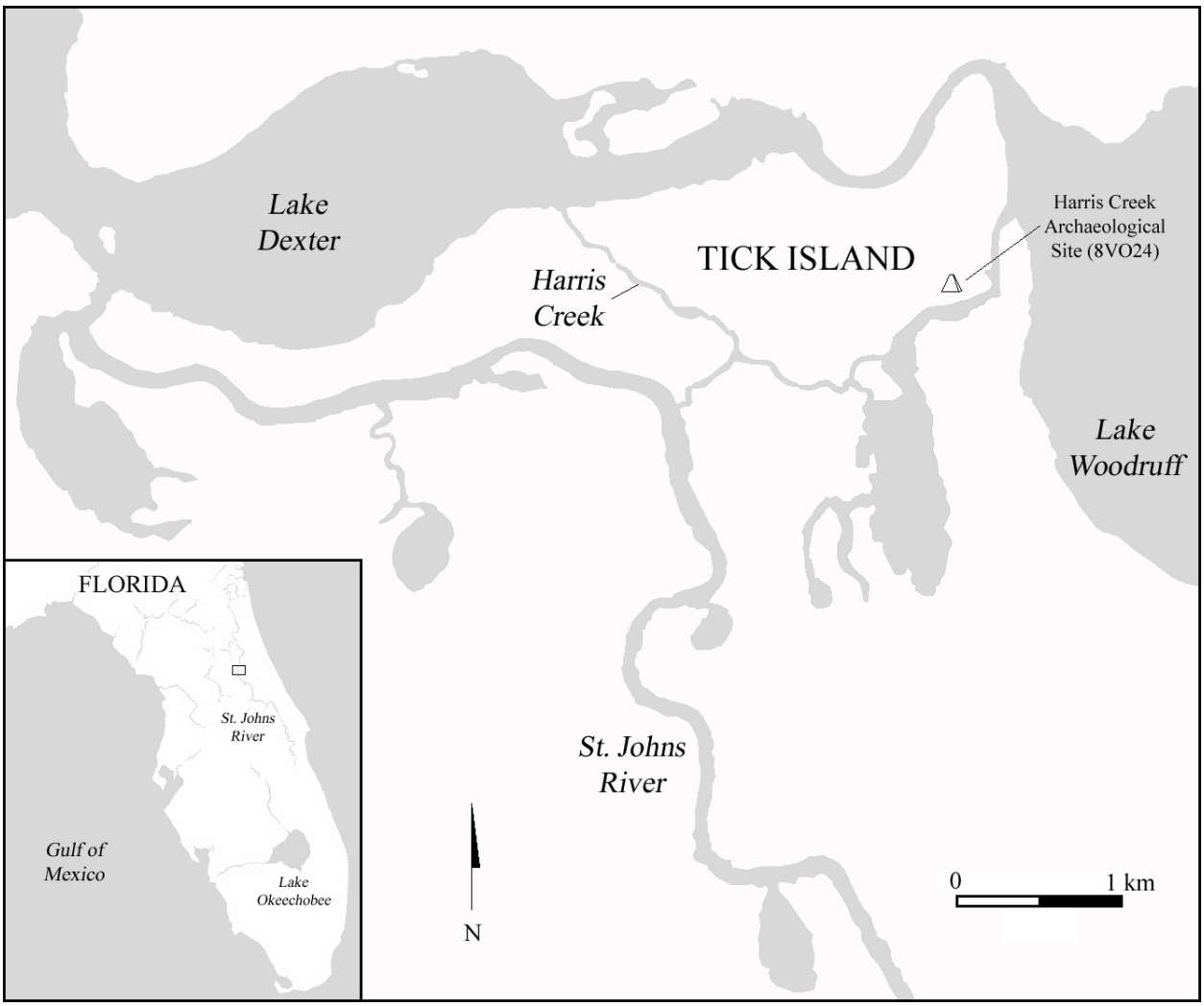


Figure 2-1. Location of the Harris Creek site.

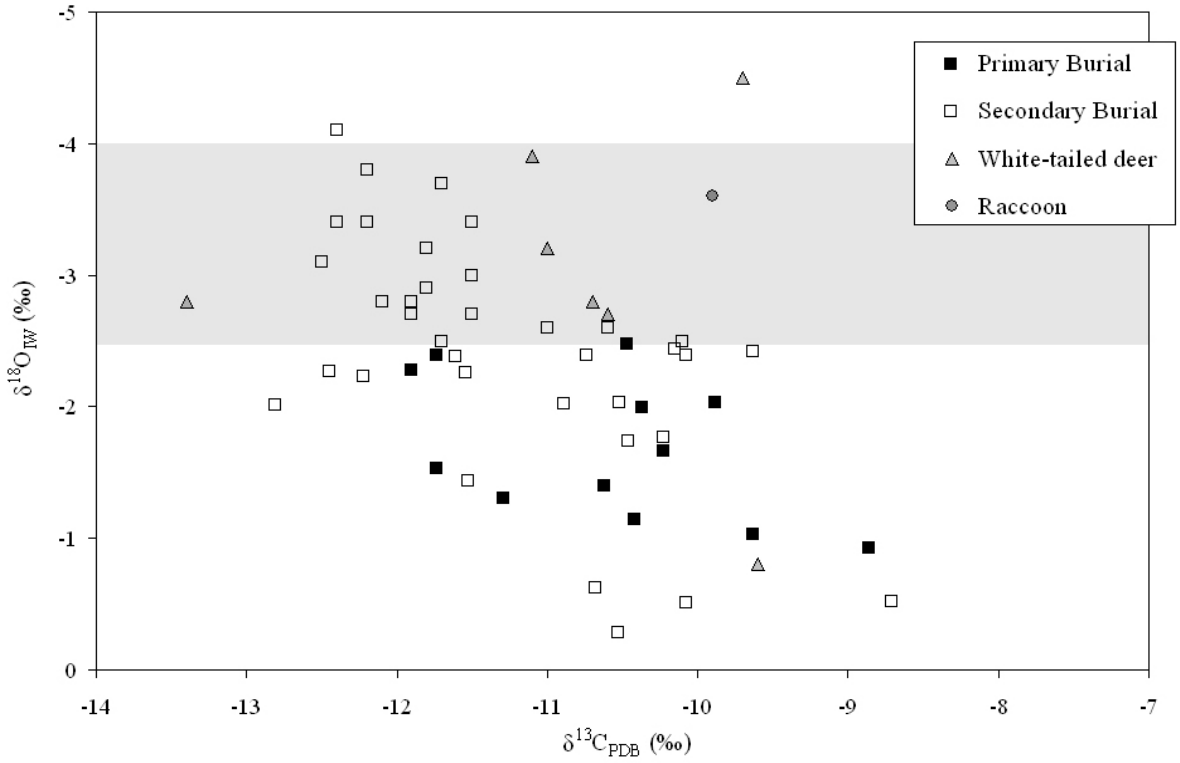


Figure 2-2. A plot of $\delta^{18}O$ and $\delta^{13}C$ ratios of humans and fauna from Harris Creek. The shaded area is the range of local $\delta^{18}O$ ratios.

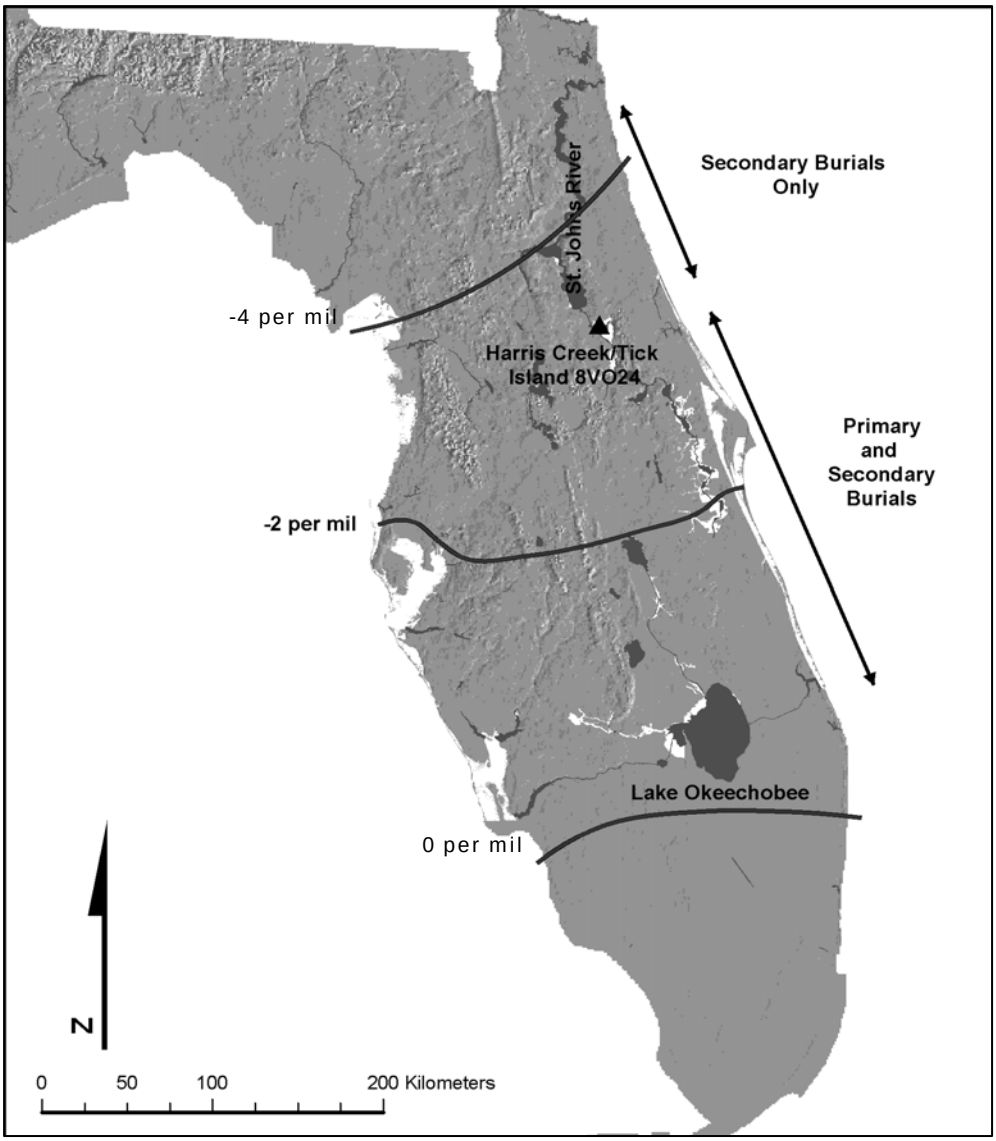


Figure 2-3. Estimated $\delta^{18}O$ isopatches of river water for the state of Florida.

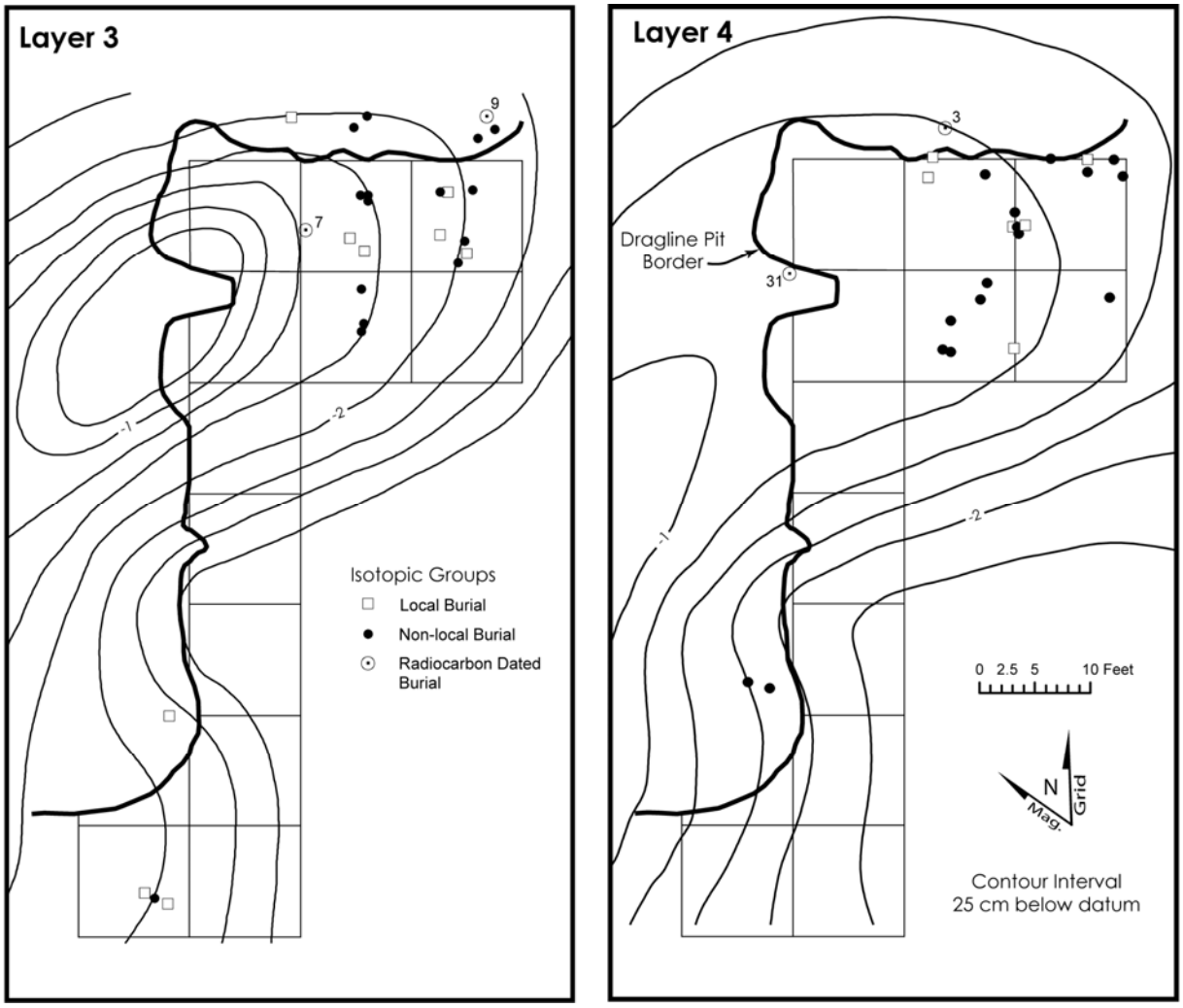


Figure 2-4. Distribution of local and non-local burials sampled in this research and the location of AMS dated individuals. Image courtesy of Asa Randall.

CHAPTER 3
DIETARY CONTINUITY AND CHANGE DURING THE FLORIDA ARCHAIC

Introduction

Traditional cultural evolutionary models for the Archaic Period in the St Johns region of Florida assert the start of the Middle Archaic Period is marked by a new and intense use of riverine resources (Milanich, 1994; Milanich & Fairbanks, 1980). Large mounds composed of freshwater shell along the St Johns River are often cited as evidence of this shift in subsistence (Milanich, 1994; Milanich & Fairbanks, 1980; Russo et al., 1992; Wheeler & McGee, 1994). Stable isotope ratios recovered from human bone from Windover, an Early Archaic site, and Harris Creek, a Middle Archaic site are used to evaluate the dietary shift. These data are also used to assess models of human mobility for the St Johns region of Florida during the Archaic Period.

Evidence from Archaic sites in and around the St Johns River basin suggests the inhabitants of riverine sites interacted with the coast through seasonal occupation or trade. Shark's teeth and *marginella* beads have been recovered from Windover (Doran, 2002) and marine shells (*Busycon carica, Busycon contrarium, Strombus gigas*) and shark's teeth have been recovered from most, if not all, Mt. Taylor sites including Harris Creek (Aten, 1999; Wheeler et al., 2000). Middle Archaic Period sites have been documented in the coastal zone and Florida Archaic stemmed points and baked clay objects, both associated with the Mt. Taylor culture, have been found on many of these sites (Piatek, 1994; Russo & Ste. Claire, 1992; Ste. Claire, 1990). However, the nature of the contact between riverine Mt Taylor populations and the coast remains unclear. Two settlement models have been suggested to explain the relationship of Mt Taylor sites on the St. Johns River to Middle Archaic sites on coast. Milanich and Fairbanks (1980) suggest people occupied the St. Johns River drainage during the warm

months, but split into smaller groups during the winter and dispersed to the coast or to the interior highlands. Russo and Ste. Claire (1992) offer an alternative model. Based on faunal data from Late Archaic sites they assert that separate cultures occupied the river basin and coast throughout the year (Russo & Ste. Claire, 1992). Groups may have been mobile, but movement was along the coast or river rather than between them (Russo & Ste. Claire, 1992).

By the beginning of the Mt. Taylor period, populations inhabited the St. Johns River drainage for at least a portion of each year and appear to be heavily reliant on aquatic resources. (McGee, 1995; Milanich, 1994; Milanich & Fairbanks, 1980; Russo et al., 1992; Wheeler & McGee, 1994). Based on food remains recovered from Groves Orange Midden (8VO2601), freshwater snails contributed between 33 and 87% of the dietary meat weight at Mt. Taylor sites during the early Mt Taylor Period (Wheeler & McGee, 1994). The snails were supplemented by large contributions from freshwater fish and other aquatic vertebrates (Wheeler & McGee, 1994). During the late Mt Taylor and early Orange Period a shift may have occurred to a reliance on freshwater snails which may have composed as much as 98% of the meat weight in the diet (Russo et al., 1992).

In this study, $\delta^{13}C$ and $\delta^{15}N$ ratios are used to test the assertion that a significant difference exists between the diets of Middle Archaic populations and the preceding Early Archaic populations. An intense use of riverine resources should be apparent in the stable isotope ratios of individuals interred in the region. If significant dietary change did not occur and the inhabitants of the region were not eating a high percentage of freshwater shellfish, then the formation of shell mounds in the region is not explained by a change in subsistence which allows for evaluation of alternative explanations.

Background

Stable Isotopes and Dietary Reconstruction

The use of stable isotopes to reconstruct diet and movement in bioarchaeology is now (Ambrose et al., 2003; Buikstra & Milner, 1991; Dupras & Schwarcz, 2001; Montgomery et al., 2005; Price et al., 2000; Richards et al., 2001; Sealy, 2006; White et al., 1998). Many researchers have used stable isotopes to reconstruct the diet of ancient Floridians (DeLeon, 1998; Hutchinson, 2004; Hutchinson et al., 2000; Quinn, 1999; Turner et al., 2005; Tuross et al., 1994). Of the light stable isotopes, carbon and nitrogen are most commonly used to study paleodiet and are the isotopes employed in this study.

Carbon isotopes in terrestrial systems vary by photosynthetic pathway. There are three photosynthetic pathways C_3, C_4, and CAM. C_3 plants have $\delta^{13}C$ ratios from –35 to –20‰ with an average of –26.5‰ (Smith, 1972; Smith & Epstein, 1971). C_4 plants have $\delta^{13}C$ values that range from –15 to –7‰ with a mean of –12.5‰ (Smith, 1972; Smith & Epstein, 1971). Edible CAM plants, largely limited to succulents in arid areas with low summer rainfall, have $\delta^{13}C$ values that overlap with C_3 and C_4 plants. CAM plants are not a common foodstuff in the Eastern Woodlands, though prickly pear does grow along the eastern coast and has been found at Archaic sites including Windover (Doran, 2002; Newsom, 1994; Tuross et al., 1994).

Carbon isotopes also differ between terrestrial and marine systems. Marine vertebrates typically have $\delta^{13}C$ values of –19 to –9‰ compared to the –35 to –20‰ range of C_3 plants (Schoeninger & DeNiro, 1984; Smith, 1972). Therefore, in systems where C_4 or CAM input is negligible, carbon values differentiate between terrestrial and marine diets.

While carbon isotopes clearly distinguish terrestrial C_4 from terrestrial C_3 resources, the addition of nitrogen isotopes greatly expands the explanatory power of isotopic reconstruction. Though $\delta^{13}C$ values can be used to discriminate between trophic levels, $\delta^{13}C$ are only slightly

enriched per level, around 1‰ (Schoeninger & Moore, 1992). This small amount of enrichment limits the use of carbon values for the study of trophic level in all but the most controlled systems (Wada, 1980). Nitrogen isotopes exhibit a much larger enrichment factor allows for an improved understanding of terrestrial food chains and distinguishes between terrestrial and marine diets (Norr, 1995).

The $\delta^{15}N$ ratios of marine foodwebs are enriched compared to terrestrial systems because plankton and marine plants at the base of the foodweb are enriched in $\delta^{15}N$ compared to terrestrial plants (Schoeninger et al., 1983; Schwarcz & Schoeninger, 1991). In terrestrial and marine systems each successive step in the food chain is marked by a 3 to 4‰ increase in $\delta^{15}N$ values. Therefore, primary consumers are 3 to 4‰ enriched relative to primary producers, secondary consumers are 3 to 4 ‰ enriched relative to primary consumers and so on. This increase is referred to as the trophic level effect, and has been well documented (Ambrose & DeNiro, 1986; DeNiro, 1985; DeNiro & Epstein, 1981; Katzenberg, 1989; Minagawa & Wada, 1984; Schoeninger, 1985; 1989; Schoeninger & DeNiro, 1984).

Apatite to Collagen Spacing and Diet

Bone is divided into two components in preparation for isotopic sampling: the organic collagen fraction and the inorganic apatite fraction. The organic portion comprises 35% of the dry weight of bone and the inorganic component comprises 65% of the dry weight of bone (Fawcett, 1986). Differences in the way carbon isotopes are routed to the two fractions of bone make the offset between the $\delta^{13}C$ values of apatite and collagen informative. Results of controlled feeding experiments indicate the ^{13}C value of bone collagen is greatly influenced by the isotopic composition of dietary protein rather than that of the whole diet (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). The bone apatite values differed from the collagen values in that they more closely reflected the composition of the entire diet.

Ambrose and Norr (1993) developed a model to distinguish the isotopic composition of each component of the diet based on the difference in $\delta^{13}C$ between bone collagen and apatite. Since collagen values disproportionately reflect the isotopic composition of dietary protein and apatite values more closely mirror the composition of the whole diet, the difference in the $\delta^{13}C$ values between the fractions can evaluate the isotopic value of carbohydrates in the diet. When the dietary protein and energy sources have similar isotopic values, the spacing between them is intermediate, around 5.7% ± 0.4%. When the $\delta^{13}C$ value of the dietary energy source is more negative than that of the dietary protein, for example a C_3 plant and marine fish diet, the spacing between the collagen and apatite values is quite small, from 1.2 % ± 0.1% to 2.1% ± 0.2%. If the $\delta^{13}C$ value of the dietary protein is more negative than the $\delta^{13}C$ value dietary energy source, for instance, in a terrestrial diet of C_3 protein with maize or other C_4 plants for dietary energy, the difference between the apatite and collagen values is large, 7.2% ± 0.3% to 11.3% ± 0.4%. Ambrose and Norr (1993) demonstrated that even a small amount of a C_4 energy source (21%) added to a C_3 diet would greatly affect the apatite values and thus the apatite-collagen spacing.

Previous Isotopic Studies of Harris Creek and Windover

Preliminary isotopic studies of diet have been undertaken at Windover and Harris Creek (Quinn, 1999; Tuross et al., 1994). Tuross et al. (1994) conducted an isotopic analysis of the Windover (8Br246) in 1994 and found an average $\delta^{13}C$ ratio of human bone collagen ($\delta^{13}C_{col}$) of –15.6‰ and an average $\delta^{15}N$ from bone collagen ($\delta^{15}N_{col}$) of 11.8‰. Tuross et al. (1994) suggest the $\delta^{13}C$ and $\delta^{15}N$ ratios reflect a riverine based diet with input from terrestrial fauna that consumed CAM plants and C_4 grasses. Overall, Tuross et al. (1994) suggest the people at Windover were seasonally opportunistic and made use of terrestrial, riverine, and perhaps small amounts of marine resources.

Rhonda Quinn (1999) conducted an isotopic study of dentition from the Harris Creek site for her M.A. thesis. Quinn (1999) determined the population at Harris Creek had an average $\delta^{13}C$ of –11.4‰ from human tooth enamel and an average $\delta^{15}N$ of 13.2‰ from human dentine. Quinn (1999) interprets these values as evidence of a reliance on estuarine and riverine resources, although coastal resources are not ruled out.

Overall, the existing isotopic data from both sites are remarkably similar. The isotopes from both Windover and Harris Creek suggest the populations were composed of broad spectrum foragers and hunters who made use of food resources from terrestrial, riverine, and estuarine environments. This study builds on the results of the previous studies by sampling additional individuals, sampling both components of bone, and analyzing the resulting data with additional interpretive models to better refine the isotopic life histories of individuals recovered from Windover and Harris Creek.

Site Descriptions

Though evidence of Archaic Period occupation is found throughout Florida (Milanich & Fairbanks, 1980), this research is primarily concerned with northeast Florida and the St. Johns River drainage. Two sites, Windover and Harris Creek are sampled in this research. Both sites are considered excellent examples of their respective time periods: Windover for the Early Archaic and Harris Creek for the Middle Archaic. A brief description of each site follows.

The Windover site (8BR246)

The Windover site is an Early Archaic cemetery located near Titusville, Florida (Doran, 2002). The site was discovered in 1982 when a small pond was being filled to make way for a subdivision (Doran, 2002). The site was excavated by Glen Doran and colleagues during three field seasons from 1984 to 1986 (Doran, 2002). The degree of preservation at the site was remarkable which resulted in an extensive artifact assemblage of textiles, floral remains, and

tools made of bone, antler and marine shell (Doran, 2002). At least 168 human skeletons were recovered from the shallow but persistent pond. Radiocarbon dates on the human skeletal material indicate the interments occurred between 7,100 and 7,330 rcybp (Doran, 2002). Burials were flexed on their side and held down with matting or fabric and wooden stakes in shallow depressions underwater.

The Harris Creek/Tick Island site (8VO24)

The Harris Creek site is a Mt. Taylor Period mortuary mound on Tick Island in the St. Johns River. The mound, constructed in 10 distinct layers, is primarily composed of freshwater snail (*Viviparus*) shells (Aten, 1999). Bullen recovered four radiocarbon dates from the site ranging from 5450 +/- 300 to 5030 +\- 200 rcybp (Aten, 1999). Recently, four new AMS dates from burials at Harris Creek range from (2 σ) cal BP 6793-7179 [0.96] (X-9110) to cal BP 6482-6758 [0.98] (X-9111A), ca. 500 years early on average than the conventional dates recovered by Bullen.

Prior to shell mining the site consisted of a large mound with multiple shell ridges and middens (Aten, 1999). The Harris Creek site has a long history of investigation and was first excavated by Clarence B. Moore between 1891 and 1894. After Moore's work, the site was mapped and surface collected by Francis Bushnell in 1959. Finally, in 1961, Ripley P. Bullen conducted salvage excavations prior to its destruction from shell mining operations. Bullen recovered over 175 human burials which consisted primarily of two types: loosely flexed primary burials and tightly flexed secondary burials (Aten, 1999). Aten (1999) interpreted the different burial modes as evidence of rank or status among the burials. The secondary burials have under gone extensive post-mortem processing indicating a higher status than the less processed burials (Aten, 1999). However, recent work by Tucker and Krigbaum (2005) suggests

the burials likely represent two or more residential groups and that the differences in burial mode are related to different mortuary customs rather than differences in status.

Materials

Additional isotopic data are collected from Windover and Harris Creek. A total of 62 human bone samples were collected in the course of this research. Twenty proximal carpal phalanges were selected from Windover representing 10 males and 10 females. Only adults were chosen for analysis and they range in age from ca. 21 to 82. These samples were chosen to complement those sampled by Tuross et al. (1994).

Forty-two samples from Harris Creek were chosen to complement those collected by Quinn (1999). Various skeletal elements were selected from individuals buried in layers 3 and 4 at Harris Creek, including both tightly flexed and loosely flexed individuals. Due to the highly fragmentary nature of the collection age and sex could not be reliably assessed for the majority of the individuals sampled.

Methods

Collagen and apatite samples were prepared based on methods detailed elsewhere (Lee-Thorp, 1989). Bone for collagen samples was cleaned, crushed, and then demineralized in ~50.0 ml of 0.2 m HCL. The HCL was refreshed as needed until demineralization was complete. After decanting the HCL, ~50 ml of 0.125 m NaOH was added to remove humic acids. After 12 hours the samples were rinsed to neutral, and ~50 ml of 10^{-3} m HCL was added. The solution was decanted and condensed to ~5ml or less in a 65°C oven. The resulting sample was freeze dried.

The apatite samples from both sites were prepared with similar methods. Bone for the apatite samples was mechanically cleaned and crushed into a fine powder. Samples were treated with ~12 ml of a solution of 50% Clorox and 50% distilled water, which was replaced as needed

until all organics were removed from the sample. Next, ~12 ml of 0.2m acetic acid was added and the sample was allowed to sit 24 to 36 hours. Finally, the samples were rinsed and freeze dried. Prior to the Clorox solution, the Windover was treated to remove Rhoplex, a preservative, which was applied to the samples.

Previous isotopic research on remains from Windover demonstrated that the preservative applied to the remains, Rhoplex, is difficult to remove and would be expected to skew $\delta^{13}C$ values derived from bone collagen (Tuross et al., 1994). Fortunately, Rhoplex is an organic molecule and should not interfere with $\delta^{13}C$ values derived from the inorganic bone apatite fraction of bone. Nevertheless, Toluene was used to remove the Rhoplex from each bone sample, in anticipation of analyzing the organic fraction. However, due to the complexities of removing all the Rhoplex from the organic fraction of bone from Windover, that research is not being pursued at this time. The Rhoplex and Toluene treatment should not complicate the collection of data from bone apatite.

Results

Harris Creek: The average $\delta^{13}C$ of human bone apatite ($\delta^{13}C_{ap}$) from Harris Creek (n=42) is –9.9‰. The average $\delta^{13}C_{col}$ is -16.5 and the average $\delta^{15}N_{col}$ is 12.5‰ (see Table 3-1). The average collagen to apatite spacing for Harris Creek is 6.3‰. This value was calculated by subtracting the $\delta^{13}C_{col}$ from the $\delta^{13}C_{ap}$ for each individual and averaging the results.

Windover: The average $\delta^{13}C_{ap}$ (n=20) for Windover is –10.2‰. The average $\delta^{13}C_{col}$ value from Tuross et al. (1994), -15.6‰ is paired with the apatite value in Table 3-1. The average collagen to apatite spacing for Windover was 5.4. This spacing was calculated differently from the average for Harris Creek. Unfortunately, it was not possible to sample the same individuals as Tuross et al. (1994). Therefore, collagen to apatite spacings could not be calculated for individuals. Instead the average $\delta^{13}C_{ap}$ for the site was subtracted from the average

$\delta^{13}C_{col}$ for the site and the average taken. As a control, the average spacing for Harris Creek was recalculated in this fashion and resulted in a difference of only 0.3‰.

Discussion

Overall, the results of the isotopic assays for Windover and Harris Creek are similar, the $\delta^{13}C$ and $\delta^{15}N$ ratios of collagen and apatite, as well as the collagen to apatite spacing, from the two sites are all within 1.0‰ (Table 3-1). The average $\delta^{13}C_{ap}$ is -10.2‰ from Windover and -9.9‰ from Harris Creek, a difference of only 0.3‰. The apatite ratios from both sites reflect a bulk diet that borders between a marine and a terrestrial C_3 diet. Marine vertebrates typically have $\delta^{13}C$ values of -19 to -9‰ compared to the -35 to -20‰ range of C_3 plants and the animals that feed upon them (Schoeninger & DeNiro, 1984; Smith, 1972). However, due to isotopic fractionation $\delta^{13}C_{ap,}$ $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ do not directly represent the average values of the food consumed. To calculate the $\delta^{13}C$ and $\delta^{15}N$ values of the diet, the $\delta^{13}C_{ap}$ must be adjusted by -9.5‰, $\delta^{13}C_{col}$ by between -0.8 to -1.0‰ (-1.0‰ is used here), and $\delta^{15}N_{col}$ by between -2.5 and -3.4‰ (-3.0‰ is used here) (Bocherens & Drucker, 2003; DeNiro & Epstein, 1981; Kelly, 2000; Minagawa & Wada, 1984; Vanderklift & Ponsard, 2003).

The adjusted $\delta^{13}C_{ap}$ values are -19.7‰ for Windover and -19.4‰ for Harris Creek. These values cluster at near the intersection of marine, freshwater, and terrestrial resources (Figure 3-1). Therefore, based on an analysis of bulk diet, these ratios suggest all three types of foods were consumed in moderate amounts.

The $\delta^{15}N$ ratios from Windover and Harris Creek differ by only 0.7‰. Like the $\delta^{13}C_{ap}$, the $\delta^{15}N_{col}$ values of bone collagen fall between a marine and terrestrial C_3 diet. The $\delta^{15}N_{col}$ ratios from both sites are higher than would be expected from a diet consisting of 100% terrestrial C_3 resources and fall into the low range of what could be expected from a diet consisting of marine and estuarine foods. Tuross et al. (1994) considered the possibility that the $\delta^{15}N_{col}$ ratios could

be explained by the use of marine shellfish in the diet, but this interpretation was dismissed because no accumulations of marine shells were found during excavations. Windover is an inland mortuary site without associated habitation and would not necessarily show the consumption of marine foods even if they were present in the diet. As such the $\delta^{15}N_{col}$ ratios of both populations support the assertion that marine, freshwater, and terrestrial C_3 foods were consumed.

The average $\delta^{13}C_{col}$ values from Windover and Harris Creek differ by only 0.9‰. The average $\delta^{13}C_{col}$ from both sites is lower than expected for a diet composed of C_3 resources. The $\delta^{13}C_{col}$ values at Windover and Harris Creek, like the $\delta^{13}C_{ap}$ values, suggest a mixed diet of marine, freshwater, and terrestrial food resources. The influence of marine protein is apparent in both sites.

Finally, the average collagen to apatite spacings at Windover and Harris Creek were 5.4‰ and 6.3‰ respectively, a difference of 0.9‰. The ap-col spacings indicate that the $\delta^{13}C$ ratios of the dietary protein and carbohydrates consumed by the people buried at Windover and Harris Creek were similar (Figure 3-2). This monoisotopic diet could result from a diet of all C_3 resources, all C_4 resources, or a diet that included a mix of C_3 and C_4 carbohydrates and proteins (Norr, 1995). The small differences in isotopic ratios between the two sites are not what would be expected if one population was consuming 30 to 80% of their dietary meat weight from freshwater fish or shellfish and the other was not.

Kellner and Schoeninger (2007) recently developed a protein regression model to interpret $\delta^{13}C$ values recovered from human bone. This model controls for protein in the diet with three regression lines: one for C_3 protein, one for marine protein, and one for C_4 protein. The model also provides information about carbohydrates in the diet. The upper ends of the regression lines

indicate more C_4 carbohydrates in the diet while the lower ends of the regression line indicate more carbohydrates from C_3 sources. When the average (2 std. devs.) $\delta^{13}C_{col}$ and $\delta^{13}C_{ap}$ values from Windover and Harris Creek are plotted on the regressions, they are intermediate to the C_3 and marine protein lines, suggesting these populations consumed both protein types (Figure 3-3). These results support the interpretation of a substantial marine component in the diet. Surprisingly, the earlier population from Windover plots closer to the marine line and may have consumed more marine protein than the population from Harris Creek.

To refine the diets of the people at Windover and Harris Creek, IsoSource is used to model the dietary inputs at Windover and Harris Creek. IsoSource is a visual Basic computer program designed to incorporate multiple isotopic sources into a single mixing model (Phillips & Gregg, 2003). The user inputs the isotopic signatures of the sources (foods), the mixtures (population averages), the source increment and mass balance tolerances. Five broad categories of food resources with different isotopic ranges were defined for the region: freshwater fish, marine fish, terrestrial game, marine mollusks, and freshwater snails/mollusks. The average isotopic values for each of these categories were determined from published samples collected from Florida (Table 3-2) (Hutchinson, 2004; Tuross et al., 1994). The average isotopic values of the populations at Windover and Harris Creek were entered into the program and different combinations of the five source categories were calculated in an attempt to match the human values. To produce robust estimates, a source increment of 1% and a tolerance of .5‰ were used. In the absence of a single solution for the mixtures and resources the program returns a range of feasible combinations, which are shown in Table 3-3. Based on the stable isotope values the people at Windover and Harris Creek were consuming the majority of their diet as marine fish with smaller contribution of freshwater fish, terrestrial game and fresh and saltwater

shellfish. There is a slight increase in the amount of freshwater fish and terrestrial game in the diets of the population at Harris Creek.

A significant marine component is suggested by this model, however, *caution must be used when interpreting these value*s. Linear models, such as IsoSource, make several assumptions that may not be accurate. These models assume that an equal proportion of carbon and nitrogen are incorporated into the consumer's tissue from a given food resource. This may not always be true if the food resources in the model have strongly divergent C:N ratios or different digestibility factors. Though models, Isoerror and Isoconc, have been developed to help deal with these problems, they are unable to handle more than 3 potential sources. Fortunately these factors should not greatly impact these models because they are based on the $\delta^{13}C$ and $\delta^{15}N$ of bone collagen of consumers and potential food sources. As such, the contribution of plant resources is excluded from these models. This exclusion does not imply that plant resources were not an important dietary resource during the Florida Archaic period, rather in diets with adequate protein intake, the $\delta^{13}C$ of collagen has been shown to primarily reflect the protein portion of the diet (Ambrose & Norr, 1993; Tieszen & Fagre, 1993). In terms of N, plants have significantly lower amounts of digestible N and only contribute significant amounts of N to the collagen of the consumer when very little animal protein is available (Hedges, 2004; Newsome et al., 2004; Richards & Hedges, 1999). Terrestrial meat, marine fish, and shellfish have all been shown to have roughly similar C:N ratios and digestibility factors (Newsome et al. 2004) and the C and N in meat and fish are 100% digestible (Pritchard & Robbins, 1990).

Finally, an additional potential source of error is the sample sizes of the fauna used to calculate the end members for each source category. If the sample sizes are small they may not accurately define the range of isotopic value for each category. Therefore, the ranges presented

in Table 3-3 should only be used as a measure of relative importance, not as a percentage of actual diet. Despite the potential sources of error, all the data presented here suggest a previously understated marine contribution to human diet at Windover and Harris Creek.

Taken as a whole, these results broadly support the assertion that Mt. Taylor groups were adapted to aquatic subsistence systems, but suggest that these groups relied more on marine or estuarine resources than previously noted. In this respect these groups may have been similar to the population recovered from Bay West, a Middle Archaic pond burial in Collier County, Florida. Isotopic studies by DeLeón (1998) suggest the people buried at Bay West consumed a diet rich in marine resources. Based on the results from Windover, this adaptation may have had roots in the Early Archaic, rather than being a Middle Archaic innovation. Tools and ornaments made from marine shell or sharks teeth are found on most Mt. Taylor sites and marginella beads and shark's teeth tools were recovered from Windover (Doran, 2002; Wheeler et al., 2000). In light of the isotopic data, these marine resources may be better interpreted as evidence of coastal occupations, rather than evidence of trade with coastal groups or the result of short term logistical foraging trips to the coast. Rising sea levels may have destroyed most evidence of the coastal occupations of these groups, however, the Tomoka Mound Complex and other coastal pre-pottery sites may be evidence of these occupations (Piatek, 1994; Russo, 1992; Russo, 1996; Russo & Ste. Claire, 1992; Ste. Claire, 1990). Marine resources, including marine shellfish, were definitely exploited by the Late Archaic as evidenced by season of capture studies at Tomoka Stone Park (8VO2571), Useppa Island-Calusa Ridge (8LL51), and Horr's Island (8CR209) (Quitmyer et al., 1997; Russo, 1998).

The isotopic data collected from Harris Creek indicate the Mt Taylor people building the mound were not consuming large amounts of freshwater snail. This suggests layers of mounded

snail shell were not foods remains and were intentionally used as a building material rather than merely deposited as midden. The use of freshwater shellfish as a building material has been argued by Claassen (1991; 1996) for Archaic Period mounds in the mid-South. Sassaman (2004) suggests the use of freshwater snail as building material in the St Johns region and Randall and Sassaman (2005b) cite layers of clean shell and slabs of redeposited concreted midden at Hontoon Island, as evidence of intentional construction. The mound at Harris Creek exhibited similar layers alternating layers of midden and clean shell, though redeposited midden was not reported (Aten 1999). If the shell was not a major food resource, the use of shell as a building material indicates that Mt Taylor Period shell mounds were more than trash dumps that gradually grew in size and were made meaningful as part of the landscape. These mounds were likely intentional monumental structures created by communal efforts of seasonally mobile groups.

Conclusion

Analyses of $\delta^{13}C$ and $\delta^{15}N$ ratios in bone collagen and $\delta^{13}C$ ratios in bone apatite from Windover and Harris Creek indicate a minor shift in diet between the Early Archaic and Middle Archaic Periods. Contrary to widely held beliefs (Wheeler and McGee, 1994; Wheeler et al., 2000; Russo, 1992) if Harris Creek is representative, Mount Taylor populations in the St. Johns region were not consuming large numbers of freshwater snails. Surprisingly, based on their $\delta^{13}C$ and $\delta^{15}N$ ratios and the estimated isotopic end member values of potential food resource from the region, people at Harris Creek *and* Windover consumed large amounts of marine/estuarine fish.

Based on the isotopic data gathered from these two sites, no major shift in resource use occurred between the Early and Middle Archaic in northeastern Florida. The data suggest that during the Mt Taylor Period, an existing coastal aquatic adaptation may have been extended into the river basin. As such the impetus for the creation of shell mounds along the river valley must be attributed to something other than a heavy reliance on riverine resources. Obviously

something changed around 7500 BP which resulted in the creation of freshwater shell mounds. As we move away from explanatory schemes based on evolutionary thought, we are also able to move away from explanatory schemes driven by environmental change. New avenues of research based on archaeologies of landscape and practice may prove more fruitful (Randall & Sassaman, 2005a). In the end, the beginning of the Shell Mound Archaic may have had more to do with what was in people's heads than in their bellies.

Table 3-1. Windover and Harris Creek/Tick Island $\delta^{13}C$ and $\delta^{15}N$ ratios

Site	$\delta^{13}C_{col}$	$\delta^{13}C_{col}$ adj.	$\delta^{13}C_{ap}$	$\delta^{13}C_{ap}$ adj.	Col -Ap	$\delta^{15}N_{col}$	$\delta^{15}N_{col}$ adj.	References
Windover	–15.6	–14.6	–10.2	–19.7	5.4	11.8	8.8	Tuross et al. 1994; This paper
Harris Creek/Tick Island	–16.5	–15.5	–9.9	–19.4	6.3	12.5	9.5	This paper
Difference	0.9	0.9	0.3	0.3	0.9	0.7	0.7	

Table 3-2. Isotopic endpoints for the Isosource linear mixing model.

Food type	$\delta^{13}C$	$\delta^{15}N$
freshwater fish	-23.5	9.6
marine fish	-15.2	9.5
terrestrial game	-21.3	7.6
marine shellfish	-15.7	7.8
freshwater snail	-25.7	4

Table 3-3. Results of Isosource remixing model for Harris Creek and Tick Island.

IsoSource	Freshwater Fish	Marine Fish	Terrestrial	Marine Shellfish	Freshwater Snail
Windover	0-22%	12-90%	0-30%	0-71%	0-17%
Harris Creek/Tick Island	2-33%	38-80%	0-27%	0-31%	0-6%

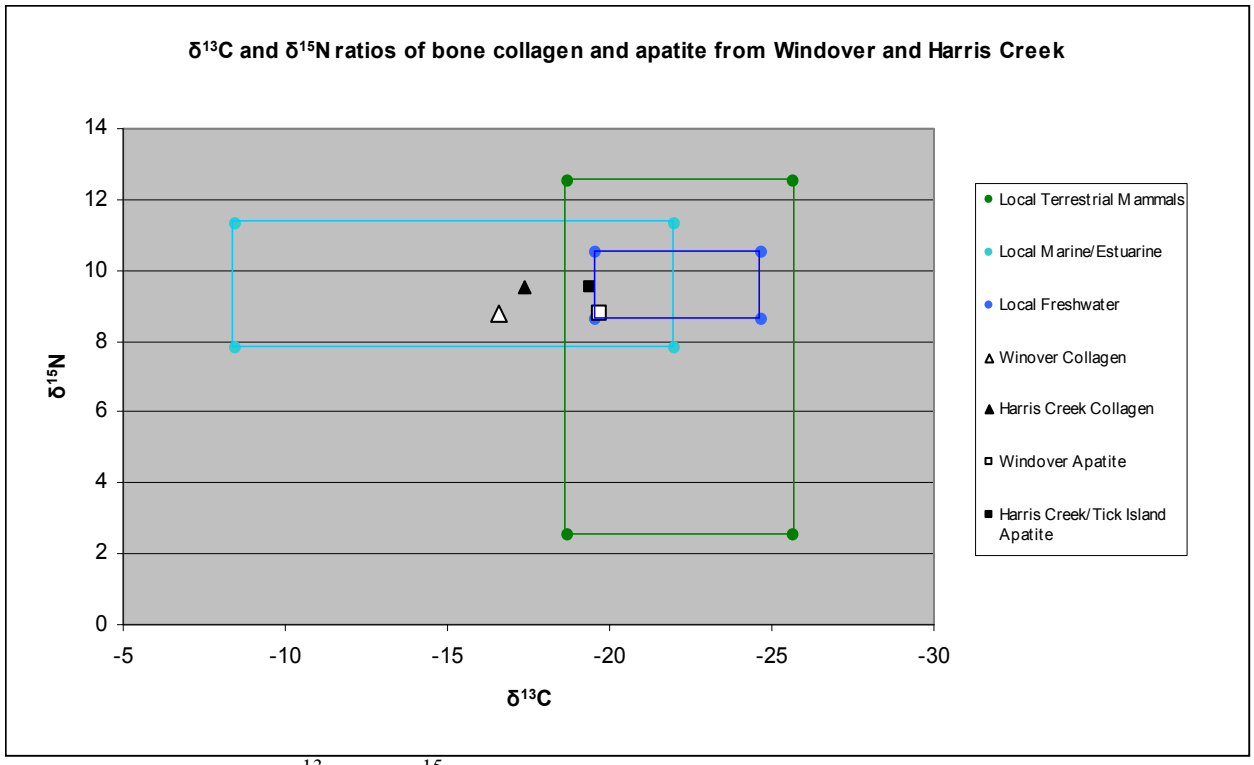


Figure 3-1. Adjusted $\delta^{13}C$ and $\delta^{15}N$ ratios of bone collagen and apatite from Windover and Harris Creek

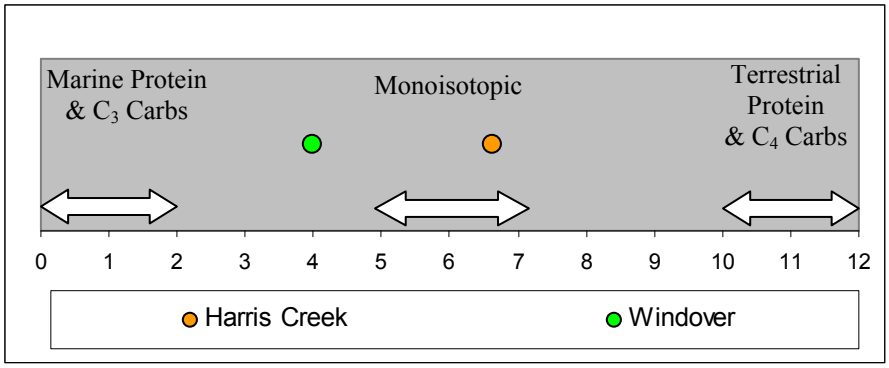


Figure 3-2. Difference in mean $\delta^{13}C$ ratios between apatite and collagen from Windover and Harris Creek.

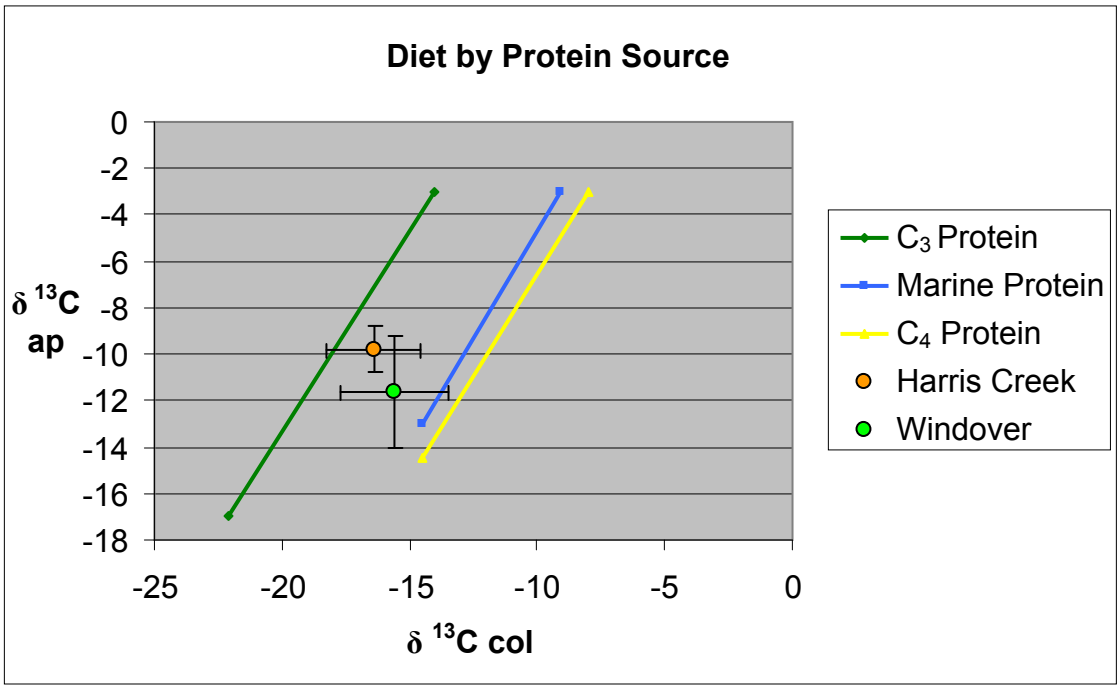


Figure 3-3. Regressions of protein $\delta^{13}C$ ratios. Regressions from Kellner and Schoeninger 2007. Sites averages are shown with 2 standard deviations.

CHAPTER 4
EVALUATING A SERIAL SAMPLING METHODOLOGY

Introduction

Serial sampling or isotopic "zoning" studies (Kohn & Cerling, 2002) assess changes in diet or environment recorded as a series of stable isotopic ratios in biological tissues (Balasse et al., 2002; Balasse et al., 2005; Fricke & O'Neil, 1996 ; Gadbury et al., 2000; Kohn et al., 1998; MacFadden et al., 2004; Passey et al., 2002; Straight et al., 2004; Wiedemann et al., 1999). Tooth enamel is the tissue of choice because the appositional nature of enamel development produces growth layers encapsulating isotope ratios from different periods of enamel formation. Sampling discrete increments of enamel produces isotopic data which allow changes in ecology and diet that occurred during enamel formation to be observed.

Several factors complicate serial sampling studies including environmental and physiological processes which buffer or attenuate the isotopic signal recorded in tooth enamel (Balasse, 2003). One of greatest concerns in serial sampling human and faunal teeth is secondary mineralization. During amelogenesis, enamel is only partially mineralized as it is deposited as along appositional growth fronts. The remaining mineral content of the enamel is introduced during the maturation phase by a process known as secondary mineralization (Avery, 2000; Schroeder, 1991). This process significantly prolongs the period of enamel maturation and introduces isotopes into the enamel from food and water ingested after the formation of the appositional growth structure (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005).

Serial sampling studies are infrequently applied to humans, in part because human teeth are small and bunodont compared to the larger, more hypsodont teeth of fauna. However, serial sampling studies of human and hominin remains have been successful. For example, human

molars from Wharram Percy were sectioned (as opposed to sampled) to infer the timing of weaning in a Medieval British population (Fuller et al. 2003). The dental remains of a ~2mya old robust australopithecine, *Parathropus robustus,* were effectively serially sampled by laser ablation to provide dietary and environmental data (Sponheimer et al. 2006).

A recent study of mammalian enamel demonstrates that isotopic sampling the growth layers between the inner and outer enamel recovers isotopic variation which remains intact after the maturation phase (Humphrey et al., 2007). Humphrey et al. (2007) identified changes in strontium/calcium ratios in infant enamel before and after birth and these changes were retained after mineralization was complete. Richards et al (2008) also used laser ablation to recover strontium isotopes from Neanderthal enamel which showed the Neanderthal moved over 20km during its lifetime. The success of these studies, coupled with the widespread success using faunal teeth, suggests the effects of secondary mineralization do not significantly impact isotopic studies.

This research evaluates the effects of secondary mineralization in human tooth enamel by sampling teeth along two different axes: (1) cross-cutting the appositional fronts, roughly parallel to the enamel prisms and (2) parallel to the perikymata on the tooth surface (Figure 4-1). We also compare the amount of variation recovered from modern and prehistoric samples to determine if the variation recovered results from environmental signals or an internal biological rhythm.

Environmental Buffering and Isotopic Attenuation

Initially the layers of enamel were thought to record the $\delta^{18}O$ values of ingested water in a relatively direct fashion (Fricke & O'Neil, 1996 ; Wiedemann et al., 1999). Despite the early successes, concerns over the length of time enamel requires to fully mineralize emerged (Balasse, 2003; Balasse et al., 2002; Passey & Cerling, 2002). Enamel is essentially a

hydroxyapatite mineral which is precipitated discontinuously at different times and rates over a period of weeks or months (Sakae & Hirai, 1982; Suga, 1982; 1989) which may result in an attenuated (time averaged) isotopic signal (Balasse, 2003; Balasse et al., 2002; Hoppe et al., 2004; Zazzo et al., 2005). Waves of mineralization do not follow the growth structures and as such the isotopic signature associated with the formation of the structures may be lost or greatly attenuated. The influence of later mineralization phases may prevent the recovery of chronological signals from the growth structures (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005).

Factors unrelated to mineralization can also complicate the interpretation of serially sampled data. Surface water produces a reservoir effect as precipitation is mixed and 'stored' in lakes and rivers. Such water sources ultimately reflect seasonal variation isotopically, though the isotopic values are muted (Balasse, 2003; Kohn & Cerling, 2002). Body water constitutes another reservoir in which oxygen isotopes are stored and mixed in the organism before they are locked into tooth enamel (Balasse 2003; Kohn and Cerling 2002).

Despite these sources of potential buffering, serial sampling is a proven means to recover isotopic time series data from teeth (Balasse et al., 2002; Balasse et al., 2006; Balasse et al., 2005; Fricke & O'Neil, 1996 ; Gadbury et al., 2000; Kohn et al., 1998; MacFadden et al., 2004; Nelson, 2005; Sharp & Cerling, 1998; Sponheimer et al., 2006; Straight et al., 2004; Zazzo et al., 2006). For example, Gadbury et al. (2000) interpreted serially sampled $\delta^{13}C$ and $\delta^{18}O$ ratios as evidence of a drought which affected herds of bison prior to the catastrophic event that formed the Hudson-Meng bone bed in Nebraska. Additionally, Balasse and colleagues (2005; 2006) have investigated the seasonal consumption of seaweed by sheep with $\delta^{18}O$ and $\delta^{13}C$ values recovered by serial sampling.

Variation in $\delta^{18}O$ is interpreted as a proxy to seasonal $\delta^{18}O$ variation in precipitation and surface water, an assertion supported by studies of African gazelle and other fauna in which the primary source of $\delta^{18}O$ variation was seasonal fluctuation of $\delta^{18}O$ values in precipitation (Balasse, 2003; Fricke & O'Neil, 1996 ; Gadbury et al., 2000; Kohn et al., 1998; MacFadden et al., 2004; Wiedemann et al., 1999). However, variation in $\delta^{18}O$ values may also result from changes in developmental physiology including changes in diet, metabolism, or water turnover rates (Kohn et al., 1998).

Tooth and Enamel Development

Teeth begin to form as enamel is secreted in layers which stack on the previous layer until the crown is fully formed (Figure 4-2.). There are three phases of enamel development; differentiation, secretion, and maturation. (Avery, 2000; Moss-Salentijn et al., 1997). The maturation stage is of particular interest to researchers involved in serial isotopic sampling of mammalian tooth enamel.

Maturation and Mineralization Waves

New enamel matrix is transformed into mature crystalline enamel during the process of enamel maturation (Schroeder, 1991). These changes include growth of enamel crystals, concentration and hardening of the mineralizing structure, selective changes in the composition of the enamel matrix, a decrease in the volume of organic matrix, and a loss of water (Schroeder, 1991). In general, these changes occur through the process of mineralization.

As soon as amelogenesis is complete the matrix begins a progressive and discontinuous process of mineralization (Weinmann et al. 1942; Suga et al. 1970, 1987; Suga 1979, 1982; Sakae and Hirai 1982; Engel and Hilding 1984; Moss-Salentijn et al. 1997). Mineralization proceeds in a series of four phases or waves (Suga et al., 1987). These successive waves of mineralization proceed as successive fronts in multiple directions across the enamel layer

between the enamel surface and the dentine-enamel junction (DEJ) (Balasse, 2003; Suga et al., 1987).

During mineralization, small crystal seeds of apatite are deposited in the newly secreted enamel (Avery, 2000; Schroeder, 1991). The initial phase of enamel mineralization occurs as weakly (ca. 20%) mineralized protein matrix is secreted. An exception occurs in the first layer of enamel secreted adjacent to the DEJ, this layer (ca. 8um thick) is more heavily mineralized (ca. 60%) than later enamel and is less affected by the successive waves of mineralization (Sakae & Hirai, 1982; Suga, 1982). The second phase of mineralization increases mineral content as the wave progresses from the surface toward the DEJ (Suga et al., 1987). A tertiary phase occurs as a wave of increased mineralization moves from the DEJ to the surface of the tooth (Suga et al., 1987). Lastly, during the quaternary phase, the narrow outer layer of enamel (ca. 15um) which lags behind in mineralization, undergoes a rapid mineralization to become the most mineralized tissue in the human body ca. 95% (Suga, 1989; Suga et al., 1987). The high mineral content results in the loss of almost all water and organic material during maturation.

The increasing mineral content during mineralization is a result of the growth of the apatite crystals. The growth of these crystals has been documented during the third wave of mineralization (Allan 1967). Initially, the young crystals are 1.5nm thick and 30nm wide. By the end of the third phase the crystals increase to 20-60 nm thick and 30-90 nm wide.

Carbonate Substitutions in Enamel

Attenuation caused by mineralization waves is a major concern in serial sampling studies (Balasse, 2003; Balasse et al., 2002; Passey & Cerling, 2002; Zazzo et al., 2005). However, the manner in which carbonate substitutions occur in enamel suggests these waves do not result in significant buffering when sampling the structural carbonate component of tooth enamel.

The principal component of enamel is hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ but carbonates and trace minerals are frequently substituted into the hydroxyapatite matrix (Weatherell & Robinson, 1973). Carbonate in enamel mineral is the third most common constituent following calcium and phosphate. The chemical and structural features of enamel carbonate have been studied extensively because carbonate is thought to be related to cariogenesis (Boyde, 1979). However, Moreno and Aoba (1990) suggest that hydroxyapatites containing carbonate are more thermodynamically stable than hydroxyapatites without carbonate, indicating carbonate may not be the "weak link" which precipitates the formation of carious lesions.

Sydney-Zax et al. (1991) examined the carbonate content of forming, maturing, and mature enamel in 22 human teeth and 46 bovine teeth. They found that carbonate concentration was highest in newly secreted enamel and began to decrease at the beginning of the maturation stage, finally reaching the lowest concentration in mature enamel. They suggest the decreasing carbonate concentration with the increasing mineralization of enamel results from the dilution of carbonate rich enamel with carbonate poor enamel. Robinson et al. (1995) support these results demonstrating that as mineralization advances, the carbonate concentration, as well as trace minerals such as magnesium and fluoride, are reduced.

In addition to humans and bovines, the early secretory enamel of porcine enamel is enriched in carbonate as well (Aoba & Moreno, 1990). The formation of a carbonate rich apatite during early enamel deposition may be a generalized process in several species and may reflect a mechanism of mineral precipitation (Aoba & Moreno, 1990; Hiller et al., 1975; Sydney-Zax et al., 1991). For example, Hiller et al. (1975) reported similar enrichment in the development of a rat incisor.

Carbonate is incorporated into the hydroxyapatite molecule at two different sites: (1) in place of the PO_4 or phosphate group, a Type B substitution, and (2) in place of the OH or hydroxyl ion, a Type A substitution (Elliott et al., 1985). Using X-ray diffraction on newly formed secretory enamel, Aoba and Moreno (1990) detected carbonate only in the position normally occupied by PO_4 (a Type B substitution). However, incorporation of carbonate into the Type A or hydroxyl position becomes evident as amelogensis proceeds (Aoba & Moreno, 1990). X-ray diffraction showed a significant increase in the α parameter between the secretory stage and mature enamel which Aoba and Moreno (1990) attribute substitution of the hydroxyl ion with carbonate (a Type A substitution).

Most carbonate in mature enamel, is at the PO_4 position (Type B); only ca. 10-15% of the carbonate ions in human mature enamel are in the OH position (Type A) (Elliott et al., 1985). Aoba (1996) suggests the selective occupation of hydroxyl sites by carbonate in the later stages of enamel formation is due to a competition for two sites, one of which (A-type) is favored energetically but limited in number while the B-type site is less favored but present in greater numbers (Aoba, 1996; Sydney-Zax et al., 1991). When there are lower concentrations of carbonate the energetic considerations prevail. However, when carbonate is available in greater concentration, the probability of occupation at either site is largely determined by the absolute number of sites. If this model is correct, there may be differences in the mineralizing environment during different mineralizing phases (Aoba, 1996). The preferential B-type substitution in early development supports the presence of carbonate rich fluid during initial enamel secretion and mineralization. Supporting evidence is found in porcine enamel; the liquid phase surrounding the forming enamel mineral contains significant amounts of HCO_3 ions (Aoba & Moreno, 1987).

The difference in the timing of the two substitutions is important for researchers sampling enamel carbonates. Of the total carbonate in mature enamel 10-15% are in the OH (Type A) position and the remaining 85-90% occupy the PO_4 (Type B) position (Elliott et al., 1985). The majority of the carbonate present in newly formed enamel is in the PO_4 position, and there is a preference for the OH sites to be filled as mineralization proceeds (Aoba & Moreno, 1987). Therefore, the majority of the carbonate in each sample of mature enamel (ca. 85-90%) is present at the point of enamel secretion and chronologically associated with the visible growth structure. Only ca. 10-15% of the total carbonate in a sample of mature enamel is introduced during subsequent waves of mineralization.

Striae of Retzius and Perikymata and Crown Formation Times

Serial sampling requires the relative amount of time encompassed by each sample be known. Striae of Retzius or Retzius lines are growth lines frequently discussed in serial sampling literature. More specially, such studies often involve the surface manifestation of these lines, called perikymata (Figure 4-3). As tooth growth proceeds, the sequential layers of enamel produce appositional lines that can be seen after tooth formation is complete. These features represent the successive positions of the enamel forming front as tooth growth proceeds. The growth rate of teeth is not constant and the spacing of lines of Retzius and perikymata vary throughout the tooth. Shellis (1998) found the rate of enamel apposition in the lateral enamel of human permanent dentition increases from 2-3um/day in the initial stages to 5-6um in the final stages as enamel formation process. Based on a count of cross-striations, lines of Retzius and perikymata have an average periodicity of ca. 9 days in humans and great apes (Benyon et al., 1998; Dean et al., 2001; FitzGerald, 1998). All estimates for Homo are between 6 and 11 days (summarized in FitzGerald, 1998).

Histological examination of periodic growth features in dental enamel has been shown to provide better estimates of crown formation times than more tradition radiological examinations (Reid & Dean, 2006). Radiological studies often have problems detecting the onset of mineralization and do not have the resolution to identify the near microscopic changes which occur during dental development (Benyon et al., 1998; Reid & Dean, 2006). Reid and Dean (2006) collected data on crown formation time from 326 molars from southern Africa, northern Europe and North America. Based on the periodicity of Striae of Retzius and cross-striations, the crown formation time for various teeth was calculated. Molars exhibited very little variation in crown formation time compared to other types of teeth; all molars completed enamel formation over a period of 3.0 to 3.4 years (Reid & Dean, 2006). Based on Reid and Dean's (2006: Figure 4) estimates of chronological age for each decile of crown height, roughly 2 years of growth is present along the external tooth surface, the remaining year of growth is folded inside later growth layers and does not reach the tooth surface.

Materials and Methods

Sample selection

Fifteen human molars were selected to assess the effects of secondary mineralization through serially sampling. Modern teeth were obtained from extant collections in Gainesville, Florida and New Castle-on-Tyne, England. Two teeth were selected for sampling from each locality. Unfortunately, the individual life histories of the individuals are not known. The remaining 11 teeth are from 3 different archaeological contexts: Niah Cave West Mouth, Borneo, Niah Cave Lobang Jeragan, Borneo, and Gua Cha, Malaysia.

Site Descriptions

Individuals from Niah Cave were recovered from the West Mouth portion of the cave system. Niah Cave is located in Sarawak, Borneo and contains one of the most extensive

stratified records of human occupation in Southeast Asia (Barker, 2002). The site spans the late Pleistocene and Holocene and over 170 human burials have been recovered (Krigbaum, 2005). Lobang Jeragan is separate site within the Niah Cave complex. Over 60 Neolthic burials were recovered from the site. Gua Cha is a rock shelter in northeast Malaysia. The site was occupied during the Mid Holocene by broad spectrum hunter-gatherers and later used as a burial site by Neolithic populations (Bellwood, 1997).

External Sampling—Dental Drill

Tooth surfaces were mechanically cleaned with distilled H_2O and inspected under magnification. The external surface of each molar was lightly abraded with a Brasseler dental drill and carbide bit (Brasseler #170) to remove remaining debris. A series of six to eight samples, between .4 and 1.0 mg were removed under magnification, parallel to the perikymata starting just above the CEJ and proceeding toward the occlusal surface (Figure 4-1B).

Internal Sampling—Micromill

A New Wave Research-Merchantek MicroMill system fitted with a carbide bit (Brasseler #170) was used to remove samples from the interior of each tooth. The Micromill is a micro-sampling system specifically designed to collect small samples for isotopic or chemical analysis. The user defines the sample areas with the graphical interface and the drilling is fully automated. After the drilling is complete the user collects the sample and prepares it for isotopic assay. Prior to sampling, the molars were mechanically cleaned in distilled water. Once dry, each tooth specimen was sectioned along the mesio-distal mid-section and half of each specimen was mounted on a glass slide. The first sample was collected between the DEJ and the tooth surface under the tip of the cusp. Sampling proceeded toward the CEJ with each sample following the prism orientation and typically included around 6 samples (Figure 4-1A).

Pretreatment

After both sampling protocols were completed, enamel powder was placed directly into pre-weighed stainless steel capsules and loaded into a multiprep inlet system attached to a VG PRISM II mass spectrometer. The enamel samples were not chemically pretreated. Conventional sampling includes chemical pretreatment of bone and enamel with a 2% sodium hypochlorite (NaOHCl) solution to remove organics followed by an acetic acid (CH_3COOH) solution to remove adsorbed labile or secondary carbonates. However, these treatments result in significant sample loss. A recent trend is to avoid strong chemical treatments (Garvie-Lok 2004; Koch et al. 1997), especially for enamel, which is less likely to be diagenetically altered because it is more thermodynamically and kinetically stable than bone (Nielson-Marsh and Hedges 2000). Passey et al. (2002) found no predictable difference between untreated and pretreated samples of modern and fossil fauna from various localities in Nebraska and Texas. Such findings, along with the geologically young age of the samples (less likely to have absorbed secondary carbonates) argue against pretreatment. In addition, not conducting pretreatment allows for very small samples to be analyzed. Larger samples mix more growth bands and result in more time-averaging per sample.

Results

Fifteen individuals from diverse environments and time periods were sampled in this research. Series of between 6 and 9 samples were removed from the external surface of each tooth for a total of 104 samples, 97 of which returned acceptable results. The micromill was used to collected series of between 5 and 10 samples from the interior of the teeth. Of 109 samples collected with the micromill, 103 produced suitable values. Combined, 213 enamel samples were collected and 200 returned satisfactory results. Summary statistics for each individual are shown in Table 4-1.

Discussion

Effects of Secondary Mineralization

Fifteen human molars were sampled for $\delta^{18}O$ and $\delta^{13}C$ (Table 4-1). Combined the $\delta^{18}O$ and $\delta^{13}C$ samples provide 30 cases of paired data to assess the variability produced by each sampling method. The possible outcomes can be expressed as a null hypothesis and two alternatives.

H_0: There will be no significant difference in the amount of variation recovered from the growth structures and the mineralization wave.

H_1: Sampling growth structures will recover more isotopic variation.

H_2: Sampling parallel to the enamel prisms will recover more variation.

Of 15 sets of $\delta^{18}O$ values, sampling the visible growth structure, recovered more isotopic variation in 10 of the 15 cases (Figure 4-4). Sampling roughly parallel to the enamel prisms recovered more variation in 4 of the 15 cases. One sample recovered similar variation with both methods. The average difference between the two methods was .69‰.

The 15 sets of $\delta^{13}C$ values produced results similar to the $\delta^{18}O$ values. Of the 15 cases, sampling the perikymata recovered more isotopic variation in 13 of the 15 cases (Figure 4-5). Sampling parallel to the enamel prisms only recovered more variation in only 2 of the 15 samples. The average difference in $\delta^{13}C$ between the two methods is .54‰.

In total, sampling parallel to the perikymata recovered more variation in 23 of 30 cases. The average difference between sampling along the enamel prisms and the growth structures for all 30 samples was .62‰. Though the difference is relatively small, the results overwhelmingly support alternative hypothesis H_1—sampling growth structures recovers more isotopic variation.

Source of Isotopic Variation

The results of the external sampling of modern and prehistoric teeth are compared to determine if the isotopic variation recovered is due to climatic or physiological factors. If the intratooth variation in $\delta^{18}O$ ratios primarily reflects the consumption of isotopically fluctuating precipitation and surface water, then we expect little to no variation in the modern samples. The pooling and storage of drinking water in reservoirs, the consumption of bottled and/or canned beverages, and possible buffering from secondary mineralization is expected to erase any seasonal $\delta^{18}O$ variation in modern samples. If the variation is primarily the result of a physiological process then the variation between the modern and prehistoric teeth should be similar. The modern sample consists of two molars collected from Gainesville, FL and two molars collected from New Castle-on-Tyne, U.K.

The results from the modern teeth reflect their places of origin (Table 4-6). The mean $\delta^{18}O$ ratios differ by over 2.0‰ between the Florida and New Castle specimens as is expected based on the global distribution of $\delta^{18}O$ ratios. Interestingly, the $\delta^{13}C$ ratios also differ between the two locations; both individuals from Gainesville were enriched compared to the two New Castle individuals. The enrichment of the Gainesville specimens relative to the New Castle individuals is probably due to the U.S.'s reliance on corn based products. According to the Food and Agriculture Organization of the United Nations, in 2003 the average kg of corn consumed per captia annually in the U.K. was 3.0kg. Conversely, the average consumption of corn per year per person in the U.S. in 2003 was 13.0kg; this cultural preference in food choice likely accounts for the difference in the $\delta^{13}C$ ratios.

As expected, the modern teeth exhibit less isotopic variation in $\delta^{18}O$ than the prehistoric teeth; the average difference in min/max values of $\delta^{18}O$ for the modern samples is 0.98‰ compared to 1.4 ‰ for prehistoric samples. However, the difference of only .42 between the

prehistoric samples and the modern samples is not as large as expected. This difference suggests a considerable amount of buffering is occurring in the prehistoric samples or that modern teeth show more of a seasonal signal than initially expected.

Estimates of modern seasonal variation from Gainesville and New Castle-on-Tyne predict that precipitation in New Castle-on-Tyne will exhibit more seasonal variation than in the Gainesville area (Bowen, 2005; Bowen & Revenaugh, 2003; Bowen et al., 2005; Bowen & Wilkinson, 2002) but the mean difference in $\delta^{18}O$ for each site is almost equivalent. The similar mean difference in $\delta^{18}O$ ratios for each locality suggests that the variation in modern teeth is not accurately reflecting a seasonal signal and likely results from isotopic buffering of the signal prior to ingestion. Since the majority of $\delta^{18}O$ present in mature enamel is incorporated during enamel deposition, this averaging does not result from secondary mineralization. The lower variation in the modern samples probably results from the buffering and mixing of the drinking water consumed by modern populations. Buffering occurs as groundwater pools and is mixed in rivers, streams, and lakes, as well as within the reservoir of body water before it is incorporated into enamel. Though the difference between the modern and prehistoric samples is not as large as expected, there is little variation in the modern teeth and no pattern of variation that could be attributed to a biological rhythm (Figure 4-7).

When the isotopic series are averaged, the isotopic samples from the modern teeth accurately reflect average differences in climate and diet, but the individual serial samples do not show a seasonal pattern of precipitation or evidence a pattern attributed to an internal biological rhythm. Instead they establish a baseline of variation for two highly buffered populations of around 1.0‰. The prehistoric samples exceeded this average only by ca. 0.4‰ which suggests the archaeological populations from Southeast Asia, may have also experienced considerable

environmental buffering. Based on the four modern teeth, no pattern of variation is apparent that might be caused by an internal biological rhythm, instead the prehistoric teeth reflect an attenuated record of seasonal variation in $\delta^{18}O$ values.

Conclusion

Interpreting isotopic time-series data remains challenging. The isotopic signals are subject attenuation from a variety of source prior to and after ingestion by an organism. Despite these factors, many serial sampling studies produce results which indicate an environmental signal is recorded in tooth enamel. This study offers evidence which indicates why these studies work.

Sampling parallel to the visible growth structures recovers more isotopic variation than does sampling parallel to the enamel prisms roughly along the projected path of mineralization. These results do not suggest secondary mineralization is a significant source of isotopic attenuation. Though enamel is only light mineralized when secreted, ca. 20% (Avery, 2000; Schroeder, 1991), it already contains 85-90% of the carbonate present in mature enamel. Additionally, this 85-90% of the total carbonate preferentially occupies the PO_4 position which is assayed during isotopic study. The remaining 10-15% of the total carbonate in mature enamel is introduced during the maturation phase but this enamel preferentially substituted into the OH position which is not assessed during isotopic study. Therefore, nearly 100% of the carbonate sampled in most isotopic studies of tooth enamel is directly associated with the visible growth structure. In these cases secondary mineralization will not result in attenuation of the isotopic signal. However, the relatively small amount of variation found in the prehistoric teeth sampled here suggest other forms of isotopic buffering still result in significant attenuation. Continued work is needed to model these factors in the absence of attenuation caused by secondary mineralization.

These results indicate secondary mineralization is not a concern for researchers who sample carbonates, but secondary mineralization remains an obstacle when sampling phosphates. Though the majority of the carbonate present in mature enamel is present at deposition, this is not true of phosphate. The amount of phosphate in a sample appears to greatly increase over the maturation phase and as such, concerns over attenuation still apply. In these cases, models such as those by Passey and Cerling (2002), Passey and colleagues (2005) and Zazzo and colleagues (2005) may help to recover the original amplitude and structure of the isotopic signal.

When sampling phosphate the portion of the tooth sampled is also a concern. Previous studies have suggested the inner most layer of enamel immediately adjacent to the EDJ would produce superior results because it is more heavily mineralized at deposition and is therefore less affected by the effects of secondary mineralization (Balasse, 2003; Sakae & Hirai, 1982; Suga et al., 1987). However, this inner layer is thin, only around 8-10um thick and is located in the interior of the tooth requiring the tooth to be sectioned, a potentially expensive and destructive process (Sakae & Hirai, 1982; Suga et al., 1987). Another approach might be to sample the outer layer of enamel; this layer is thicker than the inner layer ca. 15um and more easily accessible. The outer layer remains lightly mineralized until late in development when it undergoes a rapid mineralization to become the most mineralized tissue in the human body (Suga, 1989; Suga et al., 1987). If this mineralization front follows a predictable path, then the outer layer might provide a source of phosphate samples that encapsulate a relatively small amount of time due to the rapid mineralization of the layer. Further research may reveal when other isotopes, like lead and strontium, are incorporated into enamel and if they are subject to the effects of secondary mineralization.

Table 4-1. Summary statistics for individuals sampled in this research.

New Castle 2 $\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-5.8	-4.3	-1.4	Mean	-13.0	-12.5	-0.5
Std. Dev.	0.5	0.2	0.3	Std. Dev.	0.3	0.2	0.1
Median	-5.5	-4.3	-1.3	Median	-13.0	-12.5	-0.5
Max	-5.1	-4.1	-1.1	Max	-12.3	-12.2	-0.2
Min	-6.7	-4.5	-2.2	Min	-13.3	-12.7	-0.7
Diff.	1.6	0.4	1.1	Diff.	1.0	0.5	0.5

New Castle 3 $\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-4.7	-4.9	0.2	Mean	-12.3	-12.5	0.2
Std. Dev.	0.1	0.1	0.0	Std. Dev.	0.2	0.1	0.1
Median	-4.7	-4.9	0.2	Median	-12.3	-12.5	0.3
Max	-4.6	-4.8	0.2	Max	-12.0	-12.5	0.5
Min	-4.9	-5.0	0.1	Min	-12.6	-12.7	0.1
Diff.	0.3	0.1	0.1	Diff.	0.6	0.2	0.4

Gainesville G-3 $\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-2.9	-2.6	-0.3	Mean	-9.1	-9.2	0.2
Std. Dev.	0.1	0.3	-0.1	Std. Dev.	0.1	0.2	0.0
Median	-2.9	-2.6	-0.3	Median	-9.1	-9.3	0.3
Max	-2.7	-2.2	-0.5	Max	-8.8	-9.0	0.2
Min	-3.2	-3.0	-0.2	Min	-9.3	-9.4	0.1
Diff.	0.5	0.8	-0.3	Diff.	0.4	0.4	0.0

Gainesville G-4 $\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-3.0	-2.9	-0.1	Mean	-8.1	-8.8	0.7
Std. Dev.	0.7	0.1	0.6	Std. Dev.	0.5	0.1	0.4
Median	-2.7	-2.9	0.2	Median	-8.0	-8.8	0.8
Max	-2.4	-2.8	0.4	Max	-7.3	-8.6	1.3
Min	-4.0	-3.0	-1.0	Min	-8.5	-8.9	0.4
Diff.	1.6	0.2	1.4	Diff.	1.2	0.3	1.0

Niah N-36 $\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.6	-5.5	-1.1	Mean	-13.3	-13.5	0.3
Std. Dev.	1.4	0.9	0.5	Std. Dev.	0.5	0.2	0.3
Median	-6.2	-5.9	-0.3	Median	-13.4	-13.6	0.2
Max	-5.5	-3.9	-1.6	Max	-12.5	-13.2	0.7
Min	-9.8	-6.2	-3.6	Min	-13.9	-13.7	-0.1
Diff.	4.3	2.3	2.0	Diff.	1.3	0.5	0.8

Table 4-1. Continued

Niah N-83

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-4.7	-4.9	0.2	Mean	-14.7	-15.9	1.2
Std. Dev.	0.5	0.4	0.1	Std. Dev.	0.3	0.1	0.3
Median	-4.8	-4.8	0.0	Median	-14.8	-15.9	1.1
Max	-4.0	-4.4	0.5	Max	-14.2	-15.8	1.6
Min	-5.5	-5.7	0.2	Min	-15.1	-16.0	0.9
Diff.	1.6	1.3	0.3	Diff.	0.8	0.1	0.7

Niah N-160

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.4	-6.6	0.2	Mean	-12.0	-12.7	0.7
Std. Dev.	0.6	0.4	0.2	Std. Dev.	0.2	0.4	-0.2
Median	-6.2	-6.7	0.5	Median	-12.1	-12.5	0.5
Max	-5.6	-5.8	0.1	Max	-11.6	-12.3	0.7
Min	-7.2	-6.9	-0.2	Min	-12.4	-13.6	1.3
Diff.	1.5	1.1	0.4	Diff.	0.8	1.3	-0.5

Niah N-173

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-7.7	-6.5	-1.2	Mean	-13.0	-13.3	0.3
Std. Dev.	0.3	0.3	0.0	Std. Dev.	0.5	0.3	0.2
Median	-7.6	-6.6	-1.0	Median	-13.0	-13.4	0.4
Max	-7.3	-5.8	-1.6	Max	-12.3	-12.7	0.4
Min	-8.1	-6.8	-1.4	Min	-13.6	-13.6	0.0
Diff.	0.8	1.0	-0.2	Diff.	1.3	1.0	0.3

Lobang Jeragan B1

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-7.1	-6.9	-0.2	Mean	-11.0	-12.4	1.4
Std. Dev.	0.2	0.7	-0.5	Std. Dev.	0.6	0.5	0.1
Median	-7.1	-7.1	0.0	Median	-11.2	-12.6	1.4
Max	-6.9	-5.5	-1.5	Max	-9.9	-11.5	1.6
Min	-7.3	-7.7	0.4	Min	-11.6	-12.9	1.2
Diff.	0.4	2.2	-1.8	Diff.	1.7	1.4	0.3

Lobang Jeragan B12

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.7	-6.2	-0.4	Mean	-11.6	-12.0	0.4
Std. Dev.	0.2	0.1	0.1	Std. Dev.	0.5	0.3	0.2
Median	-6.7	-6.2	-0.5	Median	-11.6	-12.1	0.5
Max	-6.2	-6.0	-0.2	Max	-10.8	-11.5	0.7
Min	-6.9	-6.3	-0.6	Min	-12.1	-12.2	0.1
Diff.	0.7	0.3	0.4	Diff.	1.3	0.7	0.6

Table 4-1. Continued

Lobang Jeragan B28

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.5	-7.0	0.5	Mean	-10.9	-12.4	1.5
Std. Dev.	0.2	0.3	-0.1	Std. Dev.	0.6	0.3	0.3
Median	-6.6	-7.2	0.6	Median	-10.7	-12.5	1.8
Max	-6.2	-6.6	0.5	Max	-10.2	-12.1	1.9
Min	-6.8	-7.3	0.5	Min	-11.7	-12.7	1.0
Diff.	0.7	0.7	0.0	Diff.	1.6	0.7	0.9

Lobang Jeragan B33

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-7.1	-6.5	-0.6	Mean	-11.0	-12.8	1.9
Std. Dev.	0.3	0.4	-0.1	Std. Dev.	0.8	0.4	0.4
Median	-7.1	-6.5	-0.5	Median	-10.9	-13.0	2.1
Max	-6.7	-6.0	-0.7	Max	-10.2	-12.1	1.9
Min	-7.5	-7.0	-0.5	Min	-12.1	-13.2	1.1
Diff.	0.8	1.0	-0.2	Diff.	1.9	1.1	0.8

Gua Cha B13

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.3	-6.2	-0.1	Mean	-11.6	-12.9	1.2
Std. Dev.	1.5	0.6	0.8	Std. Dev.	0.8	0.6	0.2
Median	-5.6	-6.1	0.4	Median	-11.8	-12.7	1.0
Max	-5.2	-5.6	0.4	Max	-10.6	-12.3	1.7
Min	-8.8	-7.7	-1.1	Min	-13.1	-14.4	1.3
Diff.	3.6	2.1	1.5	Diff.	2.5	2.1	0.4

Gua Cha B19B

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-7.7	-6.6	-1.1	Mean	-14.4	-15.3	0.9
Std. Dev.	0.4	0.2	0.2	Std. Dev.	0.4	0.1	0.3
Median	-7.8	-6.7	-1.2	Median	-14.3	-15.4	1.0
Max	-7.2	-6.3	-0.9	Max	-13.9	-15.1	1.2
Min	-8.1	-6.8	-1.3	Min	-14.9	-15.4	0.5
Diff.	0.9	0.5	0.4	Diff.	1.0	0.3	0.7

Gua Cha B21B

$\delta^{18}O$	External	Internal	Diff.	$\delta^{13}C$	External	Internal	Diff.
Mean	-6.4	-6.8	0.4	Mean	-13.9	-14.4	0.5
Std. Dev.	0.2	0.1	0.1	Std. Dev.	0.4	0.4	0.0
Median	-6.4	-6.8	0.4	Median	-13.9	-14.5	0.6
Max	-6.1	-6.7	0.6	Max	-13.5	-13.8	0.4
Min	-6.5	-6.9	0.4	Min	-14.3	-14.8	0.6
Diff.	0.4	0.2	0.2	Diff.	0.8	1.0	-0.2

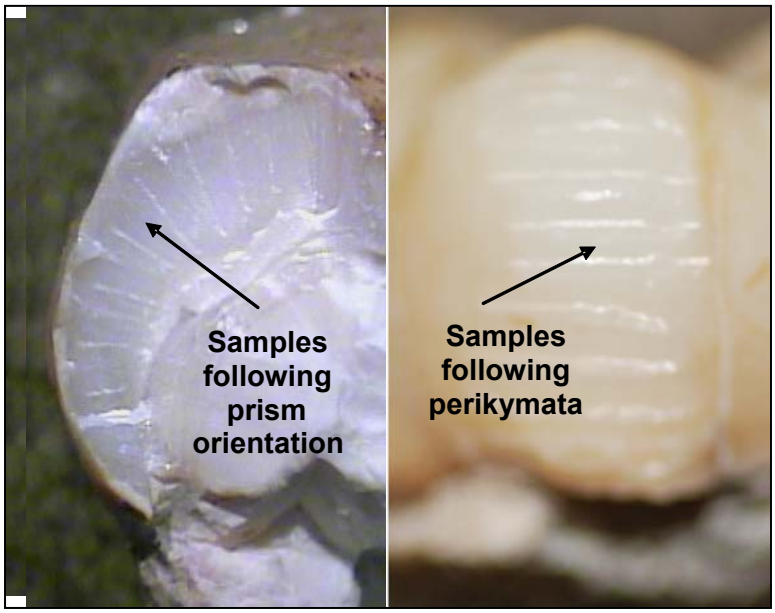


Figure 4-1. Serial sampling methods employed in this study.

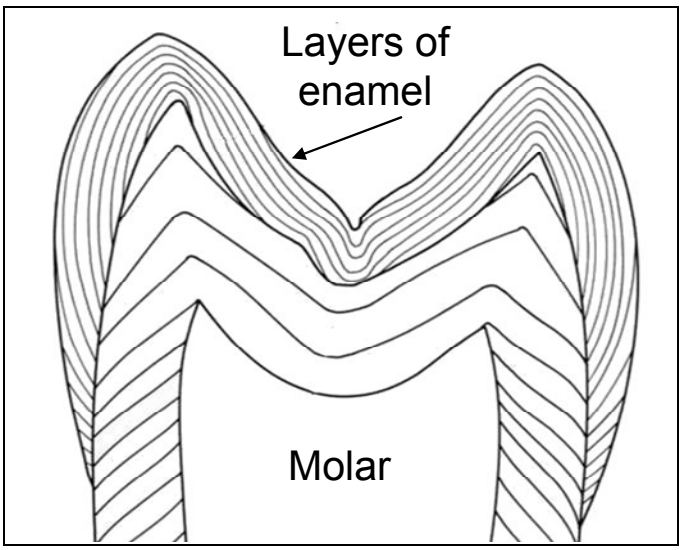


Figure 4-2. Appositional nature of enamel formation. Adapted from Hilson S. 1996. Dental Anthropology. Cambridge, Cambridge University Press.

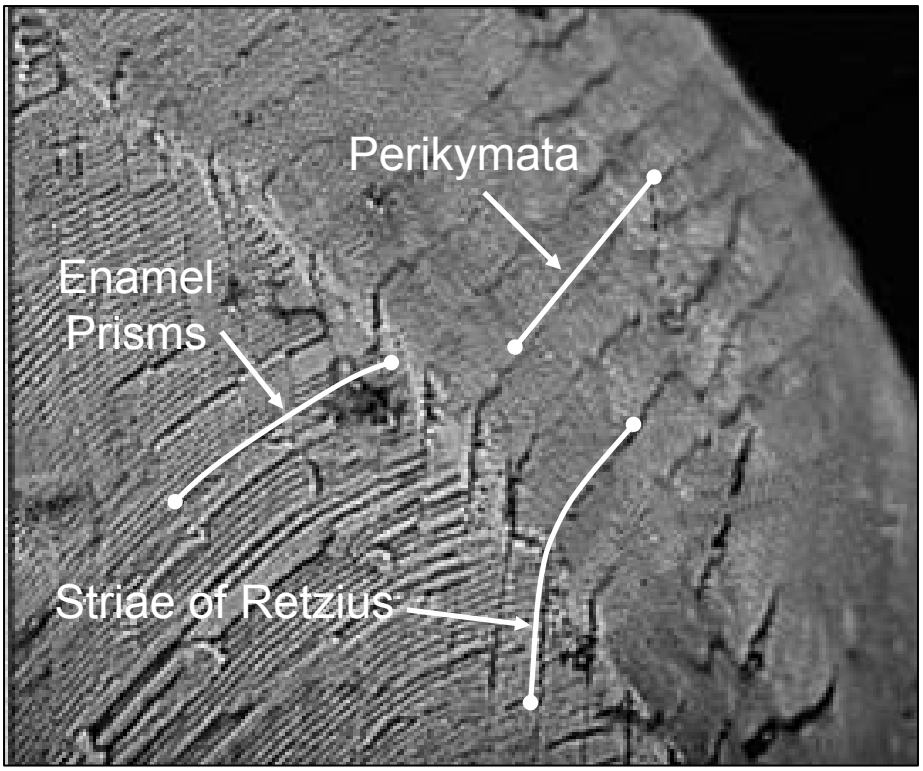


Figure 4-3. Picture of tooth microstructure showing perikymata, enamel prisms and Striae of Retzius. Adapted from Guatelli-Steinberg D., Reid D. J., Bishop T. A. & Larsen C. S. 2005. Anterior tooth growth periods in Neandertals were comparable to those of modern humans. Proceedings of the National Academy of Sciences 102:14197-14202.

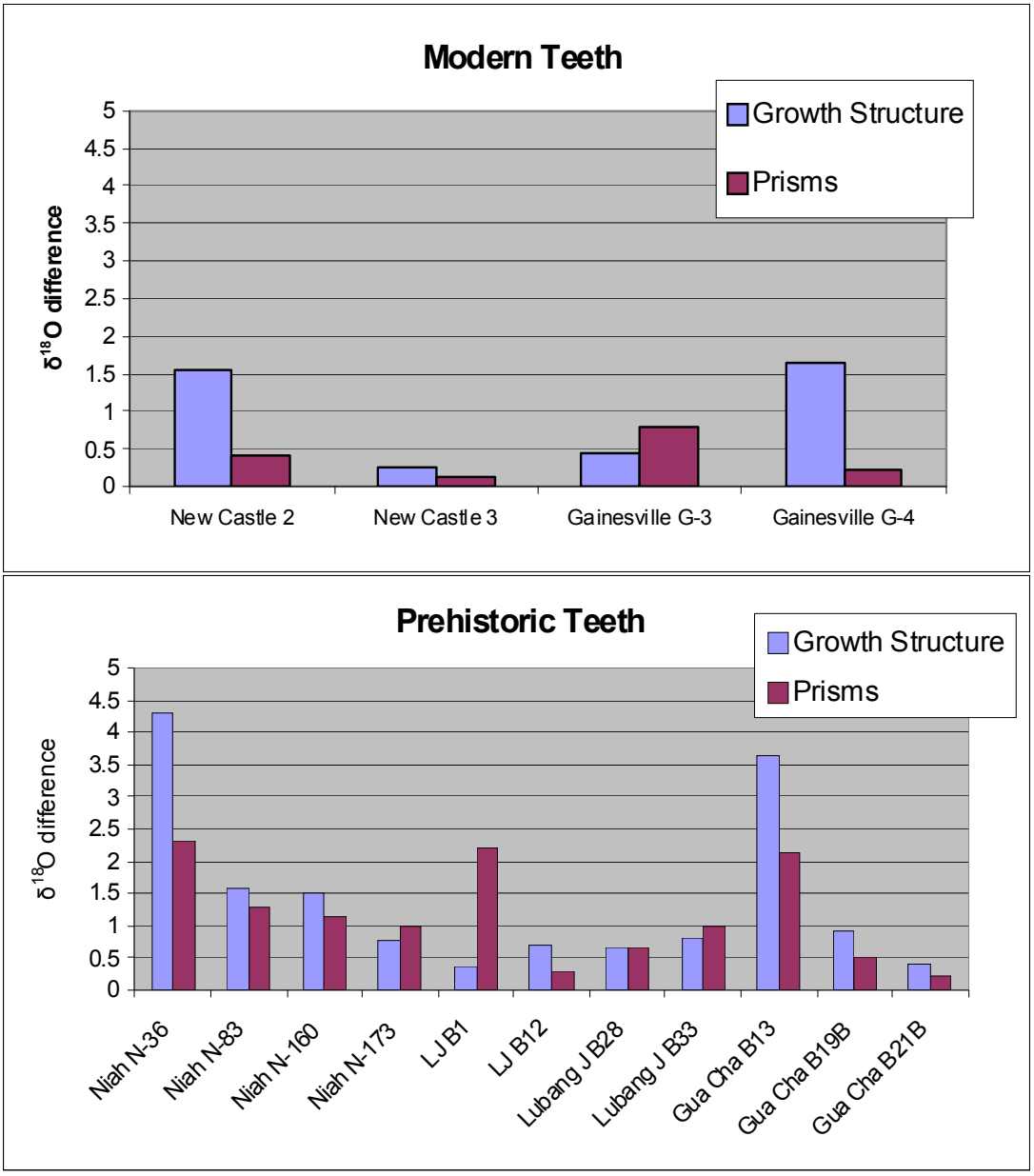
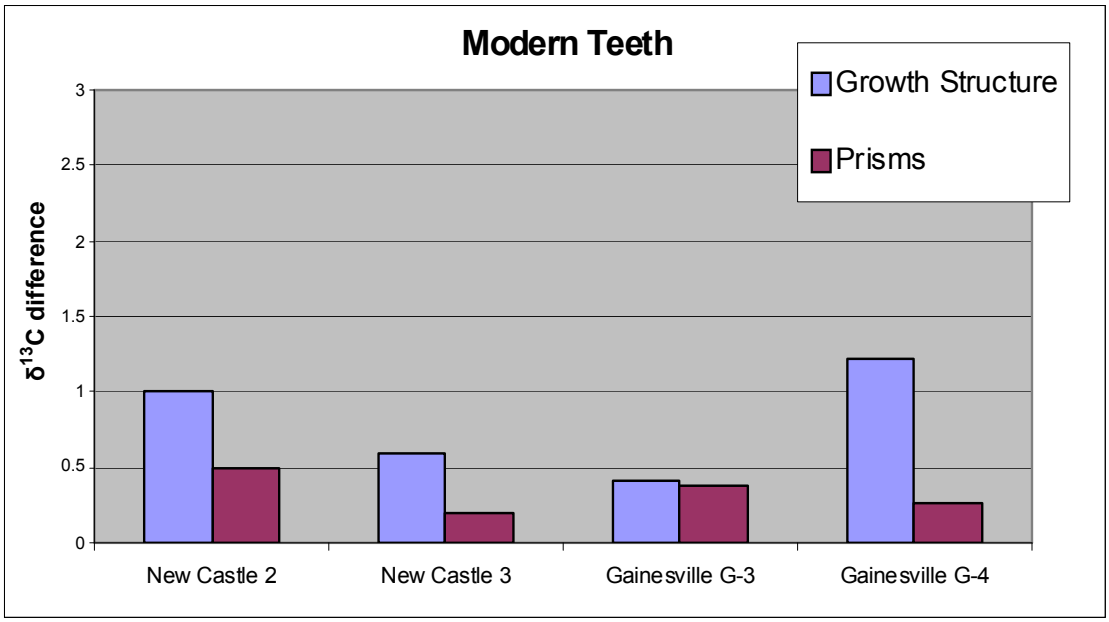


Figure 4-4. Difference in $\delta^{18}O$ ratios recovered from modern and prehistoric human molars.



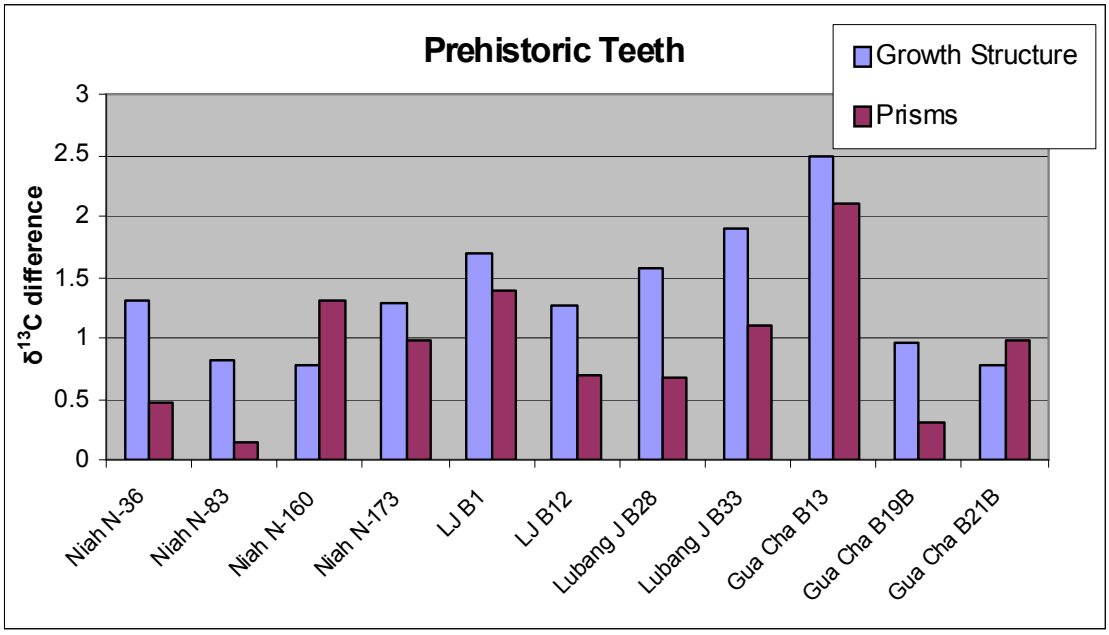


Figure 4-5. Difference in $\delta^{13}C$ ratios recovered from modern and prehistoric human molars.

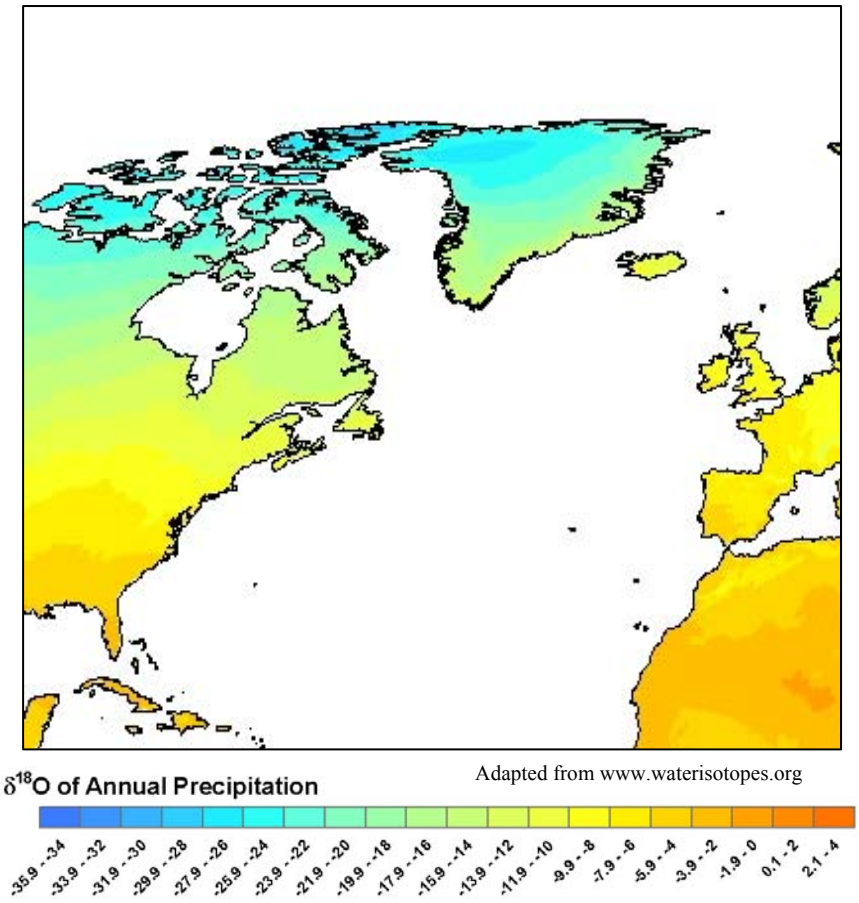


Figure 4-6. Distribution of $\delta^{18}O$ ratios for Western Europe and the Eastern US.

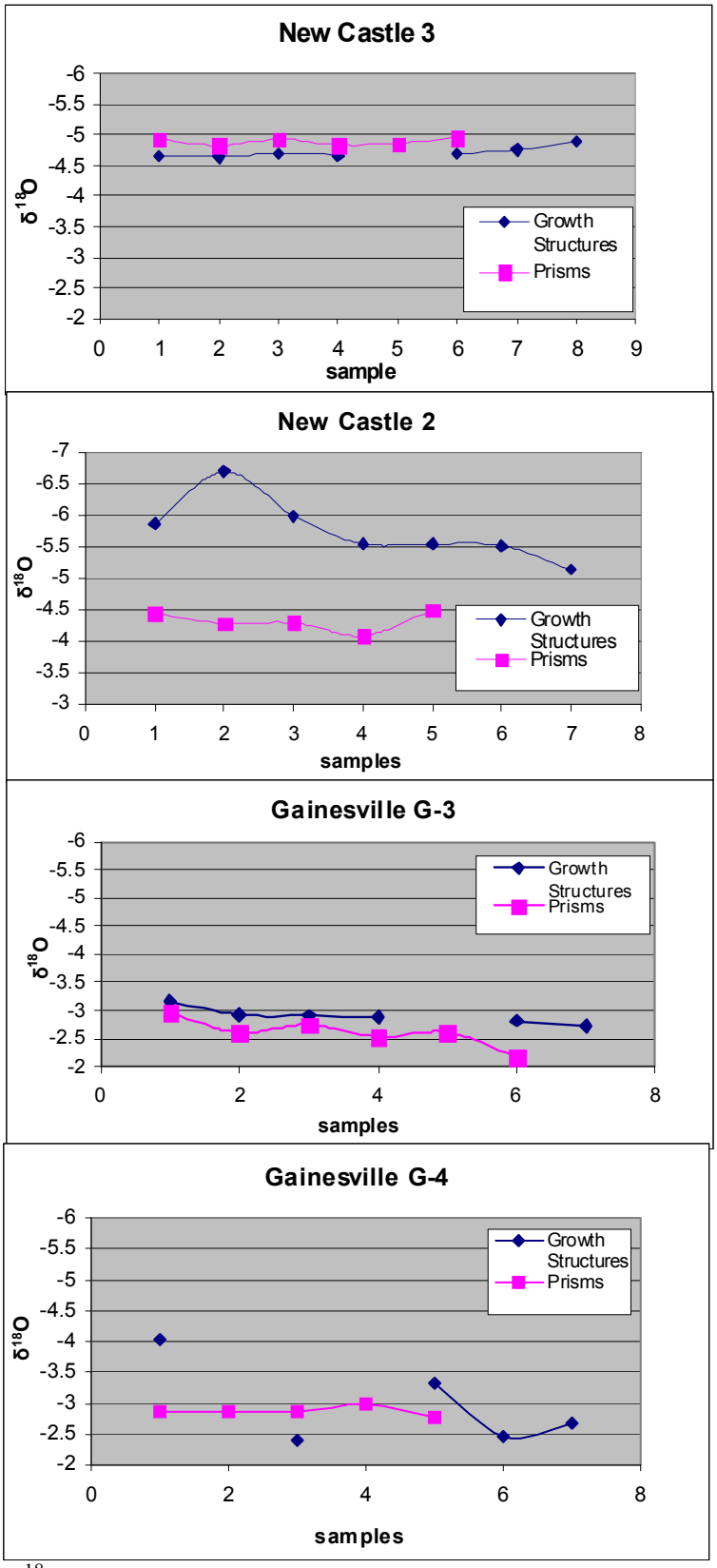


Figure 4-7. Series of $\delta^{18}O$ ratios from each sampling method for the modern teeth. Very little variability is present except for New Castle 2.

CHAPTER 5
PIERCING THE SEASONAL ROUND: USING STABLE ISOTOPES TO RECONSTRUCT HUMAN DIET BY SEASON AT WINDOVER AND HARRIS CREEK

Introduction

Mobility is a universal part of human existence that stretches back to our earliest human ancestors (Brantingham, 1998; Close, 2000). Changes in mobility are often associated with changes in food storage, trade, territoriality, social and gender inequality, sexual division of labor, subsistence and demography, as well as cultural notions of material wealth, privacy, individuality, cooperation, and competition (Kelly, 1992:44). Mobility allows hunter-gatherers to manage risk by moving away from scarce resources as part of their yearly "seasonal round" (Cashdan, 1992:237; Halstead & O'Shea, 1989; Kelly, 1983; 1992; Steward, 1938). Non-economic factors also influence mobility, the build up of trash and vermin or the depletion of local resources like firewood can necessitate movement (Smith & McNees, 1999; Wandsnider, 1992). Social factors are equally important, mobility may occur if there is a need to seek spouses, allies, shamans, or to move away from sorcery, death, or political concerns (Griffin, 1989; Vickers, 1989).

Traditionally, increasing social/political complexity is associated with the emergence of agriculture and a high degree of sedentism (Christenson, 1980:52-53; Cohen, 1977; Rindos, 1983). However, areas with bountiful food resources allow for relatively sedentary societies with large populations and complex political and social systems in the absence of agriculture. Many of these complex hunter-gatherer societies subsist on aquatic resources (Erlandson, 2001; Moseley, 1975; 1992; Rick et al., 2001; Russo, 1996). Aquatic resources can support large populations (Binford, 1968:332-333; Moseley, 1975; Sealy, 2006) and the richness and availability of aquatic resources foods may obviate many of the shortages that necessitate residential mobility (Bailey & Milner, 2002; Bailey & Parkington, 1988; Binford, 1968; Cohen,

1977). The St Johns region of Florida is a rich environment where coastal, esturine and riverine environments meet producing ecotones which support a diverse fauna rich in food resources. These environments can support a variety of societies with levels of mobility and sedentism ranging from seasonally mobile to fully sedentary settlements (Perlman, 1983:293; Widmer, 1988). Delineating the types of mobility and the relative level of sedentism practiced by groups in the St Johns region through time could allow the relationship between settlement pattern and social/political complexity to be examined.

The St Johns River basin and the Atlantic coast have been subject to archaeological study for over 100 years (Moore, 1892a; b; c; 1894; Wyman, 1868). Archaeological sites in the area suggest a continuous occupation of the region from the Paleoindian to the Mission Period. The Archaic Period in the region has received extensive study due to the presence of large man-made freshwater shell mounds along the St Johns River and coquina middens along the coast. Researchers were quick to draw a connection between the riverine and coastal sites, by the early 1900s researchers suggested people migrated between the coastal and interior sites on a seasonal basis occupying the coast in the winter and the river in the summer months. Subsequent researchers adopted these ideas, often incorporating additional justifications such as 'oysters taste better in the winter' (Bullen and Bullen 1961). This scenario of seasonal transhumance was adopted by Milanich and Fairbanks when they published *Florida Archaeology* in 1980. In their model, Archaic groups occupied base camps along the St Johns River during the warm months and dispersed to the coast and/or interior highlands during the cooler months (Figure 5-1). In the early 1990s, researchers began to test the model of seasonal transhumance with data from flora and fauna recovered from sites along the coast and river. Based on floral and faunal data, Russo et al. (1992a, 1992b) suggest that separate ethnically distinct groups occupied the coast and the

St Johns basin year-round. Though these groups may not have been fully sedentary, they maintained separate territories and remained in their respective costal or riverine zone (1992a).

Regional settlement patterns and mobility are prerequisites to the study of ethnicity, immigration, trade, social complexity or the role of monumental architecture. Unfortunately, the archaeological study of mobility is complicated by an imperfect relationship between movement and material culture (Kelly, 1992:21) and the ephemeral nature of movement that seldom leaves any material trace in the archaeological record (Close, 2000). Archaeological studies typically assess mobility through "patterns of mobility" or "mobility strategies" and evaluating group mobility based on the organization of technology or the sourcing of raw materials (Amick, 1996; Close, 2000; Simms et al., 1997). These techniques lack the analytical power to identify the movement of individuals in the archaeological record because the movement of material is independent from the movement of people. Materials may curated, cached, or traded down-the-line.

Mobility is also evaluated by the study of human remains which, unlike artifacts, cannot be decoupled from the individual. Two methods are common in biological studies of mobility; biomechanical markers in human bones and stable isotope analysis of human bones and teeth. Bone is a living tissue and reacts to stresses from repeated activities leaving evidence of the activity in its morphology. These markers can provide life history information including the degree of mobility (Carlson et al., 2007; Larsen et al., 1991; Merbs, 1983; Wanner et al., 2007). For instance, in a study of pre and post-contact Native Americans in the Georgia Bight, Larsen and Ruff (1991) interpret changes in the cross-sectional geometry of femora as evidence of reduced mobility.

Stable isotopes are a common way to assess mobility in many animals including humans (Balasse et al., 2002; Hoogewerff et al., 2001; Knudson & Price, 2007; Knudson et al., 2005; Koch et al., 1992; Koch et al., 1995; Prowse et al., 2003; Richards et al., 2008; Richards et al., 2001). Differences in light stable isotope ratios of carbon and oxygen can distinguish broadly dissimilar subsistence regimes and environments, unlike the analysis of artifacts, flora or fauna, and settlement patterns, stable isotopes provide evidence of individual mobility (e.g. Montgomery et al., 2005; Price et al., 2000; White et al., 1998). Stable isotopic studies of mobility are not subject to same problems of equifinality as are archaeological studies based on material culture or subsistence remains. Unlike artifacts, stable isotope ratios are locked in tooth enamel and may not be decoupled from the individual.

The masses of the elements assessed in stable isotopic are so small that stable isotope abundances are reported in delta (δ) notation which expresses the ratio of heavy to light isotopes in a sample compared to a standard measure in parts per thousand. The two light stable isotopes most often employed in isotopic studies of diet and environment are carbon, $\delta^{13}C$, and oxygen $\delta^{18}O$. Differences in the fractionation of carbon isotopes in terrestrial and marine ecosystems render them useful in dietary studies. The ratio of ^{13}C to ^{12}C varies in terrestrial systems due to differences in plant's photosynthetic pathways. Each type of photosynthetic pathway, C_3, C_4, and CAM (Crassulacean Acid Metabolism) produces a different range of carbon isotope values. C_3 resources include almost all flora in the southeastern US, while edible C_4 resources are limited primarily to maize and a few starchy seed plants like amaranths. Edible CAM plants in the Florida largely are limited to prickly pear cactus. Carbon stable isotope ratios also differ between terrestrial and marine systems, the carbon values of marine systems overlap those of C_4 plants and are considerably less negative than terrestrial C_3 systems.

In this study $\delta^{18}O$ ratios provide the time line against which the $\delta^{13}C$ ratios are interpreted. Stable isotope ratios of $\delta^{18}O$ from surface water are determined in large part by temperature, precipitation, and evapotransporation. The $\delta^{18}O$ of precipitation results from the interaction of the ambient temperature and the amount of precipitation. Generally, warmer weather results in enriched $\delta^{18}O$ values and cooler weather in decreased $\delta^{18}O$ values (Bryant and Froelich 1996). In temperate regions, which have relatively constant rainfall paired with varied temperatures throughout the year, $\delta^{18}O$ values are enriched during the summer months (Gonfiantini 1985). In tropical regions, which have varied rainfall and more constant annual temperatures, $\delta^{18}O$ values track the amount of rainfall (Njitchoua et al. 1999). Environmentally similar regions have similar seasonal $\delta^{18}O$ averages which fractionate in a predictable fashion according to latitude, altitude, and distance from the sea. The $\delta^{18}O$ values of precipitation are incorporated into the surface water of lakes and rivers and eventually into the biological tissues of the animals and humans (Longinelli 1984; Luz et al. 1984). Significant differences in $\delta^{18}O$ ratios between regions have been used to assess migration and immigration in archaeological contexts (Balasse et al. 2002; Bentley and Knipper 2005; Evans et al. 2006; Hoogewerff et al 2001; Prowse et al. 2003; Turner et al. 2005; White et al. 1998, 2001)**.**

This research recovers isotopic signatures from human teeth by serially sampling the dentition along growth layers. Removing multiple samples from a single tooth along an axis of growth provides a view of dietary and environmental change through time. Serial sampling studies are well established for a variety of fauna (Fricke and O'Neal 1996; Gadbury et al. 2000; MacFadden et al. 2004; Wiedemann et al. 1999) but are infrequently applied to humans. However, the few serial sampling studies of humans and human ancestors have been successful (Fuller et al., 2003; Richards et al., 2008; Sponheimer et al., 2006). With this technique each

sample represents a period of months rather than the year or more provided by traditional "bulk" techniques. This precision allows researchers to examine differences in seasonal food consumption and to address the issue of a "seasonal round" using stable isotopes.

Human molars from two well known Archaic sites in the St Johns region of Florida, Windover (8BR246) and Harris Creek (8VO24), are serially sampled to examine human diet diachronically (Figure 5-3). For the first time, stable isotopes provide human dietary data with sub-annular resolution allowing isotopic assessment of a seasonal round. These data are used to test settlement models for the region outlined above (e.g. Milanich & Fairbanks, 1980; Russo et al., 1992; Russo & Ste. Claire, 1992). If populations were moving out the river basin to exploit marine/estuarine resources on a seasonal basis, then evidence of this dietary change should be evident in stable carbon and oxygen isotopes recorded in their tooth enamel.

Background

Site Descriptions

This study is based on a sample of human dentition recovered from Windover (8BR246) and Harris Creek/Tick Island (8VO24). Both sites are considered to be good representatives of their time period and are well known in the archaeological literature of the Southeastern US and of the Archaic Period.

Windover (8BR246)

The Windover site is an Early Archaic cemetery located near Titusville, Florida (Doran 2002). The site was discovered in 1982 while a small pond was being filled in preparation for the construction of a subdivision (Doran 2002). The site was excavated by Dr. Glen Doran and colleagues over three field seasons from 1984 to 1986 (Doran 2002). The anaerobic environment afforded excellent preservation which resulted in an extensive artifact assemblage including textiles, floral remains, and tools made of bone, antler, and marine shell (Doran 2002).

At least 168 human skeletons were recovered from the shallow but persistent pond (Doran 2002). Radiocarbon dates on the human skeletal material indicate the interments occurred between 7,100 and 7,330 rcybp (Doran 2002). Burials were flexed on their side and held down with matting or fabric and wooden stakes in shallow hollows underwater (Doran 2002).

Harris Creek (8VO24)

Prior to its destruction, Harris Creek, also referred to as Tick Island, was a series of shell middens and ridges with a substantial bean-shaped platform mound constructed of freshwater shell estimated to have been 5.5 to 10.7 m above ground level (Aten 1999). The site was first investigated by Moore in 1891. Bullen conducted excavations of the northeastern slope of the mortuary mound in 1961 and recovered more than 175 burial features. Firsthand accounts from people involved in shell mining operations assert that mining activities destroyed hundreds of burials prior to Bullen's mitigation (Aten 1999). This suggests the original number of interments at the site greatly exceeded those recovered by Bullen (Aten 1999).

Jahn and Bullen (1978) reported 4 conventional radiocarbon dates from samples taken from his Harris Creek excavations, two of which bracket the mortuary layers (Table 5-1). Charcoal at the base of layer 3 produced a radiocarbon date of 5450±300 rcybp (M-1264) and charcoal from layer 8 produced a date of 5320±200 rcybp (M-1265) (Aten 1999). Recently, four new AMS dates on human bone, two from layer 3 and two from layer 4, produced older dates than those reported by Jahn and Bullen. Two individuals from layer 3 produced dates of 6125±83 rcybp (X-9110) and 6053±65 rcybp (X-9112RA). Two individuals from layer 4 date are slightly younger in age at 5904±62 rcybp (X-9109A) and 5825±62 rcybp (X-9111A).

There is considerable variation present in the origin of the individuals buried at Harris Creek/Tick Island. Recent work by Quinn et al. (2008) identified four isotopically distinct immigrants in a sub-sample of the burial population. Isotope ratios of $\delta^{13}C$ and SR^{87}/SR^{86}

indicate two immigrants were from a coastal zone. Two other immigrants were identified based on their $\delta^{18}O$ values which suggest they originated as far north as Tennessee or Virginia.

Previous Studies of Paleodiet at Windover and Harris Creek

In an unpublished study, Tucker and colleagues (2007) examined paleodiet at Windover and Harris Creek and found both populations had enriched $\delta^{13}C$ ratios which indicated the consumption of marine resources. Bone collagen $\delta^{13}C$ ratios from Windover (Tuross et al., 1994) and Harris Creek are compared to Woodland Period hunter-gatherers from the interior of Georgia (Tucker, 2007), Late Archaic inhabitants of Horrs Island, Florida (Kelly et al., 2006), and St. Johns Period remains from the nearby Ross Hammock site (Tucker et al. 2007) (Figure 5-4). The Georgia population did not have access to a significant amount of marine resources, confirmed by their average bone collagen $\delta^{13}C$ ratio of -19.5‰. Ross Hammock and Horr's Island have both been interpreted as year-round coastal occupations and their populations have $\delta^{13}C$ collagen ratios of -10.6‰ and -10.2‰, respectively. The average bone collagen $\delta^{13}C$ ratio from Windover is -15.6‰ (Tuross et al., 1994) and Harris Creek has an average value of -16.5‰. These ratios are between the interior Georgia population and the coastal populations at Ross Hammock and Horrs Island. The intermediate position of Windover and Harris Creek indicates a marine component in the diet. Other isotopic indicators including $\delta^{15}N$ ratios and collagen-to-apatite spacing support the presence of a substantial marine component.

Season of Site Occupation

Establishing the time season of occupation for riverine and coastal sites is critical to understanding Archaic settlement patterns. Archaic interior sites with seasonality data include Windover, Groves Orange Midden, and to a lesser extent Munroe Outlet Midden (Table 5-2). The Early Archaic Windover site predates Harris Creek by ca. 2000 radiocarbon years. Botanical remains including wax myrtle, cabbage palm, holly, hickory, bottle gourd, oak, black

gum, hackberry, grape, maypop, persimmon, nightshade, elderberry, and prickly pear, were recovered from Windover and indicate a summer to fall use of the mortuary site (Tuross et al. 1994). Supporting evidence comes from the stakes used to keep the bodies submerged in the lake; study of the growth rings in these stakes indicate they were cut during the late summer or fall.

Groves Orange Midden is a large freshwater Middle to Late Archaic shell midden (3100 to 5700 BP) partially submerged in Lake Monroe (Volusia County). The remains of hickory nuts, acorns, persimmons and grapes suggest occupation of the site occurred in the summer and fall (Russo et al. 1994).

Lake Monroe Outlet Midden, like Groves Orange Midden, is a Middle Archaic site partly submerged in Lake Monroe. Botanical remains recovered from the site, including blueberries, hickory nuts and acorns, indicate a late summer/fall occupation. However, Ruhl (2001) cautions that mast are often stored and that their season of ripening is not a good indicator of site occupation.

Coastal sites with seasonality data include Cotten, Tomoka Stone, Crescent Beach, Rollins, Spencers Midden, and the Guana Shell Ring. Seasonality data for Tomoka and Cotten are derived primarily from the size classes of fish and shellfish while the data from Crescent Beach, Rollins, Spencers Midden, and Guana are the result of isotopic studies and the sclerochronology of shellfish recovered from the middens at these sites.

The Cotten site is a Late Archaic coquina midden on the west bank of the Halifax River in Ormond Beach, Florida. Investigations by Hale (1984) suggest coquina was collected in the summer months, the size classes of the coquina coincided with modern collections from June.

Hale (1984) further suggests the site may be used in the winter months based on the presence of migratory birds.

Tomoka Stone is primarily a Late Archaic coquina midden located just north of the Cotten site. Excavations uncovered a substantial amount of fiber tempered pottery and several Archaic stemmed and side notched points. Russo and Ste. Claire (1992) assessed the season of capture of coquina, quahog, pinfish, and croakers. All of these, except the quahog, suggest a summer or early fall occupation. The quahogs are distributed throughout the midden in small amounts and appear to have been collected in the winter and/or spring months. The only botanical remains recovered from the site are hickory nuts, which tentatively support a summer/fall occupation.

Spencers Midden, Crescent Beach, Rollins, and Guana were surveyed by Jones et al. (2005) who used oxygen isotopes recovered from coquina to estimate paleotemperature and the season of collection. Of these site Spencer's Midden is the oldest, ca. 5570±80 rcybp, and is likely contemporaneous with Harris Creek. Crescent Beach is a late Middle Archaic site which dates to around 4240±80 rcybp. Rollins and Guana Shell Ring are both Late Archaic sites and date to 3760±60 and 3600 ±50 rcybp respectively. Though Jones et al. (2005) only evaluated a single shell from each of the four archaeological sites, all the results suggest the coquina were collected during the fall.

With the exception of a few quahog from Tomoka Stone and the scattered remains of migratory birds, the floral and faunal remains from coastal and riverine sites in the region suggest occupation in the summer and fall; a pattern which holds from the Early to Late Archaic. Data suggest both the coast and river were occupied during the summer and fall. The floral and faunal data do not indicate where the Archaic groups spent the winter and spring. However, this may be due to inherent difficulties involved in floral and faunal assessments of seasonality rather

than suggesting the Archaic inhabitants wintered elsewhere. Most floral resources ripen during the warm months but many, like mast, might be stored and consumed during the winter and spring limiting their usefulness as markers of seasonality. Many of the estimates for coastal sites rely on isotopic studies of coquina, however, coquina have a growth season limited to the warm months making the winter months isotopically invisible. These limitations make flora and fauna ill-suited to identify winter occupations.

Serial Sampling

A study of human diet by season can detect the consumption of marine vs. non-marine foods throughout the year, including the winter months, possibly indicating the season of occupation. Unlike coquina, tooth enamel continuously records the isotopes ratios of food and water consumed during enamel formation. Temperature and rainfall vary in a predictable pattern with the season, allowing $\delta^{18}O$ variation recorded in tooth enamel to indicate the season that unit of enamel was deposited. Ratios are also recorded in enamel and are recovered from the same samples as the $\delta^{18}O$ ratios. The $\delta^{18}O$ ratios can provide a seasonal time scale against which the $\delta^{13}C$ can be evaluated. If significant amount of marine foods are consumed during a portion of the year, then this difference should be visible in the isotopic ratios recorded in the tooth enamel.

This research employs a serial sampling methodology to recover variation in $\delta^{13}C$ and $\delta^{18}O$ ratios recorded in human tooth enamel. In serial sampling or isotopic "zoning" studies (Kohn & Cerling, 2002) small units of enamel are removed from a tooth along the axis of growth. Fauna are frequently sampled using this method (Fricke & O'Neil, 1996 ; Gadbury et al., 2000; MacFadden et al., 2004; Wiedemann et al., 1999), and these studies range from identifying seasonal seaweed consumption by sheep (Balasse et al., 2006; Balasse et al., 2005) to paleoclimatic reconstructions based on tyrannosaurid teeth (Straight et al., 2004).

Many factors complicate serial sampling human teeth including their relatively small size and concerns over isotopic buffering common to all serial sampling studies of tooth enamel. Isotopic signals can be attenuated due to many factors before and after ingestion by an organism. These factors include a reservoir effect as precipitation is collected, mixed, and 'stored' in lakes and rivers (Balasse, 2003; Kohn & Cerling, 2002). A similar effect occurs once water is consumed by an organism when oxygen isotopes are stored and mixed in body water before they are locked into tooth enamel (Balasse 2003; Kohn and Cerling 2002).

The primary concern in serial sampling human and faunal teeth is isotopic attenuation caused by secondary mineralization, a process by which the mineral content of enamel slowly increases after initial deposition prolonging the period of enamel formation and divorcing the isotopic signal for a given unit of enamel from the time period of its formation (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005). However, a recent study of mammalian enamel demonstrates that isotopic sampling of growth layers between the inner and outter enamel recovers isotopic variation which remained intact after the maturation phase (Humphrey et al., 2007). Humphrey et al. (2007) identified changes in strontium/calcium ratios in the human infant enamel before and after birth and these changes were retained after mineralization was complete. Additionally, dental studies indicate the majority of the carbonate in mature enamel is present during deposition, therefore, secondary mineralization is not likely to complicate isotopic assessments of carbonate (Aoba & Moreno, 1990; Elliott et al., 1985).

The incremental nature of human tooth growth allows sampling of enamel which encapsulates isotopic ratios representing discrete units of time. Human teeth begin to form as enamel is deposited on a few millimeters of dentin at the tip of the cusp. (Avery 2000). Additional layers of dentin and enamel are laid down as the tooth grows from the cusp

downward until the apex of the root is complete (Dean 1989). Sequential layers of enamel appear as stacked cones on the surface of the tooth after formation is complete (Figure 5-5). The edges of these layers form a system of ridges and furrows on the tooth surface called perikymata which are the surface manifestation of brown striae of Retzius; each perikymata takes ca. 9 days to form (Dean et al. 2001; FitzGerald 1998).

Methods

A series of six to eight enamel samples, between .25 and .5mg were removed from each tooth under magnification with a low speed dental drill parallel to the perikymata (Figure 5-7). Samples were not chemically pretreated and were placed directly into pre-weighed stainless steel capsules and loaded into a multiprep inlet system attached to a VG PRISM II mass spectrometer.

Results

A total of 60 samples were obtained from 10 individuals from Windover and the fifteen individuals sampled from Harris Creek produced a total of 103 samples. The average number of samples per individual from Windover was 6.0 and 6.4 from Harris Creek. Summary statistics for the samples are included in Table 5-3.

The amount of buffering in the samples was greater than expected. The average difference between the minimum and maximum $\delta^{18}O$ values for Windover was 1.0 and the average difference in minimum and maximum $\delta^{13}C$ ratios was only 1.7‰. Similarly, the average difference between minimum and maximum scores from Harris Creek was 1.1‰ for $\delta^{18}O$ and 1.5% for $\delta^{13}C$. These values suggest a large amount of time averaging is occurring in these samples.

This averaging may be due to the amount of time represented by each sample. Perikymata counts were obtained for a subset of the dentition (Table 5-4). In some cases the perikymata were visible on the tooth surface under magnification. When possible, the number of

perikymata per sample were noted. These counts were performed under magnification, but are considered estimates of the actual number of perikymata.

Enamel deposition does not occur at a constant rate and as a result perikymata are not spaced evenly across the surface of the tooth. The perikymata are packed more tightly near the cervical region of each tooth and grow wider near the crown. Therefore, the first few samples in each series span a greater number of days than the last few samples in the series. In many cases the first sample in a series spans an estimated duration of ca. four months while the last sample may only encompass a month. The large amount of time incorporated by the first half of each series results in the greater amount of time averaging and isotopic buffering. The unequal distribution of time distribute across the tooth also complicates the interpretation of the $\delta^{18}O$ ratios as a reflection of seasonality. Though sinusoidal patterns result from the sampling of these teeth, the structure of these signals cannot be interpreted directly as a seasonal pattern.

Discussion

To overcome the difficulties imposed by the unequal amount of time encompassed by each sample, correlation coefficients were calculated for each data series. If the diets of these individuals varied in a predictable fashion by season, then the $\delta^{18}O$ and $\delta^{13}C$ values should be related in a positive or negative correlation regardless of the time encompassed by each sample.

Pearson Product Moment Correlation Coefficients were calculated for each data series in SAS Enterprises' JMP 7.0.1 and the results and associated p-value are shown in Table 5-3. The $\delta^{13}C$ and $\delta^{18}O$ ratios are positively correlated at the 0.10 level in two individuals (92.76 and 99.5) from Windover. The $\delta^{13}C$ and $\delta^{18}O$ ratios from Harris Creek were also correlated by the correlation showed more variation. Of seven significant correlations ($p>.10$), three were significantly negatively correlated (8, 100/101, 128) and four (108, 132, 141, 147/148) were significantly positively correlated. These correlations indicate there is a relationship between

diet and season. A positive correlation indicates the $\delta^{13}C$ values are enriched in tandem with the $\delta^{18}O$ values, which suggest increased marine food intake during the summer months. The negative correlation found at Harris Creek indicates just the opposite, that more marine food was consumed in the colder months. However, closer inspection of the negatively correlated signals from Harris Creek reveals that they appear to be positively correlated over much of the sequence, suggesting the correlation could be an artifact of sampling or an atypical event recorded in the tooth enamel. These discrepancies might also result from the correlation methodology itself. Correlation, like regression, quantifies the linear relationship between two variables (Bewick et al., 2003). If a relationship is non-linear, as these sinusoidal signals suggest, then correlation might not detect or adequately describe all relationships (Bewick et al., 2003). Consequently, more qualitative visual inspection of the structure of the isotopic series may be better suited to these data.

When inspected visually, it is apparent the $\delta^{13}C$ and $\delta^{18}O$ ratios from Windover also vary in concert with one another; this relationship is especially apparent in individuals 99.5 and 69.1 (Figure 5-7). Additionally, if the first two to three data points are excluded from each sequence (on average these points span much more time then the latter parts of the series) then 81.11 also appears highly correlated.

Visual inspection also suggests the sequences from Harris Creek are positively correlated (Figures 5-8 and 5-9). In most cases the shape of each line mirrors the other to a greater or lesser degree. This trend is especially apparent in individuals B108, B132, B141, and B170. Like the Windover sequences, if the first few data points are dropped, other sequences become similar as well, e.g. B128, B91, and B36.

The visual inspection of the data reinforces the positive correlation suggested by the Pearson Product Moment Correlation Coefficients. In terms of diet, these results indicate the populations interred at both sites consumed foods more enriched in $\delta^{13}C$ during the warmer months when surface waters were more enriched in $\delta^{18}O$: they ate more marine foods in the summer. Though previous work has suggested the presence of local and non-local individuals at Harris Creek, there is no clear difference between the signals of these individuals.

The results of this study, like those of previous more traditional isotopic studies of paleodiet, do not support the presence of separate ethnically distinct groups occupying the river drainage and the coast (Russo et al., 1992; Russo & Ste. Claire, 1992). Neither Windover or Harris Creek is found on the coast, yet individuals at both sites included a significant portion of marine/estuarine foods in their diet suggesting they had direct interaction with the coast. This interaction is also supported by the presence of marine artifacts at Windover and Harris Creek. Marine shells (*Busycon carica, Busycon contrarium, Strombus gigas*) and shark's teeth have been recovered from most, if not all, Mt. Taylor sites, including Windover and Harris Creek (Aten, 1999; Doran, 2002; Wheeler et al., 2000). The presence of marine resources at interior riverine sites suggests Mt. Taylor people had access, at least indirectly, to coastal resources. The results of this study, both in terms of quantitative correlations and qualitative visual observations, indicate the marine portion of their diet was consumed during the warm portion of the year. Interestingly these results are opposite to the Milanich and Fairbanks (1980) model which suggested a winter occupation of the coast.

In terms of the overall pattern and in specific isotopic values, Windover and Harris Creek are virtually indistinguishable. This suggests that the pattern of transhumance and seasonal resource use exhibited by the population at Harris Creek was in place more than 2000 years

earlier at Windover. The continuity in resource scheduling supports the previous study of paleodiet based on bone isotopes, which suggested there was little to no dietary difference between the population at Windover and the population at Harris Creek.

Conclusion

For the first time isotopic data with sub-annual resolution was extracted from human teeth. These new data, though attenuated, provide an alternative means of evaluating Archaic settlement models for the St Johns region. These data are interpreted to suggest the populations interred at Windover and Harris Creek consumed more marine food during warm months than during the cold months. These new data support previous studies which indicated a significant marine component in the diet of people from Windover and Harris Creek. Based on these results and the distance of these sites from the sea, it is likely these hunter-gatherer groups were residentially mobility and occupied the coast or an estuarine environment for a least a portion of each summer.

Interestingly, the results from the population from Windover and the population from Harris Creek who lived over 2000 years later are almost identical. These results suggest that contrary to conventional wisdom, significant changes in subsistence and resource scheduling did not occur between the Early and Middle Archaic despite the rise of new innovations, like freshwater shell mounds and long distance trade (Wheeler et al., 2000). These results provide another source of evidence suggesting innovations like mound construction and establishing long distance trade networks could occur in mobile groups. Though suggestive, these data must be viewed as preliminary, until more populations from the region are sampled and better control of the amount of time in each sample is achieved.

Table 5-1. Conventional and AMS radiocarbon dates from Harris Creek. The new AMS dates are calibrated with CALIB 5.0.1 (Stuiver & Reimer, 1993).

Lab No.	Layer	Sample	Uncorrected ^{14}C years B.P.	Calibrated Dates, 2 sigma BP	Reference
M1264	3	charcoal	5450±300	[5590 BP:6912 BP] 0.999 [6921 BP:6929 BP] 0.001	Aten 1999
M1265	8	charcoal	5320±200	[5645 BP:6494 BP] 1.00	Aten 1999
X9110	3	human bone (Burial 7)	6125±83	[6793 BP:7179 BP] 0.96 [7195 BP:7244 BP] 0.04	New date, this paper
X9112RA	3	human bone (Burial 31)	6053±65	[6742 BP:7030 BP] 0.90 [7043 BP:7069 BP] 0.02 [7077 BP:7086 BP] 0.01 [7096 BP:7156 BP] 0.07	New date, this paper
X9109A	4	human bone (Burial 3)	5904±62	[6563 BP:6592 BP] 0.03 [6598 BP:6891 BP] 0.97	New date, this paper
X9111A	4	human bone (Burial 9)	5825±62	[6482 BP:6758 BP] 0.98 [6761 BP:6782 BP] 0.02	New date, this paper

Table 5-2. Season of site occupation of Archaic sites in the St. Johns Region.

Site	Interior or Coastal	Period	Season of Occupation	Reference
Windover	Interior	Early Archaic	Summer/Fall	Tuross et al. 1994
Groves Orange Midden	Interior	Middle to Late Archaic	Summer/Fall	Russo et al. 1994
Monroe Outlet Midden	Interior	Middle Archaic	Summer/Fall	ACI and JANUS 2001
Cotten	Coastal	Late Archaic	Summer, possible Winter	Hale 1984
Tomoka Stone	Coastal	Late Archaic	Summer/early Fall	Russo and Ste. Claire 1992
Crescent Beach	Coastal	Middle Archaic	Fall	Jones et al. 2005
Rollins	Coastal	Late Archaic	Fall	Jones et al. 2005
Spencers Midden	Coastal	Middle Archaic	Fall	Jones et al. 2005
Guana Shell Ring	Coastal	Late Archaic	Fall	Jones et al. 2005

Table 5-3. Summary statistics from Windover (8BR246) and Harris Creek (8VO24).

Site	Individual	Correlation	# of samples	Significance	mean $\delta^{18}O$	Minimum	Maximum	Difference	mean $\delta^{13}C$	Minimum	Maximum	Difference
8BR246	52.12.10.3	0.41	7	0.36	-0.7	-1.1	-0.3	-0.8	-9.7	-10.3	-9.0	-1.3
8BR246	57.3	0.22	5	0.72	-1.6	-2.5	-1.1	-1.4	-11.6	-12.0	-11.3	-0.7
8BR246	69.1	0.4	7	0.38	-1.2	-1.8	-0.7	-1.1	-11.2	-12.0	-10.0	-2.0
8BR246	81.11	0.34	6	0.50	-1.0	-1.4	-0.6	-0.8	-10.9	-11.9	-9.6	-2.3
8BR246	83.26	0.55	5	0.33	-1.0	-1.3	-0.8	-0.5	-9.3	-9.9	-8.8	-1.1
8BR246	92.76	0.97	6	*0.00*	-1.1	-1.5	-0.6	-0.9	-10.5	-11.6	-8.8	-2.8
8BR246	95.1	0.46	8	0.25	-0.6	-1.0	-0.3	-0.7	-9.5	-10.7	-8.3	-2.4
8BR246	99.5	0.98	4	*0.02*	-1.0	-1.5	-0.2	-1.2	-11.0	-11.6	-10.1	-1.5
8BR246	130.28	0.56	7	0.19	-1.0	-1.4	0.6	-2.0	-10.6	-11.3	-10.0	-1.3
8BR246	143.40	0.76	5	0.14	-1.1	-1.5	-0.4	-1.1	-11.0	-11.7	-10.4	-1.2
Mean		0.57	6.00	0.29	-1.0	-1.5	-0.4	-1.0	-10.5	-11.3	-9.6	-1.7
8VO24	4	-0.0001	7	1.00	-0.5	-1.1	-0.1	-1.0	-10.3	-11.2	-9.0	-2.2
8VO24	8	-0.7	7	*0.08*	-1.4	-1.8	-0.9	-0.9	-11.2	-11.5	-10.8	-0.6
8VO24	35	0.6	6	0.22	-2.2	-2.6	-1.4	-1.1	-10.2	-10.9	-9.7	-1.2
8VO24	35	-0.4	6	0.43	-2.7	-3.2	-2.4	-0.8	-11.0	-11.4	-10.6	-0.8
8VO24	36	0.12	6	0.82	-0.8	-1.1	-0.4	-0.7	-10.7	-11.1	-10.1	-1.0
8VO24	38	0.49	7	0.26	-1.2	-1.8	-0.7	-1.1	-9.2	-10.5	-8.6	-2.0
8VO24	46	-0.07	7	0.88	-1.1	-1.4	-0.8	-0.6	-11.0	-11.6	-10.5	-1.1
8VO24	91	0.29	6	0.58	-1.1	-1.6	-0.6	-1.0	-9.3	-10.5	-8.2	-2.3
8VO24	100/101	-0.73	7	*0.06*	-1.6	-2.3	-1.2	-1.1	-11.6	-12.4	-10.5	-1.9
8VO24	108	0.96	5	*0.01*	-1.7	-2.8	-0.7	-2.2	-11.3	-12.3	-10.4	-1.9
8VO24	128	-0.88	6	*0.02*	-1.4	-2.7	-0.7	-2.0	-11.1	-11.6	-10.3	-1.3
8VO24	132	0.92	6	*0.01*	-1.3	-2.0	-0.4	-1.6	-10.4	-11.8	-9.3	-2.6
8VO24	135	0.45	6	0.37	-1.3	-1.6	-1.0	-0.6	-11.3	-11.7	-10.9	-0.8
8VO24	141	0.8	10	*0.01*	-1.0	-1.7	-0.4	-1.3	-11.4	-12.8	-10.9	-1.9
8VO24	147/148	0.87	5	*0.05*	-1.2	-2.2	-0.6	-1.7	-9.4	-10.0	-9.0	-1.0
8VO24	170	0.2	6	0.70	-0.5	-0.7	-0.2	-0.4	-10.1	-10.6	-9.6	-1.0
Mean		0.18	6.44	0.34	-1.3	-1.9	-0.8	-1.1	-10.6	-11.4	-9.9	-1.5

Table 5-4. Perikymata counts for selected human molars from Harris Creek.

Individual	Sample #	# of perikymata	Avg # of days	Individual	Sample #	# of perikymata	Avg # of days
8VO24-4	1	10	90	8VO24-128	1	14	126
8VO24-4	2		0	8VO24-128	2	9	81
8VO24-4	3		0	8VO24-128	3	5	45
8VO24-4	4		0	8VO24-128	4	4	36
8VO24-4	5		0	8VO24-128	5	4	36
8VO24-4	6	7	63	8VO24-128	6		0
8VO24-4	7		0	8VO24-132	1	15	135
8VO24-8	1	6	54	8VO24-132	2	15	135
8VO24-8	2	7	63	8VO24-132	3	10	90
8VO24-8	3	5	45	8VO24-132	4	8	72
8VO24-8	4	5	45	8VO24-132	5		0
8VO24-8	5	3	27	8VO24-132	6		0
8VO24-8	6	4	36	8VO24-135	1	11	99
8VO24-8	7		0	8VO24-135	2	7	63
8VO24-35	1	9	81	8VO24-135	3	6	54
8VO24-35	2		0	8VO24-135	4	5	45
8VO24-35	3	6	54	8VO24-135	5	4	36
8VO24-35	4	4	36	8VO24-135	6		0
8VO24-35	5	5	45	8VO24-141	1	13	117
8VO24-35	6		0	8VO24-141	2	11	99
8VO24-36	1	12	108	8VO24-141	3	10	90
8VO24-36	2	6	54	8VO24-141	4	8	72
8VO24-36	3	4	36	8VO24-141	5	5	45
8VO24-36	4	3	27	8VO24-141	6	6	54
8VO24-36	5		0	8VO24-141	7	4	36
8VO24-36	6		0	8VO24-141	8	3	27
8VO24-38	1	11	99	8VO24-141	9		0
8VO24-38	2	8	72	8VO24-141	10		0
8VO24-38	3	7	63	8VO24-147.148	1	8	72
8VO24-38	4	4	36	8VO24-147.148	2	6	54
8VO24-38	5	3	27	8VO24-147.148	3	5	45
8VO24-38	6	3	27	8VO24-147.148	4		0
8VO24-38	7		0	8VO24-147.148	5		0
8VO24-46	1	10	90	8VO24-170	1		0
8VO24-46	2	8	72	8VO24-170	2	6	54
8VO24-46	3	5	45	8VO24-170	3	7	63
8VO24-46	4	4	36	8VO24-170	4		0
8VO24-46	5	4	36	8VO24-170	5		0
8VO24-46	6	4	36	8VO24-170	6		0
8VO24-46	7		0				
8VO24-100.101	1	20	180				
8VO24-100.101	2	16	144				
8VO24-100.101	3	11	99				
8VO24-100.101	4	10	90				
8VO24-100.101	5	6	54				
8VO24-100.101	6		0				
8VO24-100.101	7		0				

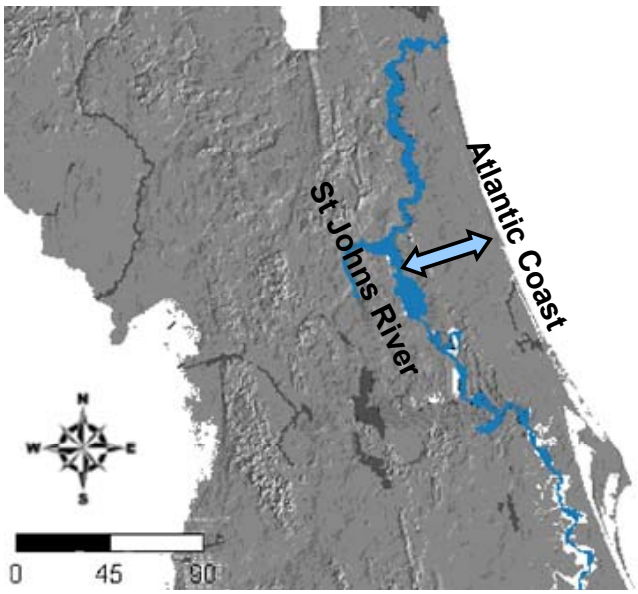


Figure 5-1. Milanich and Fairbank's (1980) model of movement between the river and coast.

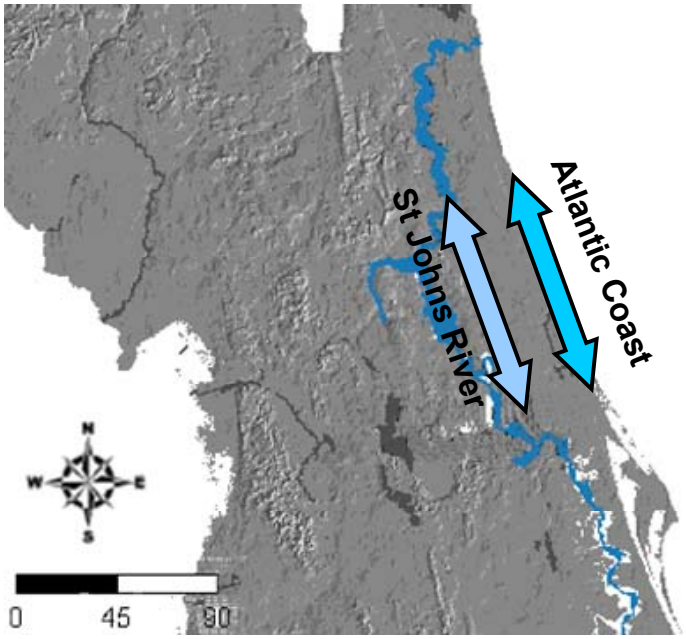


Figure 5-2. Russo and Ste. Claire's (1992) model of movement up and down the river and coast by separate ethnic groups.

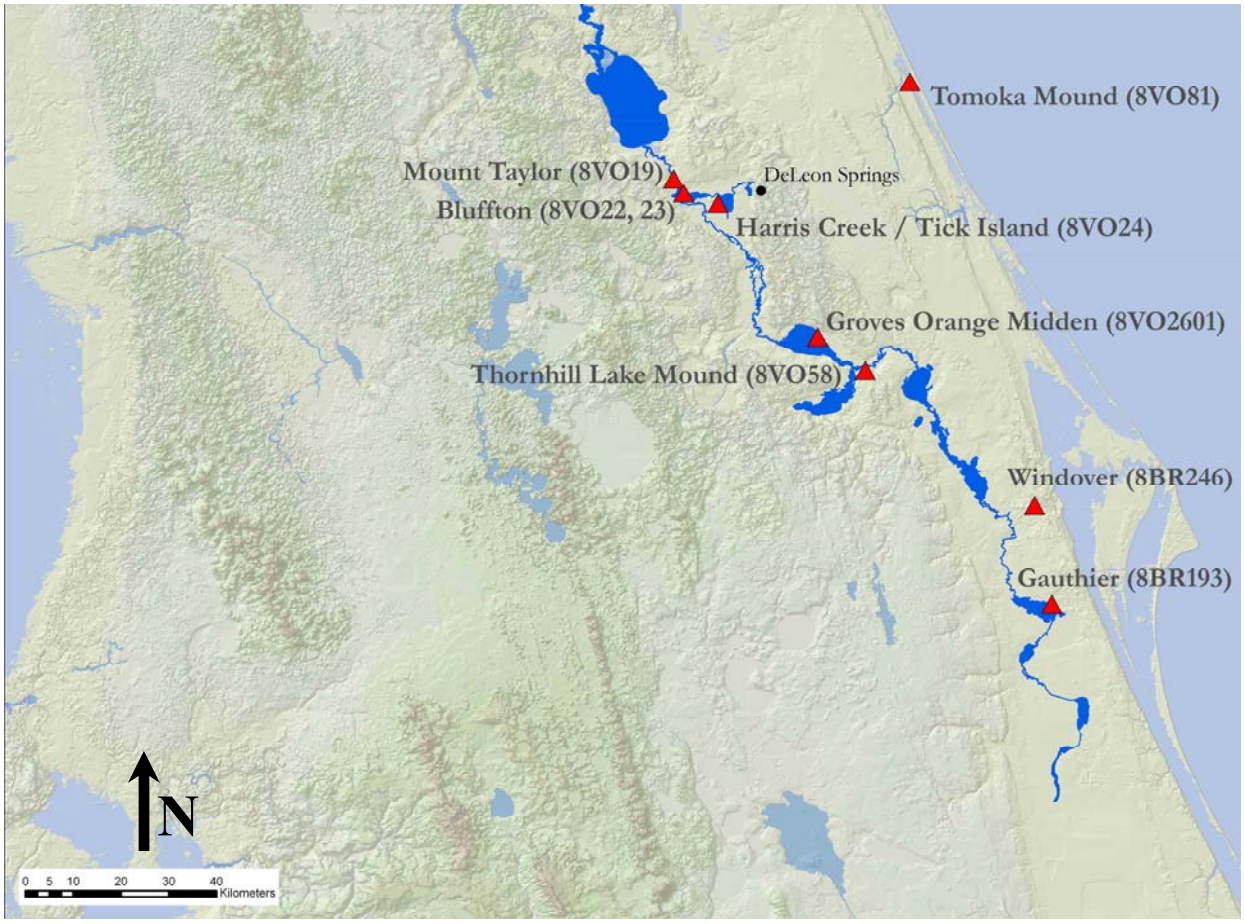


Figure 5-3. The location of Windover (8BR246), Harris Creek (8VO24) and other Archaic Period sites in the region.

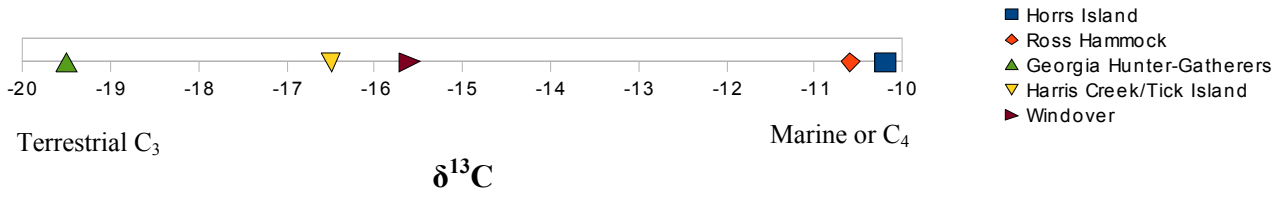


Figure 5-4. The $\delta^{13}C$ ratios of bone collagen from selected prehistoric sites. Note the intermediate position of Windover and Harris Creek.

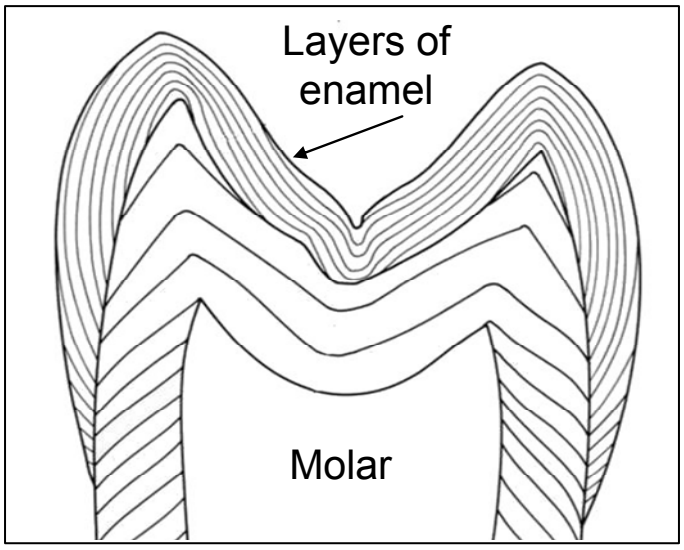


Figure 5-5. Appositional nature of enamel formation. Adapted from Hilson S. 1996. Dental Anthropology. Cambridge, Cambridge University Press.

.

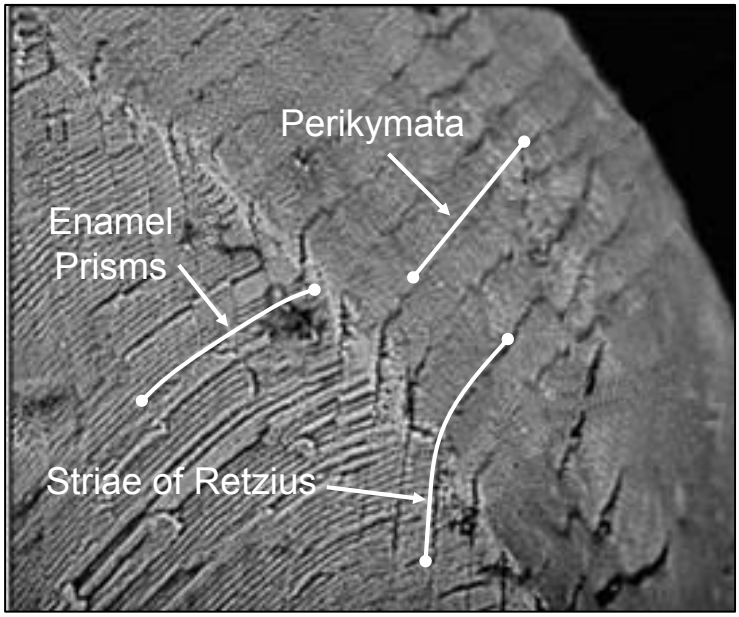


Figure 5-6. Picture of tooth microstructure showing perikymata, enamel prisms and Striae of Retzius. Adapted from Guatelli-Steinberg D., Reid D. J., Bishop T. A. & Larsen C. S. 2005. Anterior tooth growth periods in Neandertals were comparable to those of modern humans. Proceedings of the National Academy of Sciences 102:14197-14202.

Figure 5-7. Sampling tracks on a human molar.

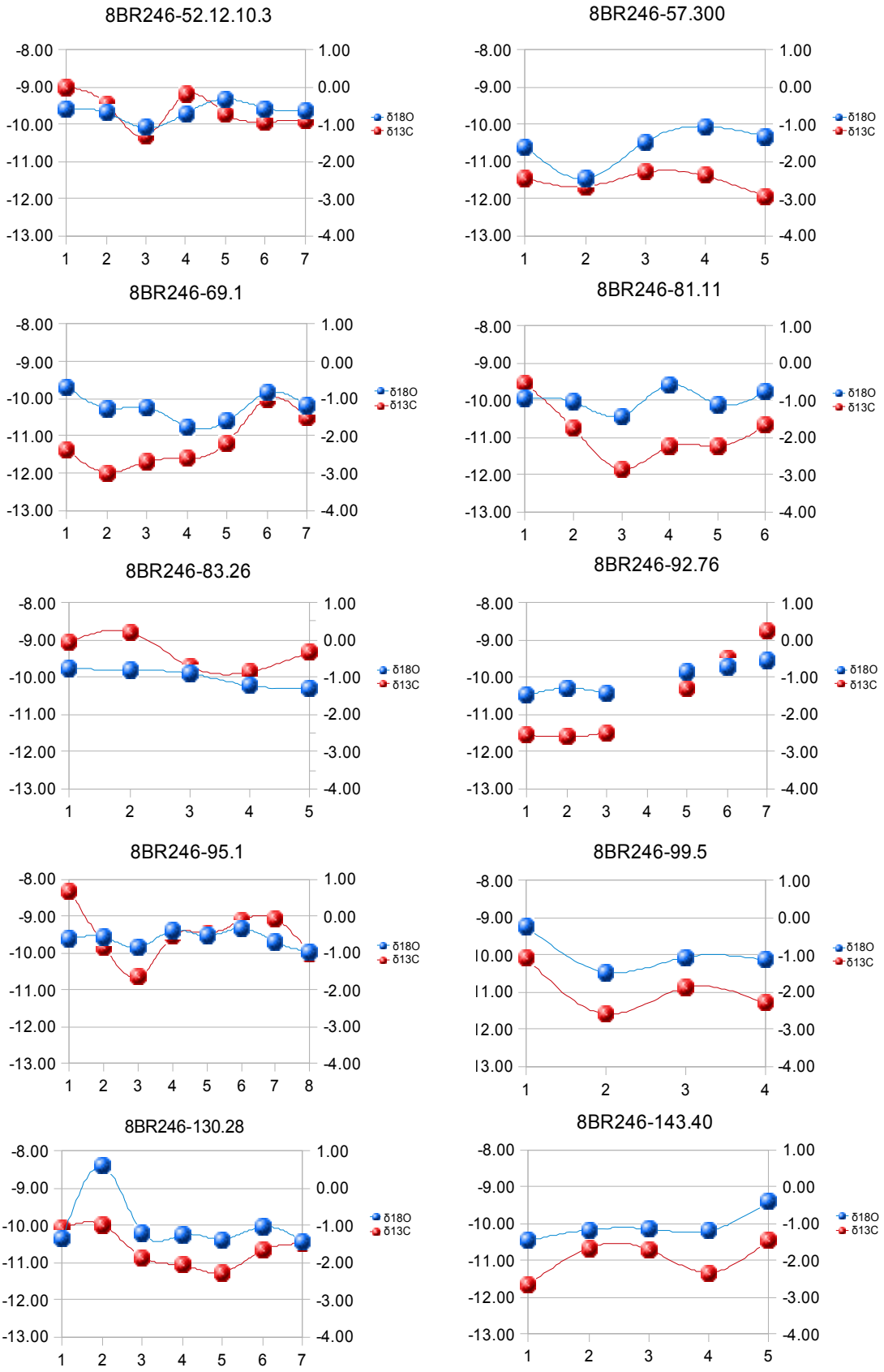


Figure 5-7. Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Windover.

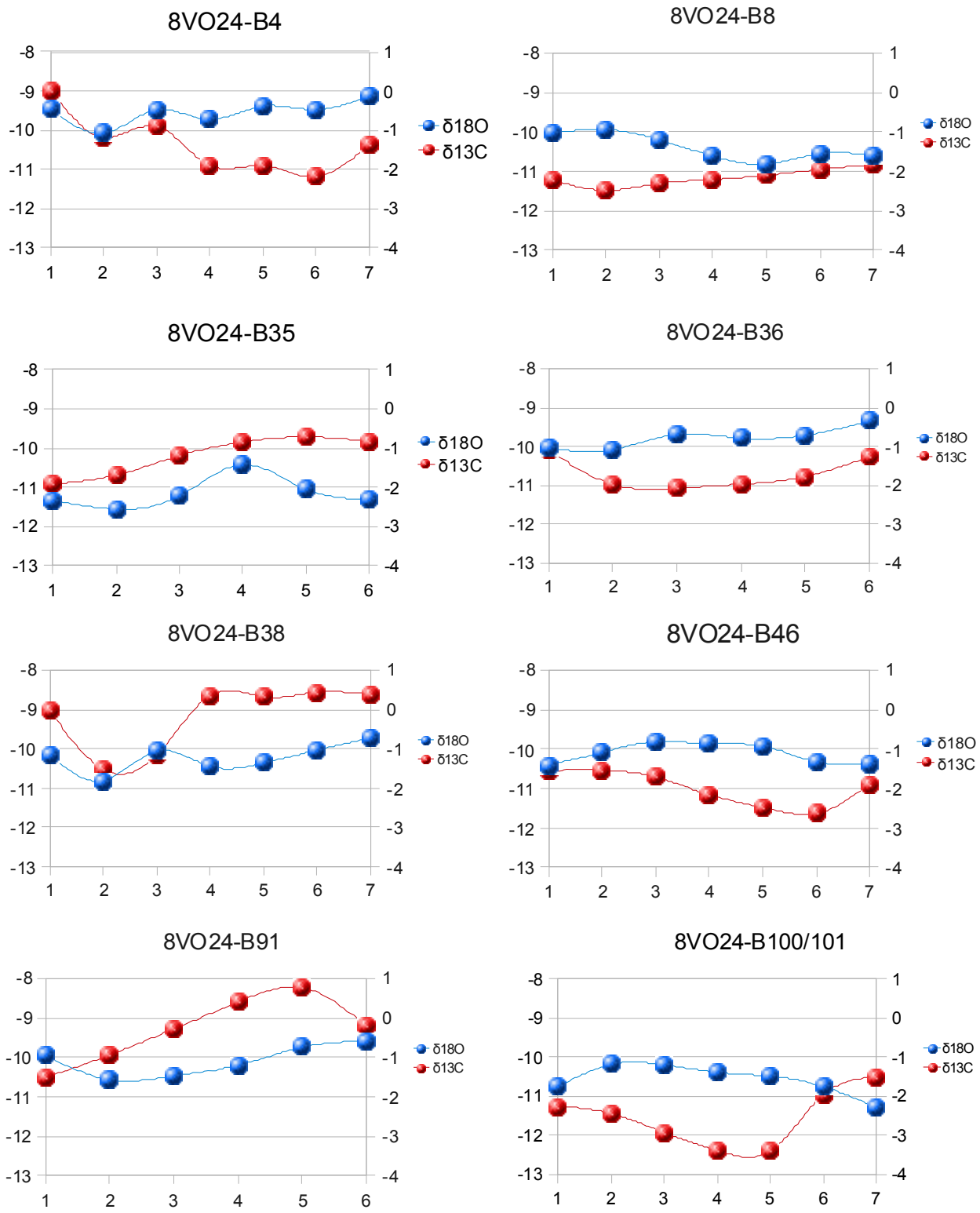


Figure 5-8. Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Harris Creek—individuals 4, 8, 35, 36, 38, 46, 91, 100/101.

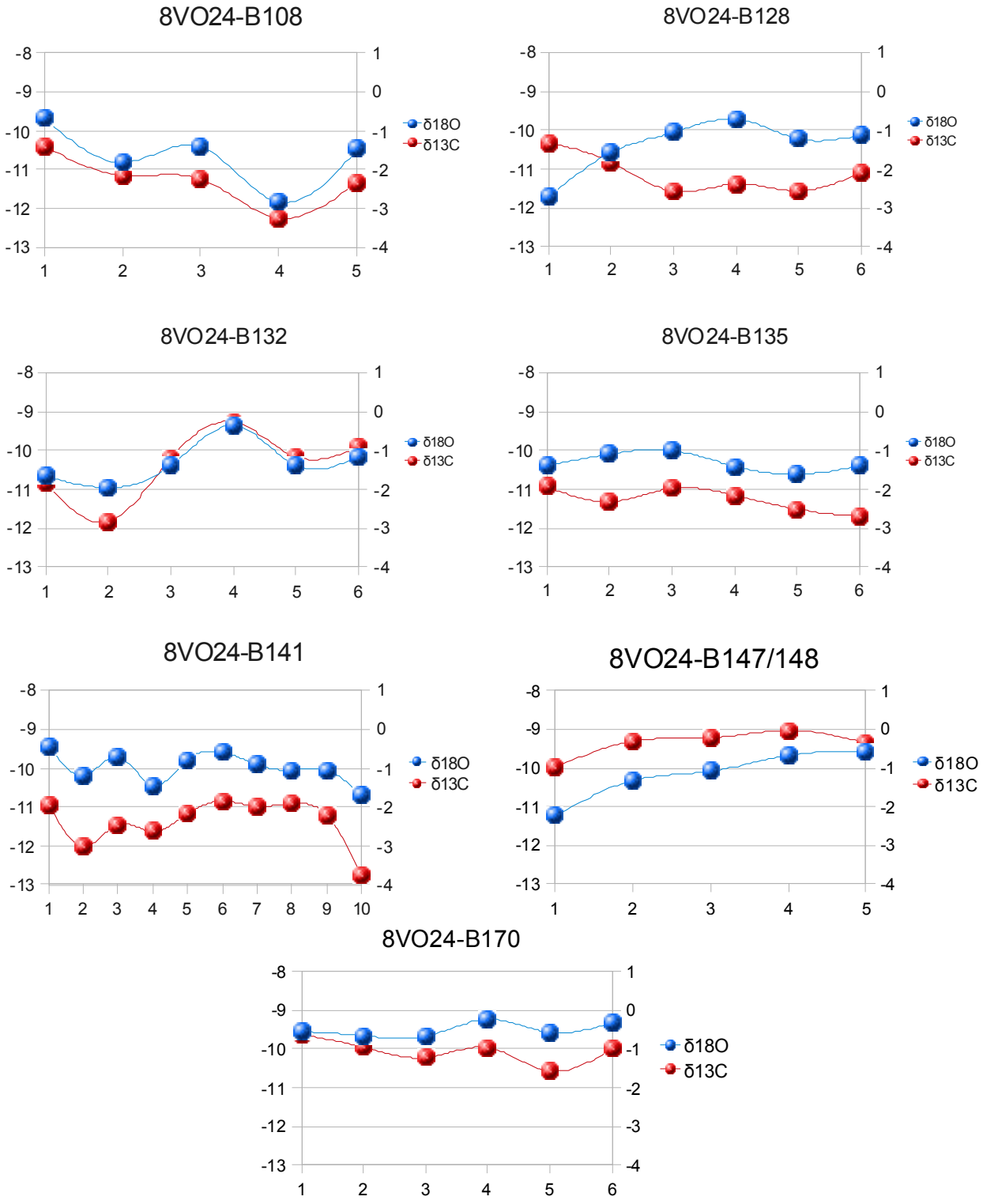


Figure 5-9. Series of $\delta^{18}O$ and $\delta^{13}C$ ratios from Harris Creek—individuals 108, 128, 132, 153, 141, 147/148, 170.

CHAPTER 6
CONCLUSION

This research uses stable isotope analysis and models of human mobility to investigate three common themes in the study of prehistoric hunter-gatherers: egalitarianism, subsistence, and settlement. The revisionist critique of hunter-gatherer studies dismissed simple causal relationships between mobility, social ranking, food production, and land use. However, many aspects of cultural historical models constructed prior to this critique have not been reexamined. Before new models of ethnicity, immigration or landscape archaeology can be applied to the St Johns region of Florida, many assumptions based on dated culture histories need to be assessed. This research examines various aspects the cultural history of the region with data unavailable to archaeologists. Stable isotopes are robust proxies for diet and environment that provide independent data which can help to avoid much of the equafinality found in archaeological studies. Stable isotopes can directly assess mobility and diet at the individual level. Though mobility, social complexity and food production are no longer linked in cultural evolutionary models, the study of the different ways in which these variables interact can enhance our understanding of the diversity of hunter-gatherer social organizations that existed in the past.

In Chapter 2 Isotopic Investigations of Middle Archaic Mortuary Practices at the Harris Creek Site, Tick Island, Florida explanations for the presence of primary and secondary burials at Harris Creek are tested with stable isotopes. Two models common in mortuary archaeology could explain the different types of burials found at the site. The first model explains the differences in burial type as reflecting status distinctions of the individuals in life. According to Tainter (1975) the complexity of body treatment and the duration of mortuary ritual is associated with social rank (Tainter 1975). If this interpretation holds true, then these burials would represent the earliest example of social ranking in North America (Aten, 1999). Alternatively,

the differences in burial treatment could be a result of temporal/geo-spatial considerations of corpse disposal. For seasonally mobile groups of hunter-gatherers death of a member might occur a considerable distance from the desired sire of interment. In such cases, the deceased must be processed and stored until the group arrived at the appropriate place and time for burial (Buikstra & Charles, 1999; Hofman, 1985).

To test these models, $\delta^{13}C$ and $\delta^{18}O$ ratios were sampled from the tooth enamel of the burials. Analysis of the $\delta^{13}C$ and $\delta^{18}O$ ratios revealed two groups were present at the site, one with local $\delta^{18}O$ values and one with enriched $\delta^{18}O$ values indicating a non-local southern origin. All of the local burials were subjected to post-mortem processing as indicated by their secondary (tightly flexed) burial but only a portion of the non-local 'southern' group received similar secondary treatment. The differences in burial treatment among the non-local 'southern' group may be evidence of rank or status among the burials, but this is not supported by isotopic differences in diet or by the inclusion of grave goods with these burials. The presence of primary and secondary burials at Harris Creek does not appear to be related to curation or transportation of the dead. Instead, the differences may be evidence of multiple ethnicities or religions among those people who joined the local population during adulthood.

The $\delta^{18}O$ ratios of the people interred at Harris Creek suggest that this population was composed of people from up and down the length of the St Johns River. Additionally, Quinn et al. (2008) used $\delta^{18}O$ and $^{86}Sr/^{87}Sr$ ratios to show several individuals interred at Harris Creek originated far from the St Johns River basin, with two from as far away as Tennessee or Virginia. These studies indicate the population buried at Harris Creek is an amalgamation of individuals from across Florida and further to the north. This suggests burial mounds like Harris Creek may have been points of contact where people from different groups came together for social,

economic, and ideological reasons. Rather than legitimizing a single groups right to resources or serving as a territorial marker, Harris Creek may be viewed as a point of articulation for multiple groups of people spread across the Archaic landscape.

Chapter 3 Dietary Continuity and Change during the Florida Archaic uses stable isotopes from human bone to assess the contribution of marine foods and riverine resources in the diets of populations at Windover and Harris Creek. A new and intense focus on riverine resources is a defining characteristic of the Middle Archaic Period in Florida (Milanich, 1994; Milanich & Fairbanks, 1980). If this shift in subsistence occurred then it should be apparent in the $\delta^{13}C$ and $\delta^{15}N$ ratios from these sites. Supporting evidence for a shift to riverine resources comes from the appearance of large freshwater shell mounds along the river. However, there is some question as to whether the shell mounds represent food refuse or the use of shell as a building material, or both. $\delta^{13}C$ and $\delta^{15}N$ ratios are used to assess the relative contribution of freshwater shellfish to the diets of both populations. Finally, artifacts made from marine resources are common at Mt. Taylor sites but marine food resources are not. Settlement models for the region suggest people occupied the coast on a seasonal basis (Milanich & Fairbanks, 1980) or that people restricted their range to the St Johns river drainage and did not occupy the coast (Russo & Ste. Claire, 1992). Based on these models any evidence of marine food consumption is interpreted as a seasonal occupation of the coast.

The results of the isotopic assay of the populations from Harris Creek and Windover were remarkably similar. There was no evidence of a massive shift to freshwater aquatic resources, though the individuals interred at Harris Creek may have consumed slightly more riverine resources than did the people at Windover. Contrary to other sources of data (Russo et al., 1992), the isotopic data do not indicate that freshwater shellfish were a significant component of

their diet. Surprisingly, both populations appear to derive a significant portion of their diet from marine or estuarine sources supporting a coastal occupation. Based on isotopic data from these two sites, no major change in subsistence occurred between the Early and Middle Archaic and innovations like the construction of large freshwater shell mounds must be explained by something other than a broad scale change in diet and settlement.

In Chapter 4 Evaluating a Serial Sampling Methodology, modern and prehistoric teeth from Southeast Asia are used to evaluate different serial sampling methodologies. Serial sampling or isotopic "zoning" studies (Kohn & Cerling, 2002) have proven effective in a number of cases but have been hampered by a concern about isotopic attenuation produced by the process of secondary mineralization (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005). After the initial deposition of enamel, secondary mineralization slowly increases the mineral content of the enamel during the maturation phase. This process introduces mineral into the sample not associated with the original growth structure. Since the majority of mineral content is introduced after deposition, the isotopic signal associated with the growth structures could be written over or swamped by the subsequent waves of mineralization (Balasse, 2003; Kohn & Cerling, 2002; Passey & Cerling, 2002; Zazzo et al., 2005).

To assess the effects of secondary mineralization, 15 human molars were sampled along two axes. The method that returned the most isotopic variation was assumed to have the least amount of isotopic attenuation. The results of the study indicate that more isotopic variation is recovered from sampling the visible growth structures than along the path of the enamel prisms. A review of carbonate substitutions in enamel supports the assertion that secondary mineralization introduces little additional carbonate into the enamel after deposition (Elliott et al., 1985). These results explain why many studies of serially sample enamel carbonates have

produced valid results but suggest secondary mineralization remains a concern for researchers sampling phosphates.

In addition to investigating the effects of secondary mineralization, the modern and prehistoric teeth were compared to evaluate whether the signals recovered from tooth enamel are the result of environmental input or the result of internal biological rhythms which produce signals that mimic those expected from climatic sources. If the variation is environmental, then the pooling and storage of drinking water in reservoirs and the consumption of bottled and/or canned beverages is expected to buffer the $\delta^{18}O$ ratios of modern teeth. The results demonstrate that modern teeth show less variation than prehistoric teeth, though the difference was small suggesting prehistoric teeth undergo more environmental buffering than expected. Still the results of this research are promising and indicate that environmental signals recorded in human tooth enamel are not swamped by secondary mineralization and can be extracted by sampling the visible growth layers on the surface of the tooth.

Finally in Chapter 5 Piercing the Seasonal Round: Using Stable Isotopes to Reconstruct Human Diet by Season at Windover and Harris Creek, the isotopic methods developed in Chapter 4 are applied to the archaeological populations from Windover and Harris Creek. Ten human molars from Windover and 15 molars from Harris Creek are serially sampled in this research. Previous paleodietary studies in Chapter 2 have indicated there is a marine component in the diet of the populations interred at Windover and Harris Creek. This research uses serially sampled $\delta^{13}C$ and $\delta^{18}O$ ratios from human tooth enamel to assess the season of consumption of marine foods. This is the first time stable isotopes have been used to reconstruct human diet with a sub-annular resolution.

The isotopic data derived from the individuals interred at Windover and Harris Creek are used to evaluate the settlement models proposed for the region. The first model posits that Archaic groups had base camps along the St Johns River during the warm months and dispersed to the coast and/or interior highlands during the cooler winter months (Milanich & Fairbanks, 1980). Based on data from flora and fauna recovered from sites along the Atlantic coast and St Johns River, Mike Russo, in collaboration with other researchers, developed a new settlement model for the region. Russo et al. (1992) suggest that separate, ethnically distinct groups occupied the coast and the St Johns basin year-round. According to Russo et al. (1992) these groups may have moved along the river or coast, but not between them. Serially sampled isotopic data collected from Windover and Harris Creek are used to evaluate these models.

The time series data collected from Windover and Harris Creek support the first model and support the bone isotope data presented in Chapter 2 which indicates a marine component in the diet. Though different amounts of time incorporated in the samples prevent an exact estimation of $\delta^{13}C$ ratios at any given point in the year, a comparison of the shape of the $\delta^{13}C$ series and the $\delta^{18}O$ series from each individual suggests that more marine foods were more often consumed during the summer and fall. These estimates mesh well with the floral and faunal data from the region. Combined the isotopic and archaeological evidence suggest a summer/fall occupation of the coast that is opposite to the original Minanch/Fairbanks model. This trend appears the same for both Windover and Harris Creek, again supporting the results of the bone data in Chapter 2 which suggest no significant difference in the types of foods consumed. Additionally, these data suggest there was no detectable change in the resource scheduling between Windover and Harris Creek, indicating the basic scheduling of the seasonal round in place during the Early Archaic was still in place over 2000 rcybp later.

These studies provide new data to assess culture historical assessments of the Archaic Period in the St Johns region of Florida. Data presented here suggest that many of the adaptations or innovations thought to have developed in the Middle Archaic or later had roots in the Early Archaic. Contrary to popular wisdom, based on isotopic data from Harris Creek and Windover, there was no major change in subsistence between the Early and Middle Archaic. Additionally, both populations exploited marine resources though not yet at the levels achieved by later Orange Period and St Johns groups. The people interred in the massive shellworks at Harris Creek were not subsisting primarily on freshwater shellfish, which supports the assertion that much of the freshwater shell was a building material (Randall & Sassaman, 2005b).

The dietary data from the bone isotope and serial sampling studies of tooth enamel suggest that the people interred at Harris Creek were seasonally mobile. Though the St. Johns River and the surrounding ecosystem could likely support a population of relatively sedentary complex hunter-gathers, the society that created Harris Creek did not simply substitute aquatic foods in place of agriculture. For these people, sedentism was not a prerequisite for the construction of massive monumental mound complexes or the formation of long-distance social networks which moved people as well as goods.

Finally, based on the population at Harris Creek, Middle Archaic mounds had large number of immigrants interred in them making it unlikely that the mounds were the "property" of any one group. The presence of individuals from across the region buried at Harris Creek significantly weakens interpretations of the mound as a territorial marker for a local group or as a means of legitimizing a single group's rights to critical but restricted resources (Goldstein, 1976 ; Saxe, 1970). The mound may have functioned as a seasonal aggregation site which served economic, political, social, and ideological functions for very widely distributed groups of

seasonally mobile hunter-gatherers (Hofman 1985). Ultimately, even this interpretation may fall short of explaining and contextualizing the complex role of mortuary mounds on the social landscape. More research is needed to establish number of immigrants and total distance encompassed by the Archaic social networks. Once the scale and scope of these interactions are known, models and theories can be developed to explain the role of Archaic Period shell mounds and cemeteries.

LIST OF REFERENCES

Ambrose S. H. 1990. Preparation and characterization of bone and tooth collagen for isotopic analysis. Journal of Archaeological Science 17:431- 451.

Ambrose S. H., Buikstra J. F. & Krueger H. W. 2003. Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. Journal of Anthropological Archaeology 22:217-226.

Ambrose S. H. & DeNiro M. J. 1986. Reconstruction of African Human Diet using Bone Collage Carbon and Nitrogen Isotope Ratios. Nature 319:321-324.

Ambrose S. H. & Norr L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: (J. B. Lambert and G. Grupe, Eds) Prehistoric Human Bone: Archaeology at the Molecular Level. Springer-Verlag, Berlin pp. 1-37.

Ames K. M. 1991. Sedentism: a temporal shift or a transitional change in hunter-gather mobility patterns. In: (S. A. Gregg, Ed) Between bands and states. Center for Archaeological Investigations, Carbondale.

Amick D. S. 1996. Regional patterns of Folsom mobility and land use in the American Southwest. World archaeology 27:411-426.

Aoba T. 1996. Recent observations on enamel crystal formation during mammalian amelogenesis. Anatomical Record 245:208-218.

Aoba T. & Moreno E. 1990. Changes in the nature and composition of enamel mineral during porcine amelogenesis. Calcified Tissue International 47:356-364.

Aoba T. & Moreno E. C. 1987. The Enamel Fluid in the Early Secretory Stage of Porcine Amelogenesis - Chemical-Composition and Saturation with Respect to Enamel Mineral. Calcified Tissue International 41:86-94.

Arnold B. & Wicker N. L., (Eds) 2001 Gender and the Archaeology of Death. AltaMira Press, Walnut Creek.

Aten L. E. 1999. Middle Archaic Ceremonialism at Tick Island, Florida: Ripley P. Bullen's 1961 Excavation at the Harris Creek Site. The Florida Anthropologist 52:132-200.

Avery J. K. 2000. Essentials of oral histology and embryology: a clinical approach. Baltimore, Mosby.

Bailey G. & Milner N. 2002. Coastal hunter-gatherers and social evolution: marginal or central? Before Farming: The Archaeology and Anthropology of Hunter–Gatherers. (http://www.waspjournals.com/) 2002/3-4(1).

Bailey G. & Parkington J., (Eds) 1988. The archaeology of prehistoric coastlines. Cambridge University Press, Cambridge.

Balasse M. 2003. Potential biases in sampling design and interpretation of intra-tooth isotope analysis. International Journal of Osteoarchaeology 13:3-10.

Balasse M., Ambrose S. H., Smith A. B. & Price D. T. 2002. The Seasonal Mobility Model for Prehistoric Herders in the Southwestern Cape of South Africa assessed by Isotopic Analysis of Sheep Tooth Enamel. Journal of Archaeological Science 29:917-932.

Balasse M., Tresset A. & Ambrose S. H. 2006. Stable isotope evidence (delta C-13, delta O-18) for winter feeding on seaweed by Neolithic sheep of Scotland. Journal of Zoology 270:170-176.

Balasse M., Tresset A., Dobney K. & Ambrose S. H. 2005. The use of isotope ratios to test for seaweed eating in sheep. Journal of Zoology 266:283-291.

Bamforth D. B. 1988. Ecology and human organization on the Great Plains. New York, Plenum Press.
Barker G. 2002. Prehistoric foragers and farmers in south-east Asia: renewed investigations at Niah Cave, Sarawak. Proceedings of the Prehistoric Society 68:147-164.
Barrett J. C. 1990. The monumentality of death: the character of early Bronze Age mortuary mounds in southern England. World Archaeology:179-89.
Bellwood P. 1997. Prehistory of the Indo-Malaysian Archipelago. Honolulu, University of Hawai'i Press.
Bentley R. A. & Knipper C. 2005. Geographical patterns in biologically available Strontium, Carbon and Oxygen isotope signatures in prehistoric SW Germany. Archaeometry 47:629-644.
Benyon A. D., Clayton C. B., Ramirez Rozzi F. V. & Reid D. J. 1998. Radiological aspects of the developing dentition in modern humans and great apes. Journal of human evolution 35:351-370.
Bewick V., Cheek L. & Ball J. 2003. Statistics review 7: Correlation and regression. Critical Care London 7:451-459.
Binford L. R. 1968. Post-Pleistocence Adaptations. In: (S. R. Binford and L. R. Binford, Eds) New Perspectives in Archeology. Aldine Publishing Co., New York, pp. 313-341.
Binford L. R. 1971. Mortuary practices: Their study and their potential. In: (J. A. Brown, Ed) Approaches to the social dimensions of mortuary practices Society for American Archaeology, Washington, D.C., pp. 6-29.
Binford L. R. 1980. Willow Smoke and Dog's Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. American Antiquity 45:4-20.
Binford L. R. 1983. Long-term land use patterns: some implications for archaeology. In: (R. C. Dunnel and D. K. Grayson, Eds) Lulu Linear Punctate: Essays in Honor of George Irving Quimby. University of Michigan, Museum of Anthropology, Ann Arbor, pp. 27-54.
Binford L. R. 1990. Mobility, Housing, and Environment: A Comparative Study. Journal of Anthropological Research 46:119-152.
Binford L. R. 2001. Constructing frames of reference: An analytical method for archaeological theory building using ethnographic and environmental data sets. Berkeley, University of California Press.
Bocherens H. & Drucker D. 2003. Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. International Journal of Osteoarchaeology 13:46-53.
Bonzani R. M. 1997. Plant Diversity in the Archaeological Record: A Means Toward Defining Hunter–Gatherer Mobility Strategies. Journal of Archaeological Science 24:1129-1139.
Bowen G. 2005. Online Isotopes in Precipitation Calculator (OIPC). (http://www.waterisotopes.org/).
Bowen G. J. & Revenaugh J. 2003. Interpolating the isotopic composition of modern meteoric precipitation. Water Resources Research 39:1299.
Bowen G. J., Wassenaar L. I. & Hobson K. A. 2005. Global application of stable hydrogen and oxygen isotopes to wildlife forensics. Oecologia 143:337-348.
Bowen G. J. & Wilkinson B. 2002. Spatial distribution of $\delta^{18}O$ in meteoric precipitation. Geology 30:315-318.

Boyde A. 1979. Carbonate concentration, crystal centres, core dissolution, caries, cross striations, circadian rhythms, and comositional contrast in the SEM. Journal of Dental Research 58b:981-983.
Brantingham P. J. 1998. Mobility, competition, and Plio-Pleistocence hominid foraging groups. Journal of Archaeological Method and Theory 5:57-98.
Brown J. 1995 On Mortuary Analysis; with Special Reference to the Saxe-Binford Research Program. In: (L. A. Beck, Ed) Regional Approaches to Mortuary Analysis. Plenum Press, New York, pp. 3-26.
Bryant J. D. & Froelich P. N. 1996. Oxygen isotope composition of human tooth enamel from medieval Greenland: Linking climate and society: Comment. Geology 24:477-478.
Buikstra J. F. & Charles D. K. 1999. Centering the Ancestors: Cemeteries, Mounds, and Sacred Landscapes of the Ancient North American Midcontinent. In: (W. Ashmore and B. Knapp, Eds) Archaeologies of Landscape: Contemporary Perspectives. Blackwell, Oxford, pp. 201-228.
Buikstra J. F. & Milner G. R. 1991. Isotopic and Archaeological Interpretations of Diet in the Central Mississippi Valley. Journal of Archaeological Science 18:319-329.
Burch E. S. 1998. The future of hunter-gatherer research. In: (J. Gowdy, Ed) Limited Wants, Unlimited Means: A Reader in Hunter-Gatherer Economics and the Environment. Island Press, Washington, D.C., pp. 201-217.
Cannon A. 2005 Gender and Agency in Mortuary Fashion. In: (G. F. M. Rakita, J. E. Buikstra, L. A. Beck and S. R. Williams, Eds) Interacting with the Dead: Perspectives on Mortuary Archaeology for the New Millennium. University Press of Florida, Gainesville, pp. 41-65.
Carlson K. J., Grine F. E. & Pearson O. M. 2007. Robusticity and sexual dimorphism in the postcranium of modern hunter-gatherers from Australia. American Journal of Physical Anthropology 134:9.
Carr C. 1995. Mortuary practices: Their social, philosophical-religious, circumstantial, and physical determinants. Journal of Archaeological Method and Theory 2:105-200.
Cashdan E. 1983. Territoriality Among Human Foragers: Ecological Models and an Application to Four Bushman Groups. Current Anthropology 24:47.
Cashdan E. 1992. The spatial organization of habitat use. In: (B. Winterhalder and E. A. Smith, Eds) Evolutionary ecology and human behavior. Aldine de Gruyter, New York, pp. 237-266.
Chapman R. 1995 Ten years after-Megaliths, mortuary practices, and the territorial model. In: (L. A. Beck, Ed) Regional Approaches to Mortuary Analysis. Plenum Press, New York, pp. 29-51.
Chapman R. 2003. Archaeologies of Complexity. London, Routledge.
Chatters J. C. 1987. Hunter-gatherer adaptations and assemblage structure. Journal of Anthropological Archaeology 6:336-375.
Christenson A. L. 1980. Change in the human niche in response to population growth. In: (T. Earle and A. Christenson, Eds) Modeling change in prehistoric subsistence economies. Academic Press, New York, pp. 32-72.
Claassen C. P. 1991. New Hypotheses for the Demise of the Shell Mound Archaic. In: (C. H. McNutt, Ed) Proceedings of the 1989 Mid-South Archaeological Conference, Memphis, TN. Archaeological Report No. 24, Mississippi Department of Archives and History, Jackson, Mississippi, pp. 66-72.

Claassen C. P. 1996. A Consideration of the Social Organization of the Shell Mound Archaic. In: (K. E. Sassaman and D. G. Anderson, Eds) Archaeology of the Mid-Holocene Southeast. University Press of Florida, Gainesville, pp. 235-258.
Close A. E. 2000. Reconstructing Movement in Prehistory. Journal of Archaeological Method and Theory 7:49-77.
Cohen M. N. 1977. The food crisis in prehistory: Overpopulation and the origins of agriculture. New Haven, Yale University Press.
Coplen T. B., C. K. & Hopple J. 1983. Comparison of stable isotope reference samples. Nature 302:236-238.
Cormie A. B., Luz B. & Schwarcz H. P. 1994. Relationship between the hydrogen and oxygen isotopes of deer bone and their use in the estimation of relative humidity. Geochimica et Cosmochimica Acta 58:3439-3449.
Crane H. R. & Griffin J. B. 1965. University of Michigan Radiocarbon Dates X. Radiocarbon 6:1-24.
Crown P. L. & Fish S. K. 1996. Gender and status in the Hohokam pre-Classic to Classic transition. American Anthropologist 98:803-817.
Dean C. & Benyon A. D. 1991. Histological reconstruction of crown formation times and initial root formation times in a modern child. American Journal of Physical Anthropology 86:215-228.
Dean C., Leakey M. G., Reid D., Schrenk F., Schwartz G. T., Stringer C. & Walker A. 2001. Growth processes in teeth distinguish modern humans from *Homo erectus* and earlier hominins. Nature 414:628-631.
Deetz J. 1968. Hunters in archaeological perspective. In: (R. Lee and I. DeVore, Eds) Man the hunter. Aldine, Chicago, pp. 281-285.
DeLeon V. B. 1998. Stable Isotope Analysis and Paleodiet at the Bay West site, Collier County, Florida. Unpublished M.A. Thesis, University of Florida, Gainesville.
DeNiro M. J. 1985. Postmortem Preservation and Alteration of in vivo Bone Collagen Isotope Ratios in Relation to Paleodietary reconstruction. Nature 317:806-809.
DeNiro M. J. & Epstein S. 1978. Carbon Isotopic Evidence for Different Feeding Patterns in Two Hyrax Species Occupying the Same Habitat. Science 201:906-907.
DeNiro M. J. & Epstein S. 1981. Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. Geochimica et Cosmochimica Acta 45:341-351.
Donald L. & Mitchell D. H. 1994. Nature and culture on the nortwest coast of North America: The case of Wakashan salmon resources. In: (E. S. Burch and L. J. Ellanna, Eds) Key issues in hunter-gatherer research. Berg, Oxford, pp. 95-117.
Doran G. H., (Ed) 2002. Windover: Multidisciplinary Investigations of an Early Archaic Florida Cemetery. University of Florida Press, Gainesville.
Drucker D. G. & Bocherens H. 2004. Carbon and Nitrogen stable isotopes as tracers of change in diet breadth during Middle and Upper Palaeolithic in Europe. International Journal of Osteoarchaeology 14:162-177.
Dupras T. L. & Schwarcz H. P. 2001. Strangers in a Strange Land: Stable Isotope Evidence for Human Migration in the Dakhleh Oasis, Egypt. Journal of Archaeological Science 28:1199-1208.
Dupras T. L., Schwarcz H. P. & Fairgrieve S. I. 2001. Infant feeding and weaning practices in Roman Egypt. American Journal of Physical Anthropology 115:204-212.

Dutton A., Wilkinson B. H., Welker J. M., Bowen G. J. & Lohmann K. C. 2005 Spatial Distribution and Seasonal Variation in 18O/16O of Modern Precipitation and River Water across the Conterminous USA. Hydrological Processes 19:4121-4146.
Elliott J. C., Holcomb D. W. & Young R. A. 1985. Infrared Determination of the Degree of Substitution of Hydroxyl by Carbonate Ions in Human Dental Enamel. Calcified Tissue International 37:372-375.
Erlandson J. M. 2001. The Archaeology of Aquatic Adaptations: Paradigms for a New Millennium. Journal of Archaeological Research 9:287-350.
Evans J. A., Chenery C. A. & Fitzpatrick A. P. 2006. Bronze Age childhood migration of individuals near Stonehenge, revealed by Strontium and Oxygen isotope tooth enamel analysis. Archaeometry 48:309-321.
Faure G. 1986. Principles of Isotope Geology. New York, John Wiley and Sons.
Fawcett D. W. 1986. A Textbook of Histology, WB Saunders Company.
FitzGerald C. M. 1998. Do enamel microstructures have regular time dependency? Conclusions from the literature and a large-scale study. Journal of Human Evolution 35:371-386.
Fricke H. C. & O'Neil J. R. 1996 Inter- and intratooth variation in the oxygen isotope composition of mammalian tooth enamel phosphate: implications for palaeoclimatological and palaeobiological research. Palaeogeography, Palaeoclimatology, Palaeoecology 126:91-100.
Fuller B. T., Richards M. P. & Mays S. 2003. Stable carbon and nitrogen isotope variations in tooth dentine subsections from Wharram Percy. Journal of Archaeological Science 30:1673-1684.
Gadbury C., Todd L., Jahren A. H. & Amundson R. 2000. Spatial and temporal variations in the isotopic composition of bison tooth enamel from the Early Holocene Hudson-Meng Bone Bed, Nebraska. Palaeogeography, Palaeoclimatology, Palaeoecology 157:79-93.
Gallivan M. D. 2002. Measuring sedentariness and settlement population: Accumulations research in the Middle Atlantic region. American Antiquity 67:535-557.
Garazhain O. & Yazdi L. P. 2008 Mortuary Practices in Bam after the Earthquake: An Ehnoarchaeological Study. Journal of Social Archaeology 8:94.
Gibson J. L. 2006. Navels of the earth: sedentism in early mound-building cultures in the lower Mississippi valley. World Archaeology 38:311-329.
Gillespie S. D. 2001. Personhood, Agency, and Mortuary Ritual: A Case Study from the Ancient Maya. Journal of Anthropological Archaeology 20:73-112.
Gluckman M. 1937. Mortuary Customs and the Belief in Survival after Death among the South-Eastern Bantu. Bantu 11:117-136.
Goldstein L. 1976 Spatial Structure and Social Organization: Regional Manifestations of Mississippian Society. Unpublished Ph.D. dissertation, Northwestern University, Evanston.
Goldstein L. 2006. Mortuary Analysis and Bioarchaeology. In: (J. E. Buikstra and L. A. Beck, Eds) Bioarchaeology: The Contextual Analysis of Human Remains. Elsevier, New York, pp. 375-388.
Gonfiantini R. 1985. On the isotopic composition of precipitation in tropical stations. Acta Amazonica 15:121-139.
Griffin P. B. 1989. Hunting, farming, and sedentism in a rain forest foraging society. In: (S. Kent, Ed) Farmers as Hunters. Cambridge University Press, Cambridge, pp. 60-70.

Halstead P. & O'Shea J. 1989. Introduction: cultural responses to risk and uncertainty. In: (P. Halstead and J. O'Shea, Eds) Bad year economics: Cultural responses to risk and uncertainty. Cambridge University Press, Cambridge, pp. 1-7.
Härke H. 2002. Interdisciplinarity and the archaeological study of death. Mortality 7:340-341.
Hedges R. E. M. 2004. Isotopes and red herrings: comments on Milner et al. and Lidén et al. Antiquity 78:34-37.
Hiller C. R., Robinson C. & Weatherell J. A. 1975. Variations in Composition of Developing Rat Incisor Enamel. Calcified Tissue Research 18:1-12.
Hitchcock R. K. 1982. Patterns of sedentism among the Basarwa of eastern Botswana In: (E. Leacock and R. Lee, Eds) Politics and history in band society. Cambridge University Press, Cambridge, pp. 223-267.
Hodder I. 1984. Burials, houses, women and men in the European Neolithic. In: (D. Miller, and Tilley,C., Ed) Ideology, Power, and Prehistory. Cambridge University Press, New York, pp. 51-68.
Hodder I. 1986. Reading the past: Current Approaches to interpretation in archaeology. Cambridge, Cambridge University Press.
Hofman J. L. 1985. Middle Archaic Ritual and Shell Midden Archaeology: Considering the Significance of Cremations. In: (T. Whyte, C. Boyd and B. Riggs, Eds) Exploring Tennessee Prehistory: A Dedication to Alfred K. Guthe. Department of Anthropology, University of Tennessee, Knoxville, pp. 1-21.
Hoogewerff J., Papesch W., Kralik M., Berner M., Vroon P., Miesbauer H., Gaber O., Kunzel K.-H. & Kleinjans J. 2001. The last domocile of the Iceman from Hauslabjoch: A geochemical approach using Sr, C, and O Isotopes and trace element signatures. Journal of Archaeological Science 28:983-989.
Hoppe K. A., Stover S. M., Pascoe J. R. & Amundson R. 2004. Tooth enamel biomineralization in extant horses: implicaitons for isotopic microsampling. Palaeogeography Palaeoclimatology Palaeoecology 206:355-365.
Horsley P. A. 2008 Death dwells in spaces: Bodies in the hospital mortuary. Anthropology & Medicine 15:133-146.
Howell T. L. 1995. Tracking Zuni Gender and Leadership Roles across the Contact Period. Journal of Anthropological Research 51:125-147.
Humphrey L. T., Dean M. C. & Jeffries T. E. 2007. An evaluation of changes in strontium/calcium ratios across the neonatal line in human deciduous teeth. In: (S. Bailey and J.-J. Hublin, Eds) Dental Perspectives on Human Evolution: State of the Art Research in Dental Paleoanthropology pp. 303-319.
Hutchinson D. L., (Ed) 2002. Foraging, Farming, and Coastal Biocultural Adaptation in Late Prehistoric North Carolina. University of Florida Press, Gainesville.
Hutchinson D. L., (Ed) 2004. Bioarchaeology of the Florida Gulf Coast: Adaptation, Conflict, and Change. University Press of Florida, Gainesville.
Hutchinson D. L., Larsen C. S., Norr L. & Schoeninger M. J. 2000. Agricultural Melodies and Alternative Harmonies in Florida and Georgia. In: (P. M. Lambert, Ed) Bioarchaeological Studies of Life in the Age of Agriculture: A View from the Southeast. The University of Alabama Press, Tuscaloosa, pp. 96-115.
Iacumin P., Bocherens H., Mariotti A. & Longinelli A. 1996. Oxygen isotope analyses of co-existing carbonate and phosphate in biogenic apatite: a way to monitor diagenetic alteration of bone phosphate? Earth and Planetary Science Letters:1-6.

Jahn O. L. & Bullen R. P. 1978. The Tick Island Site, St. Johns River, Florida. Gainesville, Florida Anthropological Society Publications.
Jochim M. A. 1976. Hunter-gatherer Subsistence and Settlement: A Predictive Model, Academic Press.
Jones D. S., Quitmyer I. R. & Andrus F. T. 2005. Oxygen isotopic evidence for greater seasonality in Holocene shells of Donax variabilis from Florida. Palaeogeography, Palaeoclimatology, Palaeoecology 228:96-108.
Katzenberg M. A. 1989. Stable isotope analysis of archaeological faunal remains from southern Ontario. Journal of Archaeological Science 16:319–329.
Katzenberg M. A. & Saunders S. R. 2000. Stable Isotope Analysis: A Tool for Studying Past Diet, Demography and Life History. In: (M. A. Katzenberg and S. R. Saunders, Eds) Biological Anthropology of the Human Skeleton. Wiley-Liss, New York, pp. 305-327.
Katzenberg M. A., Schwarcz H. P., Knyf M. & Melbye F. J. 1995. Stable-Isotope Evidence for Maize Horticulture and Paleodiet in Southern Ontario, Canada. American Antiquity 60:335-350.
Keenleyside A., Schwarcz H. & Panayotova K. 2006. Stable isotopic evidence of diet in a Greek colonial population from the Black Sea. Journal of Archaeological Science 33:1205-1215.
Kellner C. M. & Schoeninger M. J. 2007. A simple carbon isotope model for reconstructing prehistoric human diet. American Journal of Physical Anthropology 133:1112.
Kelly J. A., Tycot R. H. & Milanich J. T. 2006. Evidence for Early Use of Maize in Peninsular Florida. In: (J. E. Staller, R. H. Tykot and B. F. Benz, Eds) Histories of Maize. Academic Press, New York, pp. 249-262.
Kelly J. F. 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. Canadian Journal of Zoology 78:1-27.
Kelly R. L. 1983. Hunter-gatherer mobility strategies. Journal of Anthropological Research 39:277-306.
Kelly R. L. 1990. Marshes and mobility in the Western Great Basin. In: (J. C. Janetski and D. B. Madsen, Eds) Wetlands adaptations in the Great Basin. Museum of People and Cultures Occasional Papers. Brigham Young University, Provo, pp. 259-276.
Kelly R. L. 1992. Mobility/Sedentism: Concepts, Archaeological Measures, and Effects. Annual Review of Anthropology 21:43-66.
Kelly R. L. 1995. The Foraging Spectrum: Diversity in Hunter-Gatherer Lifeways. Washington, Smithsonian Institution Press.
Knudson K. J. & Price T. D. 2007. Utility of multiple chemical techniques in archaeological residential mobility studies: Case studies from Tiwanaku- and Chiribaya-affiliated sites in the Andes. American Journal of Physical Anthropology 132:25-39.
Knudson K. J., Tung T. A., Nystrom K. C., Price T. D. & Fullagar P. D. 2005. The origin of the Juch'uypampa Cave mummies: strontium isotope analysis of archaeological human remains from Bolivia. Journal of Archaeological Science 32:903-913.
Koch P. L., Fogel M. J. & Tuross N. 1994. Tracing the diets of fossil animals using stable isotopes. In: (K. Lajtha and R. H. Michener, Eds) Stable Isotopes in Ecology and Environmental Science. Blackwell Scientific, Oxford, pp. 63-92.
Koch P. L., Halliday A. N., Walter L. M., Stearley R. F., Huston T. J. & Smith G. R. 1992. Sr Isotopic Composition of Hydroxyapatite from Recent and Fossil Salmon - the Record of Lifetime Migration and Diagenesis. Earth and Planetary Science Letters 108:277-287.

Koch P. L., Heisinger J., Moss C., Carlson R. W., Fogel M. L. & Behrensmeyer A. K. 1995. Isotopic Tracking of Change in Diet and Habitat Use in African Elephants. Science 267:1340-1343.
Koch P. L., Tuross N. & Fogel M. L. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. Journal of Archaeological Science 24:417-429.
Kohn M. J. & Cerling T. E. 2002. Stable isotope compositions of biological apatite. Phosphates: Geochemical, Geobiological, and Materials Importance 48:455-488.
Kohn M. J., Schoeninger M. J. & Valley J. W. 1998. Variability in oxygen isotope compositions of herbivore teeth: reflections of seasonality or developmental physiology? Chemical Geology 152:97-112.
Komar D. 2008 Patterns of Mortuary Practice Associated with Genocide. Current Anthropology 49:123-133.
Krigbaum J. 2005. Reconstructing human subsistence in the West Mouth (Niah Cave, Sarawak) burial series using stable isotopes of carbon. Asian Perspectives 44:73-89.
Kroeber A. L. 1927. Disposal of the Dead. American Anthropologist 29:308-315.
Larsen C. S. 1997. Bioarchaeology: Interpreting behavior from the human skeleton. Cambrige, Cambridge University Press.
Larsen C. S. & Ruff C. B. 1991. Biomechanical Adaptation and Behavior on the Prehistoric Georgia Coast. What Mean These Bones? Studies in Southeastern Bioarchaeology:102-113.
Larsen C. S. & Ruff C. B. 1994. The stresses of conquest in Spanish Florida: structural adaptation and change before and after contact In the Wake of Contact: Biological Responses to Conquest. Wiley-Liss, New York, pp. 21–34.
Larsen C. S., Ruff C. B. & Kelly R. L. 1991. Skeletal structural adaptations in prehistoric Western Great Basin hunter-gatherers American Association of Physical Anthropologists Wisconson.
Leakey M. D. & Hay R. L. 1979. Pliocene footprints in the Laetolil Beds at Laetoli, northern Tanzania. Nature 278:317-323.
Lee-Thorp J. A. 1989. Stable carbon isotopes in deep time: the diets of fossil fauna and hominids. Unpublished Ph.D. Dissertation, University of Cape Town, Cape Town.
Lee R. & De Vore I. 1968. Man the Hunter. Chicago, Aldine.
Lewin R. 1988. New views emerge on Hunters and Gatherers. Science 240:1146-1148.
Lidén K., Eriksson G., Nordqvist B., Götherström A. & Bendixen E. 2004. The wet and the wild followed by the dry and the tame" - or did they occur at the same time? Diet in Mesolithic -- Neolithic southern Sweden. Antiquity 78:23-33.
Lightfoot K. G. & Jewett R. 1986. The shift to sedentary life: A consideration of the occupation duration of Early Mogollon pithouse villages. In: (C. Benson and S. Upham, Eds) Mogollon Variability. New Mexico State University, La Cruces, pp. 9-44.
Longinelli A. 1984. Oxygen isotopes in mammal bone phosphate: A new tool for paleohydrological and paleoclimatological research? Geochimica et Cosmochimica Acta 48:385-390
Lull V. 2000 Death and Society: a Marxist approach. Antiquity 74:576-580.
Luz B., Cormie A. B. & Schwarcz H. P. 1990 Oxygen Isotope Variations in Phosphate of Deer Bones. Geochimica et Cosmochimica Acta 54:1723-1728.

Luz B. & Kolodny Y. 1985. Oxygen isotope variations in phosphate of biogenic apatites, IV, mammal teeth and bones. Earth and Planetary Science Letters 75:29-36.
Luz B., Kolodny Y. & Kovach J. 1984. Oxygen Isotope Variations in Phosphate of Biogenic Apatites, 3 Conodonts. Earth and Planetary Science Letters 69:255-262.
MacFadden B. J., Higgins P., Clementz M. T. & Jones D. S. 2004. Diets, habitat preferences, and niche differentiation of Cenozoic sirenians from Florida: evidence from stable isotopes. Paleobiology 30:297-324.
McGee R. M. 1995. Fired-Clay Objects: Cooking Technology from the Florida Shell Mound Archaic at Groves' Orange Midden (8VO2601) Florida. Unpublished M.A. thesis, University of Florida, Gainesville.
Merbs C. F. 1983. Patterns of Activity-Induced Pathology in a Canadian Inuit Population. Ottawa, Archaeological Survey of Canada.
Milanich J. T. 1994. Archaeology of Precolumbian Florida. Gainesville, University Press of Florida.
Milanich J. T. 1998. Florida's Indians from Ancient Times to the Present. Gainesville, University Press of Florida.
Milanich J. T. & Fairbanks C. H. 1980. Florida Archaeology. New York, Academic Press.
Milner N., Craig O. E., Bailey G. N., Pedersen K. & Anderson S. H. 2004. Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations. Antiquity 78:9-22.
Minagawa M. & Wada E. 1984. Stepwise enrichment of 15 N along food chains: Further evidence and the relation between 15 N and animal age. Geochimica et Cosmochimica Acta 48:1135-1140.
Montgomery J., Evans J. A., Powlesland D. & Roberts C. A. 2005. Continuity or colonization in Anglo-Saxon England? Isotope evidence for mobility, subsistence practice, and status at West Heslerton American Journal of Physical Anthropology 126:123-138.
Moore C. B. 1892a. A Burial Mound of Florida. American Naturalist 26:128-143.
Moore C. B. 1892b. Certain Shell Heaps of the St. John's River, Florida, Hitherto Unexplored. American Naturalist 27:8-13, 113-117, 605-624, 708-729.
Moore C. B. 1892c. Supplementary Investigations at Tick Island. American Naturalist 26:568-579.
Moore C. B. 1894. Certain sand Mounds of the St. Johns River, Florida. Journal of the Academy of Natural Sciences of Philadelphia 10.
Morris I. 1991 The archaeology of ancestors: The Saxe/Goldstein hypothesis revisited. Cambridge Archaeological Journal 1:147-169.
Moseley M. E. 1975. The maritime foundations of Andean civilization. Menlo Park, California, Cummings Publishing Co.
Moseley M. E. 1992. The Incas and Their Ancestors: The Archaeology of Peru, Thames and Hudson.
Moss-Salentijn L., Moss M. L. & Yuan M. S.-t. 1997. The ontogeny of mammalian enamel. In: (W. V. Koenigswald and P. M. Sander, Eds) Tooth Enamel Microstructure. Balkema, Rotterdam, pp. 5-30.
Murdock G. P. 1967. The ethnographic atlas: a summary. Ethnology 6:109-236.
Murdock G. P. & White D. R. 1969. Standard Cross-Cultural Sample. Ethnology 8:329-69.
Nelson S. V. 2005. Paleoseasonality inferred from equid teeth and intra-tooth isotopic variability. Palaeogeography Palaeoclimatology Palaeoecology 222:122-144.

Newsom L. 1994. Archaeobotanical Data from Groves Orange Midden (8VO2601), Volusia County, Florida. The Florida Anthropologist 47:404-417.
Newsome S. D., Phillips D. L., Culleton B. J., Guilderson T. P. & Koch P. L. 2004. Dietary reconstruction of an early to middle Holocene human population from the central California coast: insights from advanced stable isotope mixing models. Journal of Archaeological Science 31:1101-1115.
Nielson-Marsh C. M. & Hedges R. E. M. 2000. Patterns of diagenesis in bone: 1. The effect of site environments. Journal of Archaeological Science 27:1139-1150.
Njitchoua R., Sigha-Nkamdjou L., Dever L., Marlin C., Sighomnou D. & Nia P. 1999. Variations of the stable isotopic compositions of rainfall events from the Cameroon rain forest, Central Africa. Journal of Hydrology 223:17-26.
Norr L. 1995. Interpreting dietary maize from bone isotopes in the New World tropics: the state of the art. In: (P. W. Stahl, Ed) Archaeology of the Lowland American Tropics: Current Analytical Methods and Applications. Cambridge University Press, New York, pp. 198–223.
Parker-Pearson M. 1993 The powerful dead: Archaeological relationships between the living and the dead. Cambridge Archaeological Journal 3:203-229.
Parker-Pearson M. 1999. The Archaeology of Death and Burial. College Station, Texas A&M University Press.
Passey B. H. & Cerling T. E. 2002. Tooth enamel mineralization in ungulates: Implications for recovering a primary isotopic time-series. Geochimica Et Cosmochimica Acta 66:3225-3234.
Passey B. H., Cerling T. E., Perkins M. E., Voorhies M. R., Harris J. M. & Tucker S. T. 2002. Environmental change in the Great Plains: An isotopic record from fossil horses. Journal of Geology 110:123-140.
Passey B. H., Cerling T. E., Schuster G. T., Robinson T. F., Roeder B. L. & Krueger S. K. 2005. Inverse methods for estimating primary input signals from time-averaged isotope profiles. Geochimica Et Cosmochimica Acta 69:4101-4116.
Pauketat T. R. 1989. Monitoring Mississippian homestead occupation span and economy using ceramic refuse. American Antiquity 54:288-310.
Perlman S. M. 1983. An optimum diet model, coastal variability, and hunter-gatherer behaviour. In: (M. B. Schiffer, Ed) Advances in archaeological method and theory. Academic Press, New York, pp. 257-310.
Phillips D. L. & Gregg J. W. 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia 136:261-269.
Piatek B. J. 1994. The Tomoka Mound Complex in Northeast Florida. Southeastern Archaeology 12:109-118.
Plog S. 1990. Agriculture, sedentism, and environment in the evolution of political systems. In: (S. Upham, Ed) The evolution of political systems. Cambridge University Press, Cambridge, pp. 177-199.
Price D. T., Burton J. H. & Bentley R. A. 2002. The characterisation of biologically-available strontium isotope ratios for investigation of prehistoric migration. Archaeometry 44:117-135.
Price D. T., Manzanilla L. & Middleton W. D. 2000. Immigration and the Ancient City of Teotihuacan in Mexico: a Study Using Strontium Isotope Ratios in Human Bone and Teeth Journal of Archaeological Science 27:903-913.

Price T. D. & Brown J. A., (Eds) 1985. Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity. Academic Press, New York.
Pritchard G. T. & Robbins C. T. 1990. Digestive and metabolic efficiencies of grizzly and black bears. Canadian Journal of Zoology 68:1645-1651.
Prowse T., Schwarcz H., Macchiarelli R. & Bondioli L. 2003. Isotopic evidence of migration at the imperial port of Portus Romae, Italy. American Journal of Physical Anthropology:172-172.
Prowse T., Schwarcz H. P., Saunders S., Macchiarelli R. & Bondioli L. 2004. Isotopic paleodiet studies of skeletons from the imperial Roman-age cemetery of Isola Sacra, Rome, Italy. Journal of Archaeological Science 31:259-272.
Quinn R. 1999. Evidence for Diet and Climate in Archaic Florida: Analyses of the Tick Island Human and Faunal Skeletal Samples. Unpublished M.A. Thesis, University of Florida, Gainesville.
Quinn R. L., Tucker B. D. & Krigbaum J. 2008. Diet and mobility in Middle Archaic Florida: stable isotopic and faunal evidence from the Harris Creek archaeological site (8Vo24), Tick Island. Journal of Archaeological Science 35:2346-2356.
Quitmyer I. R., Jones D. S. & Arnold W. S. 1997. The Sclerochronology of Hard Clams, Mercenariaspp., from the South-Eastern USA: A Method of Elucidating the Zooarchaeological Records of Seasonal Resource Procurement and Seasonality in Prehistoric Shell Middens. Journal of Archaeological Science 24:825-840.
Rafferty J. E. 1985. The archaeological record on sedentariness: Recognition, development, and implication. In: (M. B. Schiffer, Ed) Advances in Archaeological Method and Theory. Academic Press, New York.
Rakita G. F. M. & Buikstra J. F. 2005. Theories, Time, and Space. In: (G. F. M. Rakita, J. F. Buikstra, L. A. Beck and S. R. Williams, Eds) Interacting with the Dead: Perspectives on Mortuary Archaeology for the New Millennium. University Press of Florida, Gainesville, pp. 13-15.
Randall A. & Sassaman K. E. 2005a. (Re)Placing Archaic History. Paper invited to the symposium "Theorizing Place in Archaeology: Prospects and Potentialities," 70th Annual Meeting of the Society for American Archaeology Salt Lake City, UT.
Randall A. & Sassaman K. E. 2005b. St. Johns Archaeological Field School 2003-2004: Hontoon Island State Park. Laboratory of Southeastern Archaeology, Technical Report 6. Department of Anthropology, University of Florida Gainesville.
Reid D. J. & Dean M. C. 2006. Variation in modern human enamel formation times. Journal of Human Evolution 50:329-346.
Richards M., Harvati K., Grimes V., Smith C., Smith T., Hublin J. J., Karkanas P. & Panagopoulou E. 2008. Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS. Journal of Archaeological Science 35:1251-1256.
Richards M. P., Fuller B. T. & Hedges R. E. M. 2001. Sulphur isotopic variation in ancient bone collagen from Europe: implications for human palaeodiet, residence mobility, and modern pollutant studies. Earth and Planetary Science Letters 191:185-190.
Richards M. P. & Hedges R. E. M. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. Journal of Archaeological Science 26:717-722.

Richards M. P., Jacobi R., Cook J., Pettitt P. B. & Stringer C. B. 2005. Isotope evidence for the intensive use of marine foods by Late Upper Palaeolithic humans. Journal of Human Evolution 49:390-394.
Richards M. P., Mays S. & Fuller B. T. 2002. Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the Medieval Wharram Percy site, Yorkshire, UK. American Journal of Physical Anthropology 119:205-210.
Richards M. P., Schulting R. J. & Hedges R. E. M. 2003. Archaeology: Sharp shift in diet at onset of the Neolithic. Nature 425:366
Rick T. C., Erlandson J. M. & Vellanoweth R. L. 2001. Paleocoastal marine fishing on the Pacific coast of the Americas: Perspectives from Daisy Cave, California. American antiquity 66:595-613.
Rindos D. 1983. The origins of agriculture. New York, Academic Press.
Russo M. 1992. Chronologies and Cultures of the St Marys Region of Northeast Florida and Southeast Georgia. The Florida Anthropologist 45:107-126.
Russo M. 1994. Why We Don't Believe in Archaic Ceremonial Mounds and Why We Should: The Case from Florida. Southeastern Archaeology 13:93-108.
Russo M. 1996. Southeastern Mid-Holocene Coastal Settlements. In: (K. E. Sassaman and D. G. Anderson, Eds) Archaeology of the Mid-Holocene Southeast. University Press of Florida, Gainesville, pp. 177-199.
Russo M. 1998 Measuring Sedentism with Fauna: Archaic Cultures Along the Southwest Florida Coast. In: (T. R. Rocek and O. Bar-Yosef, Eds) Seasonality and Sedentism: Archaeological Perspectives from Old and New World Sites. Peabody Museum Bulletin Cambridge.
Russo M., Purdy B., Newsom L. A. & McGee R. M. 1992. A Reinterpretation of Late Archaic Adaptations in Central-East Florida: Grove's Orange Midden (8vo2601). Southeastern Archaeology 11:95-108.
Russo M. & Ste. Claire D. 1992. Tomoka Stone: Archaic Period Coastal Settlement in East Florida. The Florida Anthropologist 45:336-346.
Sakae T. & Hirai G. 1982. Calcification and crystallization in Bovine Enamel. Journal of Dental Research 61:57-59.
Sassaman K. E. 2004. Complex Hunter-Gatherers in Evolution and History: A North American Perspective. Journal of Archaeological Research 12:227-280.
Saunders R. 1994. The Case for Archaic Period Mounds in Southeastern Louisiana. Southeastern Archaeology 13:118-133.
Saxe A. A. 1970 Social dimensions of mortuary practices. Ph.D. dissertation, University of Michigan, Ann Arbor.
Schoeninger M. J. 1985. Trophic Level Effects on 15N/14N and 13C/12C Ratios in Bone Collagen and Strontium Levels in Bone Mineral. Journal of Human Evolution 14:515-525.
Schoeninger M. J. 1989. Reconstructing Prehistoric Human Diet. In: (T. D. Price, Ed) The Chemistry of Prehistoric Bone. Cambridge University Press, Cambridge, pp. 38-67.
Schoeninger M. J. & DeNiro M. J. 1984. Nitrogen and Carbon Isotopic Composition of Bone-Collagen from Marine and Terrestrial Animals. Geochimica Et Cosmochimica Acta 48:625-639.

Schoeninger M. J., Deniro M. J. & Tauber H. 1983. Stable Nitrogen Isotope Ratios of Bone-Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. Science 220:1381-1383.
Schoeninger M. J. & Moore K. 1992. Bone Stable Isotope Studies in Archaeology. Journal of World Prehistory 6:247-296.
Schoeninger M. J. & Schurr M. R. 1998. Human Subsistence at Moundville: The Stable Isotope Data. In: (V. J. Knight and V. P. Steponaitis, Eds) Archaeology of the Moundville Chiefdom. Smithsonian Institution Press, Washington, D.C., pp. 120-132.
Schrire C. 1980. An inquiry into the evolutionary status and apparent idenitity of San hunter-gatherers. Human Ecology 8:9-32.
Schrire C., (Ed) 1984. Past and present in hunter-gatherer studies. Academic Press, Orlando.
Schroeder H. E. 1991. Oral Structural Biology. New York, Thieme Medical Publishers, Inc.
Schroeder S. 2001. Secondary Disposal of the Dead: Cross-Cultural Codes. World Cultures 12:77-93.
Schwarcz H. P., Buchner S. & Walker P. L. 2005. Isotopic evidence of consumption of marine foods by ancestral Chumash. American Journal of Physical Anthropology:190.
Schwarcz H. P. & Schoeninger M. J. 1991. Stable Isotope Analyses in Human Nutritional Ecology. Yearbook of Physical Anthropology 34:283-321.
Sealy J. 2006. Diet, mobility, and settlement pattern among Holocence hunter-gatherers in southernmost Africa. Current Anthropology 47:569-595.
Semple S. & Williams H. 2007 Early Medieval Mortuary Practices. Oxford, University of Oxford.
Sharp Z. D. & Cerling T. E. 1998. Fossil isotope records of seasonal climate and ecology: Straight from the horse's mouth. Geology 26:219-222.
Shearer G. & Kohl D. H. 1986. N2-fixation in field settings: Estimations based on natural 15N abundance. Australian Journal of Plant Physiology 13:699-757.
Shellis R. P. 1998. Utilization of periodic markings in enamel to obtain information on tooth growth. Journal of Human Evolution 35:387-400.
Simms S. R., Bright J. R. & Ugan A. 1997. Plain-Ware Ceramics and Residential Mobility: A Case Study From the Great Basin. Journal of Archaeological Science 24:779-792.
Smith B. H. 1991. Standards of human tooth formation and dental age assesment. In: (M. A. Kelly and C. S. Larsen, Eds) Advances in dental anthropology. Wiley-Liss, New York, pp. 143-168.
Smith B. N. 1972. Natural Abundance of the Stable Isotopes of Carbon in Biological Systems BioScience 22:226-231.
Smith B. N. & Epstein S. 1971. Two Categories of $^{13}C/^{12}C$ Ratios for Higher Plants. Plant Physiology 47:380-384.
Smith C. S. 2003. Hunter-gatherer mobility, storage, and houses in a marginal environment: an example from the mid-Holocence of Wyoming. Journal of Anthropological Archaeology 22:162-189.
Smith C. S. & McNees L. M. 1999. Facilities and hunter-gatherer long-term land use patterns: an example from southwest Wyoming. American Antiquity 64:117-136.
Sponheimer M., Passey B. H., de Ruiter D. J., Guatelli-Steinberg D., Cerling T. E. & Lee-Thorp J. A. 2006. Isotopic evidence for dietary variability in the early hominin *Paranthropus robustus*. Science 314:980-982.

Ste. Claire D. 1990. The Archaic in East Florida: Archaeological Evidence from Early Coastal Adaptations. The Florida Anthropologist 43:189-197.
Steward J. H. 1938. Basin-Plateau aboriginal sociopolitical groups. Washington, D.C., Smithsonian Institution Press.
Stiles D. 1992. The Hunter-Gatherer 'Revisionist Debate'. Anthropology Today 8:13-17.
Straight W. H., Barrick R. E. & Eberth D. A. 2004. Reflections of surface water, seasonality and climate in stable oxygen isotopes from tyrannosaurid tooth enamel. Palaeogeography Palaeoclimatology Palaeoecology 206:239-256.
Stuiver M. & Reimer P. J. 1993. Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. Radiocarbon:215-230.
Suga S. 1982. Progressive mineralization pattern of developing enamel during the mineralization stage. Journal of Dental Research 61:1532-1542.
Suga S. 1989. Enamel hypomineralization viewed from the pattern of progressive mineralization of human and monkey developing enamel. Advances in Dental Research 3:188-198.
Suga S., Aoki H., Yamashita Y., Tsuno M. & Ogawa M. 1987. A comparative study of disturbed mineralization of rat incisor enamel induced by strontium and flouride administration. Advances in Dental Research 1:339-355.
Sullivan L. P. 2001 Those Men in the Mounds: Gender, Politics, and Mortuary Practices in Late Prehistoric Eastern Tennessee. In: (J. M. E. a. C. B. Rodning, Ed) Archaeological Studies of Gender in the Southeastern United States. University Press of Florida, Gainesville, pp. 101-126.
Sydney-Zax M., Mayer I. & Deutsch D. 1991. Carbonate content in developing human and bovine enamel. Journal of Dental Research 70:913-916.
Tainter J. A. 1973 Structure and organization of Middle Woodland societies in the lower Illinois River Valley. Masters thesis, Northwestern University, .
Tainter J. A. 1975. Social Inference and Mortuary Practices: An Experiment in Numerical Classification. World Archaeology 7:1-15.
Tainter J. A. 1978. Mortuary practices and the study of prehistoric social systems. Advances in Archaeological Method and Theory 1:105-141.
Tieszen L. L. & Fagre T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO 2, bone collagen, bioapatite, and soft tissues. In: (J. Lambert and G. Grupe, Eds) Prehistoric human bone: archaeology at the molecular level. Springer-Verlag, Berlin, pp. 121–155.
Tucker B. D. 2007. The Ocmulgee/Blackshear people and the middleman hypothesis: an isotopic evaluation. Southeastern Archaeology 26:124-133.
Tucker B. D. & Krigbaum J. 2005. Was there Social Ranking at Harris Creek? Using light stable isotopes to address status, residence, and sedentism during the Middle Archaic 62nd Southeastern Archaeology Conference (SEAC) Columbia, South Carolina.
Turner B. L., Kingston J. D. & Milanich J. T. 2005. Isotopic Evidence of Immigration Linked to Status during the Weeden Island and Suwannee Valley Periods in North Florida. Southeastern Archaeology 24:121-136.
Tuross N., Fogel M. L., Newsom L. & Doran G. H. 1994. Subsistence in the Florida Archaic: The Stable-Isotope and Archaeobotanical Evidence from the Windover Site. American Antiquity 59:288-303.
van der Merwe N. J. 1982. Carbon isotopes, photosynthesis and archaeology. American Scientist 70:596-606.

Vanderklift M. A. & Ponsard S. 2003. Sources of variation in consumer-diet d 15 N enrichment: a meta-analysis. Oecologia 136:169-182.
Varien M. D. 1999. Sedentism and mobility in a social landscape: Mesa Verde and beyond. Tucson, University of Arizona Press.
Vickers W. T. 1989. Patterns of foraging and farming in semi-sedentary Amazonian community. In: (S. Kent, Ed) Farmers as Hunters. Cambridge University Press, Cambridge, pp. 46-59.
Vogel J. C. & Van de Merwe N. J. 1977. Isotopic Evidence for Early Maize Cultivation in New York State. American Antiquity 42:238-242.
Wada E. 1980. Nitrogen isotope fractionation and its significance in biogeochemical processes occurring in marine environments. Isotope Marine Chemistry:375–398.
Wandsnider L. 1992. The spatial dimension of time. In: (J. Rossignol and L. Wandsnider, Eds) Space, time, and archaeological landscapes. Plenum Press, New York, pp. 257-282.
Wanner I. S., Sosa T. S., Alt K. W. & Blos V. T. 2007. Lifestyle, occupation, and whole bone morphology of the pre-Hispanic Maya coastal population from Xcambo, Yucatan, Mexico. International Journal of Osteoarchaeology 17:253.
Warrick G. A. 1988. Estimating Ontario Iroquoian village duration. Man in the Northeast 36:21-61.
Weatherell J. A. & Robinson C. 1973. The inorganic composition of teeth. In: (I. Zipkin, Ed) Biological Mineralization. John Wiley and Sons, Inc., New York, pp. 43-74.
Wheeler R. J. & McGee R. M. 1994. Report of Preliminary Zooarchaeological Analysis: Groves' Orange Midden. The Florida Anthropologist 47:393-403.
Wheeler R. J., Newman C. L. & McGee R. M. 2000. A New Look at the Mount Taylor and Bluffton Sites, Volusia County, with an Outline of the Mount Taylor Culture. The Florida Anthropologist 53:132-157.
White C. D., Pendergast D. M., Longstaffe F. J. & Law K. R. 2001. Social Complexity and Food Systems at Altun Ha, Belize: The Isotopic Evidence. Latin American Antiquity 12:371-393.
White C. D. & Schwarcz H. P. 1989. Ancient Maya Diet - as Inferred from Isotopic and Elemental Analysis of Human-Bone. Journal of Archaeological Science 16:451-474.
White C. D., Spence M. W., Stuart-Williams H. L. Q. & Schwarcz H. P. 1998. Oxygen Isotopes and the Indentification of Geographical Origins: the Valley of Oxaca versus the Valley of Teotihuacan. Journal of Archaeological Science 25:643-655.
Widmer R. J. 1988. The Evolution of the Calusa: A Nonagricultural Chiefdom on the Southwest Florida Coast, University of Alabama Press.
Wiedemann F. B., Bocherens H., Mariotti A., Driesch A. v. d. & Grupe G. 1999. Methodological and Archaeological Implications of Intra-tooth Isotopic Variations (δ13C, δ18O) in Herbivores from Ain Ghazal (Jordan, Neolithic). Journal of Archaeological Science 26: 697-704.
Wilmsen E. 1983. Land Filled with Flies: a Political Economy of the Kalahari. Chicago, University of Chicago.
Wobst H. M. 1978. The archaeo-ethnology of hunter-gatherers, or The tyranny of the ethnographic record in archaeology. American Antiquity 43:303-309.
Woodburn J. 1980. Hunters and gatherers today and reconstruction of the past. In: (E. Gellner, Ed) Soviet and western anthropology. Duckworth, London, pp. 95-117.

Wright L. E. & Schwarcz H. P. 1998. Stable carbon and oxygen isotopes in human tooth enamel: Identifying breastfeeding and weaning in prehistory. (vol 106, pg 1, 1998). American Journal of Physical Anthropology 106:1-18.
Wyman J. 1868. An Account of the Fresh-Water Shell Heaps of the St. Johns River, East Florida. American Naturalist 2:393-403, 440-463.
Yellen J. E. 1977. Archaeological approaches to the Present: Models for reconstructing the past. New York, Academic Press.
Zazzo A., Balasse M. & Patterson W. P. 2005. High-resolution δ13C intratooth profiles in bovine enamel: Implications for mineralization pattern and isotopic attenuation. Geochimica et Cosmochimica Acta 69:3631-3642.
Zazzo A., Balasse M. & Patterson W. P. 2006. The reconstruction of mammal individual history: refining high-resolution isotope record in bovine tooth dentine. Journal of Archaeological Science 33:1177-1187.

BIOGRAPHICAL SKETCH

Bryan Tucker began his college career at Berry College in 1994. After a year at Berry, Tucker transferred to Clayton State College and University and eventually to Georgia State University, where he received a BA in anthropology in 1998. Tucker continued his education at Louisiana State University, where he received a MA in anthropology in 2003. Finally, Tucker attended the University of Florida, where he graduated with a PhD in anthropology in 2009.