

**TESTING THE SUBSISTENCE MODEL FOR THE ADOPTION OF CERAMIC
TECHNOLOGY AMONG COASTAL SAMBAQUI FORAGERS OF SOUTHERN
BRAZIL**

A Dissertation

by

MARIA SHANNON PARKS CROUCH

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Lori E. Wright
Committee Members,	Suzanne Eckert
	Ethan Grossman
	Alston Thoms
Head of Department,	Cynthia Werner

December 2013

Major Subject: Anthropology

Copyright 2013 Maria Shannon Parks Crouch

ABSTRACT

This research tests the *subsistence model* for the adoption of ceramic technology among coastal fisher-hunter-gatherers of the southern Atlantic coast of Brazil (5000 to 600 BP). The *subsistence model* correlates the appearance of ceramic vessels at coastal *sambaqui* (shell mound) sites with changes in diet and/or food processing techniques. An alternative model, *the prestige model*, argues that prehistoric populations initially use pottery as status-bearing items in competitive feasting or as serving vessels for elite group members. To test the *subsistence model*, I conducted a stable carbon and nitrogen isotope analysis and a dental microwear texture analysis using skeletal remains from *sambaqui* sites located in Santa Catarina and Rio de Janeiro, Brazil.

The results of the stable carbon isotope analysis indicate no significant difference between Pre-Ceramic and Ceramic occupations when all individuals were considered. However, when only sexed individuals were considered, males of the Pre-Ceramic period show greater consumption of marine foods than Pre-Ceramic occupation females. This difference between males and females is not significant for the Ceramic period. Results of the nitrogen isotope analysis indicate a significant increase in the consumption of marine foods among all individuals during the Ceramic period compared to the Pre-Ceramic period.

The results of the dental microwear texture analysis indicate no significant difference between the Pre-Ceramic and Ceramic periods when all individuals were

considered. However, Pre-Ceramic occupation males show significantly greater tooth enamel complexity (*Asfc*) than males of the Ceramic period. I found no statistically significant differences between time periods for anisotropy (*epLsar*); however, a plot containing *epLsar* measurements and nitrogen isotope ratios reveals a relationship between the data. Individuals from the Ceramic period tend to plot lower for measurements of anisotropy and higher for marine food consumption, while Pre-Ceramic occupation individuals plot higher for anisotropy and lower for marine food consumption.

This study partially supports the *subsistence model* for the adoption of ceramic technology at *sambaqui* sites, as tests show significant differences based on sex. However, there is room in the data to explore ideas related to changes in social and political organization with the arrival of ceramic technology at these sites.

ACKNOWLEDGEMENTS

A great many people supported me throughout this process, and I feel tremendous gratitude for each person mentioned here. I especially want to thank Lori Wright. Dr. Wright has taught me many things, including how to prepare bone samples for stable isotope analysis, make dental casts, identify bone pathologies, and think critically about a research problem, but she has also shown me steady, unflinching encouragement that has made a profound difference for me, particularly during the past several years. Thank you, Lori.

I want to thank my husband Mike for listening to me talk for hours and hours about nitrogen isotope ratios, hunter-gatherers, and dental microwear. Thank you for being so understanding and supportive on weekends that I had to write, and evenings that I had to work, and thank you for making sure I ate something. You have done everything possible to help me finish my work, and you have kept me on an even keel. I also want to thank my boys, William and Wyatt, for offering me comic relief at the end of a long day of writing, as well as trips to the park and the ice cream shop. Your laughter makes everything worthwhile.

My parents, Doug and Karen Parks, have supported me in every aspect of my life, and I could not have finished this dissertation without their help. They have seen me through the thick and thin, and I thank them for their constant encouragement and love.

My sister, Anna Lee McNelis, phoned me nearly every day for the past year to hear how I was doing and to listen to me talk about this dissertation. She has offered me sound advice, as well as made me laugh, and she has made this process so much easier for me, in turn.

I want to thank Sheila Ferraz Mendonça de Souza for helping facilitate much of the paperwork that was needed to complete this study, as well as welcoming me to the Nation Museum of Rio de Janeiro to conduct my work. I also thank Dione Bandeira of the Museu Arqueológico de Sambaqui de Joinville for helping me with the collections and discussing *sambaqui* research with me.

I thank my committee members, Ethan Grossman, Alston Thoms, and Suzanne Eckert for their thoughtful input on my work and their valuable advice during this process. Thank you for your time and patience. I also thank my former committee member, Dr. Robson Bonnichsen, for his help facilitating my early research in Brazil, and making everything possible.

Janaina Santos, thank you for helping me navigate the city of Recife and becoming one of the best friends I have ever had. I met Janaina through Heleno Licurgo Amaral, a good friend and colleague who has been of tremendous help to me for my work in Brazil. I also thank Noeli Pertile, who offered to house me over the summer in Florianópolis and guide me through the city those first few days. Thank you all for your friendship.

To my cohorts and friends Cassady Yoder Urista and Eric Bartelink: thank you for your encouragement and support, and for helping me process some of my collagen

samples when I had no time left to spare. You really came through for me, and I thank you deeply for your help. Cassidy and Andy Scherer, our years at A&M as great friends and roommates are some of my happiest. Eric, your enthusiasm for anthropology is contagious, and you are one of the most generous persons I know.

Dr. Stan Vitha, thank you for all of the hours you spent training me in the microscopy lab, and for all of your effort to help make my project work.

Dr. Kristen Krueger, thank you for your expertise and willingness to execute the confocal microscopy and assist with the texture analysis; your input was invaluable, and I could not have completed the microscopy without your help.

I also thank Katie Custer, who helped me clean bone samples in the stable isotope lab, and Piotrek Bojakowski, who helped me keep my collagen samples safely frozen in the conservation lab. Katie and Piotrek, thank you for opening your home to me those nights I had to work in the lab.

I also thank Sheela Athreya and Masha Sukovic for allowing me to stay in their homes while I was traveling between College Station and Austin. Thank you, as well, to Ryan and Jill Dewey.

To all of my friends and colleagues in the Department of Anthropology at Texas A&M University, and the University Writing Center, thank you for the community, the exchange of ideas, and the engaging, and sometimes raucous, conversations. This is what it is all about.

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENTS	vii
LIST OF FIGURES	x
LIST OF TABLES.....	xii
CHAPTER I INTRODUCTION.....	1
What are <i>Sambaquis</i> ?.....	2
Research Models, Hypotheses, Expectations.....	3
Overview of the Dissertation.....	6
CHAPTER II THE ADOPTION OF CERAMIC TECHNOLOGY, HUNTER- GATHERER COMPLEXITY, AND COASTAL ADAPTIONS	8
The Research Model	8
Utilitarian Properties of Pottery	9
Feasting and Social Networks	12
Sedentism and the Adoption of Pottery	16
Complex Hunter-Gatherers: What Defines Complexity?.....	18
Coastal Adaptations and Recent Case Studies	27
CHAPTER III PALAEOENVIRONMENTAL RESOURCES OF SOUTHERN BRAZIL.....	33
Description of the Study Area	34
Palaeoenvironment of Coastal Southern Brazil.....	35
Vegetation and Climate Change.....	39
Plant Resources	42
Animal Resources	45
Origin and Spread of Cassava and Maize into South America	48
CHAPTER IV SAMBAQUI ARCHAEOLOGY	54
Archaeological Sites of the Study Area.....	55

Pottery Recovered from <i>Sambaqui</i> Sites	59
Stone Tools, Fish Hooks, Bone Tools, Net Weights, and Perforated Teeth	64
Theoretical Debates and Recent Research.....	70
CHAPTER V STABLE CARBON AND NITROGEN ISOTOPE ANALYSIS:	
RESEARCH METHODS AND LITERATURE REVIEW	80
Carbon and Nitrogen Isotope Fractionation and the Relationship to Diet.....	81
Carbon Isotope Analysis: Early Research and Current Applications	87
Nitrogen Isotope Analysis: Early Research and Current Applications.....	93
Stable Carbon and Nitrogen Isotope Analysis and Bioarchaeology	99
CHAPTER VI PALEODIETARY ANALYSIS USING STABLE CARBON AND	
NITROGEN ISOTOPES: DATA COLLECTION, RESULTS AND DISCUSSION.....	
Research Expectations	103
The Dataset	105
Collagen Sample Preparation	110
Evaluation of the Collagen Sample.....	112
Apatite Sample Preparation	116
Results: Pre-Ceramic and Ceramic Occupation $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ Comparisons.....	118
Paleodietary Analysis.....	127
Discussion.....	130
CHAPTER VII DENTAL MICROWEAR ANALYSIS: LITERATURE REVIEW	
AND RESEARCH METHODS.....	
Biomechanics: Mastication and Dental Anatomy.....	(00000)134
Methodological Considerations of Dental Microwear and Diet:	
Experimental Designs	(00000) 142
Dental Microwear: Analytical Techniques	(00000).. 145
3D Imaging Technology and Dental Microwear Analysis	(00000)150
Dental Microwear: Bioarchaeological Applications in Anthropology	(00000) 167
Dental Microwear Analysis: Taphonomic Considerations.....	(00000). 180
CHAPTER VIII DENTAL MICROWEAR TEXTURE ANALYSIS: DATA	
COLLECTION, RESULTS AND DISCUSSION.....	
Research Expectations	(000000). 183

The Dataset	(000000)	184
Data Collection: Methods	(000000)	186
Results: Measurements of Complexity (<i>Asfc</i>)	(000000)	191
Results: Measurements of Directionality (Exact Proportion Length-Scale Anisotropy of Relief, or <i>epLsar</i>)	(000000)	198
Dental Microwear Texture Analysis and Stable Isotope Analysis	(000000)	205
Discussion	(000000)	207
CHAPTER IX DISCUSSION AND SUMMARY		210
Summary of Isotope Analysis and Dental Microwear Analysis Results ..	(000000)	211
Stable Carbon and Nitrogen Isotope Analysis: Discussion	(000000)	213
Dental Microwear Analysis: Discussion	(000000)	216
Social Implications for the Adoption of Pottery	(000000)	220
Limitations of the Present Study	(000000)	223
Contribution of the Study	(000000)	223
Suggestions for Further Research	(000000)	224
Summary	(000000)	224
REFERENCES CITED		228

LIST OF FIGURES

FIGURE	Page
4.1. São Francisco do Sul Island, Santa Catarina.....	58
4.2. Santa Catarina Island, Santa Catarina.....	58
4.3. Sites from the Study Area.....	59
4.4. A Collection of Reconstructed Itataré Pottery from Laranjeiras II (Schmitz et al. 1993).....	62
4.5. Bone Projectile Points from Tapera (Silva et al. 1993).....	67
4.6. Fish Hooks Made out of Mammalian Bone from Forte Marechal Luz (Bryan 1993).....	68
4.7. Perforated Shark and Mammal Teeth from Tapera, Including (<i>Galeocerdo cuvier</i> (Tiger shark), <i>Odontaspis Taurus</i> (Sand Tiger shark) and <i>Carcharodon carcharias</i> (Great White shark) (Silva et al 1990).....	69
6.1. A Plot of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from Bone Collagen Shows a Positive Relationship between Isotope Signatures (Pearson's $r=.620$, $p=.01$).....	122
6.2. Nitrogen and Carbon Isotope Values of Collagen for Plant and Animal Resources (after Tykot 2006).....	123
6.3. Relationship between $\delta^{13}\text{C}_{\text{AP}}$ and $\delta^{13}\text{C}_{\text{COL}}$ Following the Model by Kellner and Schoeninger (2007).....	130
7.1. Drawing of a Mandibular Molar Showing Relevant Facets x, 9, and 10n (from Kreuger et al. 2008).....	137
8.1. Surface Features from the Center Enamel of M^1 from Morro de Ouro, Burial 1, Adult of Indeterminate Sex; $Asfc=1.25$, $epLsar=.0052$; 204x276 microns.....	188

FIGURE	Page
8.2. Surface Features from Facet x of M ¹ from Forte Marechal Luz, Burial 6, Adolescent of Indeterminate Sex; <i>Asfc</i> =2.61, <i>epLsar</i> =.0024; 204x276 microns.....	189
8.3. Surface Features from Facet 9 of M ¹ from Itacoara, Burial 2, Young Adult Male; <i>Asfc</i> =.77, <i>epLsar</i> =.0059; 204x276 microns.....	189
8.4. Mean <i>Asfc</i> by Archaeological Site (All Enamel Surfaces and Tooth Types).....	192
8.5. Mean <i>epLsar</i> by Archaeological Site (All Enamel Surfaces and Tooth Types).....	200
8.6. Plot of <i>epLsar</i> Median Measurements and Nitrogen Isotope Values for Pre-Ceramic and Ceramic Time Periods.....	206

LIST OF TABLES

TABLE	Page
3.1. Palm Remains Found at Coastal Archaeological Sites in Rio de Janeiro.....	45
4.1. Archaeological Sites of the Study Area and Their Location, Radiocarbon Dates (BP, uncalibrated), Time Period, and Museum Collection.....	56
6.1. Skeletal Sample Information and Data.....	105
6.2. Sample Quality Indicators for Bone Collagen, Including C/N Ratio, % C, % N, and % CY (Collagen Yield).....	114
6.3. Mean and S.D. of $\delta^{13}\text{C}_{\text{CO}}$, $\delta^{13}\text{C}_{\text{AP}}$, $\Delta^{13}\text{C}_{\text{CA-CO}}$, and $\delta^{15}\text{N}$ for Pre-Ceramic and Ceramic <i>Sambaqui</i> Sites.....	118
6.4. Mann Whitney U Comparing $\delta^{13}\text{C}$ from Collagen between Pre-Ceramic and Ceramic Occupations.....	119
6.5. Mann Whitney U Comparing $\delta^{13}\text{C}$ from Apatite between Pre-Ceramic and Ceramic Occupations.....	120
6.6. Mann Whitney U Comparing $\delta^{15}\text{N}$ from Bone Collagen between Pre-Ceramic and Ceramic Occupations.....	121
6.7. Mann Whitney U Comparing $\Delta^{13}\text{C}_{\text{CA-CO}}$ between Pre-Ceramic and Ceramic Occupations.....	124
6.8. Comparison of $\delta^{13}\text{C}$ from Collagen between Males and Females.....	125
6.9. Comparison of $\delta^{13}\text{C}$ from Apatite between Males and Females.....	125
6.10. Comparison of $\delta^{15}\text{N}$ from Collagen between Males and Females.....	126
6.11. Comparison of $\Delta^{13}\text{C}_{\text{CA-CO}}$ from Collagen between Males and Females.....	127

TABLE	Page
8.2. Measurements of <i>Asfc</i> and <i>epLsar</i> According to Site and Period.....	190
8.3. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Comparing Pre-Ceramic and Ceramic Groups Using all Enamel Surfaces and Tooth Types.....	193
8.4. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Using Facet x and All Tooth Types.....	195
8.5. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Using Facet 9 and All Tooth Types.....	195
8.6. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Using M ¹ Only and All Surface Enamel Types.....	197
8.7. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Using M ² Only and All Surface Enamel Types.....	197
8.8. Mann-Whitney U Test of Complexity (<i>Asfc</i>) Comparing Males and Females Using all Enamel Surfaces and Tooth Types.....	198
8.9. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) Using All Enamel Surfaces and Tooth Types.....	201
8.10. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) Using Facet x and All Tooth Types.....	202
8.11. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) Using Facet 9 and All Tooth Types.....	202
8.12. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) Using M ¹ and All Enamel Surfaces.....	203
8.13. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) of M ² and All Enamel Surfaces.....	203

TABLE	Page
8.14. Mann-Whitney U Test of Anisotropy (<i>epLsar</i>) Comparing Males and Females.....	204

CHAPTER I

INTRODUCTION

For thousands of years, groups of fisher-hunter-gatherers exploited abundant marine and terrestrial resources along the Atlantic coast of South America and constructed large shell mounds, called *sambaquis*, where people built villages and buried their dead. This research tests the *subsistence model* for the adoption of ceramic technology among maritime hunter-gatherer groups, and provides a comprehensive study of coastal forager diet in southeastern Brazil from 5000 to 600 BP. Pottery first appeared at *sambaqui* sites 1000 years ago, with no other evident change in technology (Prous 1991). Using stable carbon and nitrogen isotope analysis and dental microwear texture analysis, I investigate the exploitation of food resources before and after the adoption of ceramic technology at *sambaqui* sites. I chose to use a two-pronged approach when asking my research questions, because each method had the potential to explain different aspects of paleodiet: the isotope analysis helps answer the ‘what’ of what was eaten, and the texture analysis helps answer the ‘how’ of what was eaten. Due to the occupational history and environmental stability of this region, coastal forager groups of the Atlantic coast of Brazil are a test case for testing anthropological problems related to the sociopolitical and economic correlates of pottery at prehistoric sites, and the emergence of complexity among hunter-gather populations.

What are Sambaquis?

Brazilian *sambaquis* are shell mounds, the largest of which are found in the state of Santa Catarina, that are composed of stratified layers of shell, sediment, and faunal remains (De Blasis et al. 1998). They were built by fisher-hunter-gatherers of the Atlantic coast of Brazil beginning at least 5000 years ago, and continuing until about 600 BP. The shell mounds vary in size from about 2 to 30 meters in height; the largest of the mounds measure hundreds of meters at its base (Bryan 1993). Though *sambaquis* can vary in their composition, evidence shows that they were commonly used as burial grounds, places of habitation, and cooking. Artifacts recovered from these sites include those associated with subsistence (fish hooks, bone projectile points, net weights, hammerstones) and those associated with ornamentation and art (shark tooth pendants, mammalian tooth pendants, shell beads). All types of artifacts have been found in burial contexts (Barreto 2005; Fish et al. 2000; Gaspar 1998). Studied from the 1950s, and continuing to today, archaeological investigations have demonstrated that these coastal groups relied heavily on fish and shellfish for their subsistence for millennia (Beck et al. 1970; Bryan 1977, 1993; Chmyz 1976; Figuti 1993; Hansel 2004; Kneip 1987; Neves and Weselowski 2002; Tiburtius and Bigarella 1953).

The environment of the southern Atlantic coastal states of Santa Catarina and Rio de Janeiro is characterized by a mosaic forest that commonly contains swamplands, called *restinga*, in Brazil. Based on a macrobotanical study of charcoal fragments from six *sambaquis* (5500-1400 BP) in the state of Rio de Janeiro, Scheel-Ybert (2000, 2001) concluded that the ecosystem along the Atlantic coast has remained stable throughout

prehistoric occupation to the present, with the exception of minor fluctuations in mangrove vegetation. Each of the archaeological sites used for the proposed research are located along the coast and, while each site is environmentally rich and locally variable, coastal foraging groups enjoyed access to plant and animal resources of the forest, ocean, mangrove swamps, estuaries, bays, streams, and rivers throughout the region.

Research Models, Hypotheses, and Expectations

Some researchers argue that maritime fisher-hunter-gatherer groups display greater social complexity than foragers who live in marginal inland environments due to high resource abundance and predictability of the coastal environment (Hayden 1995; Perlman 1980; Renouf 1984; Yesner 1980). Defining “complexity” is difficult, however (Gould 1985; Sassaman 2004). Some see a correlation between resource base, sedentism, high population densities, and the development of social complexity (Price and Brown 1985; Yesner 1984), and argue that these traits, as well as territorial markers associated with some maritime foraging groups, suggest social inequality (Scheinsohn 2003; Yesner 1980). Arnold (1996) argues that none of these correlates can necessarily be used to infer complexity; prehistoric groups are only “complex” when a few individuals maintain economic power over non-kin and this power is inherited. Pre-ceramic foragers from coastal Brazil thrived in a resource-rich environment for thousands of years (Scheel-Ybert 2000, 2001), were sedentary (De Masi 1999), and constructed shell mounds that might be interpreted as symbols of social hierarchy (De Blasis et al. 1998; Gaspar 1992, 1996, 1998).

The adoption of ceramic technology by prehistoric populations is often correlated with sedentism and the practice of agriculture (Braun 1987; O'Brien 1987; Pratt 1999; Sassaman 1993; Willey 1966). According to Pratt (1999), archaeological models that aim to explain why foragers incorporate ceramic technology into their economic systems include the cooking/food processing model (Arnold 1985; Braun 1987; O'Brien 1987; Reid 1989), the storage model (Keeley 1988; Testart 1982), and the prestige value/competitive feasting model (Barnett 1990; Clark and Blake 1994; Hoopes 1995; Rice 1999). These interpretive models are largely based on analyses of group mobility, resource type and availability, archaeological context of vessels, and vessel form, thickness, decoration, size, temper, and frequency (Pratt 1999).

This research tests the *subsistence model* for the adoption of ceramic technology among prehistoric coastal groups of southeastern Brazil. The *subsistence model* correlates the appearance of ceramic vessels at hunter-gatherer sites with changes in diet and/or food processing techniques (Arnold 1985; Eerkens 2003, 2004; O'Brien 1987; Reid 1989), while the *prestige model* argues that prehistoric groups initially use pottery as status-bearing items in competitive feasting or as serving vessels for elite members of the group (Barnett 1990; Clark and Blake 1994; Hoopes 1995; Rice 1999). To determine if changes in coastal forager diet occurred after the introduction of pottery, I will analyze and compare human skeletal material from Pre-Ceramic and Ceramic occupations of *sambaqui* sites from Santa Catarina and Rio de Janeiro using stable carbon and nitrogen isotope ratios and patterns of dental microwear.

Stable carbon and nitrogen isotope ratios of human skeletons allow for the investigation of changes in marine and terrestrial resource procurement through time. Carbon isotope ratios from bone apatite reflect the whole diet of an individual, including carbohydrates, proteins, and lipids, and those from bone collagen primarily reflect the protein portion of the diet (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993). Nitrogen isotope ratios reflect the trophic level of the protein source, which allows one to distinguish marine from terrestrial foodwebs (Schoeninger and DeNiro 1984; Schwarcz et al. 1985). I expect $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ collagen values from Pre-Ceramic occupations in Santa Catarina to indicate a heavy reliance on marine resources, as well as to closely correspond to the average isotope values that have been reported for Pre-Ceramic *sambaqui* occupations in this region ($\delta^{13}\text{C}$ of $-11.8 \pm 1.04\text{‰}$ and $\delta^{15}\text{N}$ of $15.7 \pm 1.71\text{‰}$) (De Masi 1999). If coastal groups significantly altered their diet concurrent with the adoption of ceramic technology, then I should observe changes in carbon and nitrogen isotope ratios. This work is among the first to analyze stable carbon and nitrogen isotope ratios from bone collagen and apatite for coastal foragers in Brazil, which will provide greater dietary resolution regarding sources of plant foods and animal proteins before and after the introduction of pottery.

In conjunction with stable carbon and nitrogen isotopes, an analysis of dental microwear increases the interpretive power of paleodietary data. The use of dental microwear texture analysis will determine if changes in diet or food processing occurred between the Pre-Ceramic and Ceramic occupations at *sambaqui* sites. Dental microwear texture analysis is an analytic method that allows for 3D measurements of the tooth

surface, repeatability, and a lower rate of observer error than conventional microwear studies (Scott et al. 2005). This study is also among the first to use stable isotope analysis and dental microwear methods together to explore complementary aspects of diet—chemical composition and texture—which allows one to distinguish cooking and processing techniques from the actual foods eaten.

If significant changes in isotope ratios and dental microwear are observed after the introduction of pottery, then the *subsistence model* is supported. If significant changes in dental microwear are observed *without* changes in stable carbon and nitrogen isotopes, then the *subsistence model* is also supported, as pottery may be correlated to changes in food processing techniques. If *no* significant changes in carbon and nitrogen isotopes or dental microwear are observed between the Pre-Ceramic and Ceramic occupations, then the *prestige model* for the adoption of ceramic technology should receive more consideration.

Overview of the Dissertation

Chapter II focuses on the theoretical framework of this dissertation, paying close attention to models of pottery adoption among hunter-gatherer populations, complex hunter-gatherer groups, and physical properties of ceramic technology and their corresponding manner of use for a society. Chapter III discusses the environmental resources and paleoenvironmental conditions of southeastern Brazil, and the introduction of maize and manioc as cultivars into the broader region. I also discuss specific plant and animal resources that have been recovered from *sambaqui* sites. In Chapter IV, I offer a review of *sambaqui* archaeological and bioarchaeological studies that pertain to the

research interests of this dissertation, and discuss the recent findings from particular sites that are used in this study.

In Chapter V, I review the development and use of stable carbon and nitrogen isotope analyses for bioarchaeological research, and discuss some recent research that is relevant to this study. Chapter VI offers an analysis of the stable carbon and nitrogen isotope data presented in this work, and a brief discussion of the results. Chapter VII presents a review of dental microwear analysis and its methodological development, as well as its role in bioarchaeological research and the application of 3D analysis in recent studies. In Chapter VIII, I present the results of the dental microwear texture analysis that I completed on individuals from *sambaqui* archaeological sites, and briefly discuss the results. Chapter IX offers a discussion and summary of the paleodietary research presented in this dissertation, and relates these results to previous studies in the field. Based on the findings of this research, I hope to contribute to the fields of paleodiet, hunter-gatherer archaeology, and theories related to the adoption of pottery, resource use, and social organization among coastal foragers.

CHAPTER II

THE ADOPTION OF CERAMIC TECHNOLOGY, HUNTER-GATHERER COMPLEXITY, AND COASTAL ADAPTATIONS

In this chapter I discuss anthropological theory related to the adoption of ceramic technology and the attributes of complex hunter-gatherer societies. I examine theories and case studies surrounding the adoption of pottery among a wide range of cultures, and focus particularly on the use of pottery for cooking/food processing and feasting vessels. I describe the physical properties of ceramics that are found in utilitarian and ritual contexts for different archaeological groups. I also explore the concept of ‘complexity’ among archaeological researchers. The idea of what constitutes ‘complexity’ among foragers varies among archaeologists, with some placing emphasis on the environment as causative, while others look to technological innovations as driving change. Still others argue that complexity is formed through social and economic relationships within and outside of the group. Understanding different theoretical points of view regarding complexity, as well as the physical, utilitarian, and socioeconomic reasons for adopting ceramic technology aids in the understanding of coastal *sambaqui* populations of Southeastern Brazil, the focus of this work.

The Research Model

A prevailing model in anthropological theory correlates the adoption of pottery by prehistoric groups with sedentism and the practice of agriculture. Proponents of this *subsistence model* argue that the appearance of ceramic vessels at hunter-gatherer sites

indicates a change in diet and/or food processing techniques (Arnold 1985; Eerkens 2003, 2004; O'Brien 1987; Reid 1989). Other researchers support a *prestige model*, whereby foragers use pottery as status-bearing items in competitive feasting or as serving vessels for elite members of the group (Barnett 1990; Clark and Blake 1994; Hoopes 1995; Rice 1999). Archaeological investigations of coastal foragers in Brazil lend indirect support for the *prestige model* due to: [1] evidence for an emerging political elite at *sambaqui* sites (Barreto 2005; De Blasis et al. 1998; Fish et al. 2000; Gaspar 1998); [2] stability of natural resources through time (Scheel-Ybert 2001); and [3] stability in health through time (Neves and Wesolowski 2002), where elsewhere health tends to decline with the introduction of agriculture (Larsen 1995). However, the *subsistence model* is supported by [1] craniometric evidence for a genetic contribution by outsiders to coastal populations at 1000 BP, when pottery, and possibly agriculture, appeared in the archaeological record (Neves and Cocilovo 1989); [2] archaeological associations of unfired and fired vessels with boiling stones, unburned fish bones, and possible food encrustations on the interior of some potsherds (Bryan 1993); and [3] the characteristics of coastal forager pottery, which mainly consists of small, thick-walled, and undecorated bowls and jars (Beber 2004; Bryan 1993; Prous 1991). These vessel characteristics are most closely associated with cooking and food processing, while prestige ware is often highly decorated and thinner-walled (Pratt 1999; Rice 1999).

Utilitarian Properties of Pottery

What are the technological benefits of using pottery instead of basketry, gourds, or other containers for cooking and storage? Though one can boil water or other foods

using basketry, stone, animal hide, or wood containers, pottery can be placed directly on the fire. Using pottery is less time consuming and labor intensive than boiling foods using hot rock technology (Arnold 1985; Sassaman 1995). In addition, temperature control is improved with the use of ceramic technology, as food is not being placed directly on the fire, or dependent upon the shifting temperatures of hot stones. Many foods must be treated by heating or cooking to remove toxic elements, such as protease inhibitors (found in corn, potatoes, peanuts, oats, and soybeans) and cyanogenic glucoside (found in manioc, sweet potato, millet, and lima beans). Manioc, for example, needs to be chopped up, soaked in water, and boiled before being edible (Arnold 1985). Again, though pottery is not necessary for heat treating foods, the ability to boil and steam plant foods is less time consuming and more efficient with ceramic technology.

In a discussion of the social implications of adopting ceramic technology, Sassaman (1995) argues that people in the Savannah River valley of the Southeastern part of North America used the earliest semi flat-bottomed pottery to indirectly cook foods by “moist cooking” with soapstone, rather than place the ceramics directly on the fire. Though direct cooking over the fire is preferable for many tasks related to cooking, indirect cooking (or stone boiling) is better for processing bones and meat for the grease. Sassaman (1995) notes that fiber-tempered pottery with thick walls, a flat bottom and high orifice to volume ratio are the hallmarks of pottery used for indirect cooking methods. Meanwhile, ceramics that display thin walls, sand temper, round bottoms, and low orifice to volume ratio are associated with direct cooking. The foods most likely to be cooked using indirect methods includes nuts (for the oils), meat and bones (for the

grease), and shellfish (Sassaman 1995). Hoopes (1995) also discusses the merits of indirect cooking with pottery for the production of palm oil at Central American archaeological sites: “Pots would have been more durable than gourds in the extraction of palm oil through indirect stone boiling”. However, he goes on to say that even more oil could be produced by processing palms over direct heat (Hoopes 1995).

Eerkens (2004) attributes the early, mineral-tempered, and thin-walled pottery that appeared in Great Basin archaeological contexts after 600 BP to an intensified use of small seeds by boiling. This pottery was made for cooking, not for storage or to transport goods, and the author suggests that this technology served a utilitarian function in private households as well as a socioeconomic purpose. Because seeds were widely available to everyone in the community, they were not a resource that would be subject to sharing with the rest of the group. Therefore, individual households could boil and process their own seeds, and maintain ownership and control over this particular resource.

Pottery is also an indispensable technology for griddling and toasting foods, as well as producing fermented beverages (Arnold 1985). Ceramics may also be used for “dry cooking”, whereby foods are baked, broiled, roasted, and parched (Rice 1999). Other advantages of pottery include the inherent plasticity of clay that allows for any needed or desired vessel shape, porous walls that allow for the imparting of flavor to food, evaporative qualities (through the porous walls) that allow for the cooling of liquids (especially water), the ability to seal the clay through glazing, durability and reusability, and relatively cheap and common source material (Arnold 1985).

In general, ceramic studies that examine the form and function of pottery conclude that vessels used for *cooking*: [1] contain coarse temper and have thick or thin walls, depending on cooking method, [2] are undecorated, and [3] occur in high frequency in archaeological contexts. Pottery used for *food processing*, such as oil extraction and soaking, tends to have: [1] coarse temper and thick and dense walls, [2] no decoration, and [3] high frequency in archaeological contexts. Vessels used for *storage* have: [1] variable temper and thin walls [2] variable decoration, and [3] low archaeological frequency. *Feasting* ware is: [1] variable in temper and wall thickness, [2] decorated, and [3] low in frequency in the archaeological record (Pratt 1999; Rice 1987).

Feasting and Social Networks

Though one may be inclined to think of pottery solely in terms of utilitarian function and economic efficiency, the early use of ceramic technology is strongly intertwined with socioeconomic networks and feasting (Hayden 1995; Hoopes 1995; Sassaman 1995). In addition to their strictly technological and utilitarian uses, ceramics may also be used to communicate ideology through decoration or form, to be played as musical instruments, to be employed as ritual serving vessels, or to be included as grave goods (Arnold 1985). Sassaman (1995) particularly argues that it is impossible to examine the adoption of a new technology, such as pottery, without first considering the social implications for a group. For early pottery-using populations in the Savannah River valley, soapstone for indirect cooking was imported from a neighboring group. Maintaining a trade relationship was crucial, he argues, even in the face of a more efficient replacement technology; direct cooking with pottery, rather than using indirect

soapstone boiling, became a social and political issue rather than just a technological issue (Sassaman 1995). Concomitant with a change in technology is a change in social relationships and networks.

Clark and Blake (1994), rather than espouse an ecological model for the emergence of social inequality, assert that hierarchy is an unintentional by-product of societies organized around 'aggrandizers', individuals with the personalities and access to local and regional resources to attract followers and gain political power. They examine the emergence of inequality through an economy based on prestige, competitive feasting, and reciprocity. To illustrate this model, the authors discuss a prehistoric chiefdom in the Mazatan region of Chiapas, Mexico, and the manner in which the appearance of ceramic technology in this area coincided with maize cultivation, population growth, and a socially ranked society (Clark and Blake 1994).

Soconusco is a section of southern coastal Chiapas that contains the region of Mazatan, an area abundant in terrestrial fauna, plants, and coastal plain resources (Clark and Blake 1994). During the Barra phase (1550 to 1400 BC) of this region, the first pottery appears, along with evidence for settled village life. By the beginning of the Locona phase at 1400 BC, marked social distinctions are observed, including distinctions in elite and non-elite household structures, mortuary practices, and access to luxury goods (Clark and Blake 1994). The earliest pottery recovered from this region is a finely decorated ware that is grooved, incised, and impeccably finished, with thin walls. The vessels, many of them flat-bottomed *tecomates* (neck-less bowls), mimicked the appearance of gourds. Due to the level of sophistication, this pottery was likely imported

from another region, or a specialist may have been brought in to produce it at the local level. The innovative technology was created for aggrandizers to impress others at competitive feasts, the authors argue, but was not meant for cooking (Clark and Blake 1994). Instead, the *tecomates* were likely used to prepare and serve liquids. Utilitarian ware has never been found during the Barra phase, but appears during the subsequent Locona phase, along with a decline in the quantity of fire-cracked rock. This suggests that, along with fine pottery, utilitarian pottery is being used for cooking over direct heat during this later phase. The early presence and appearance of maize, as well as stable carbon isotope evidence, suggests that corn did not play a large role in the diet, but was cultivated as a plant for feasting beverages. Aggrandizers are motivated by competition for followers and the innovations that will attract even more followers, more laborers, and more production of craft items or goods that will cement their place in the local or regional polity. In time, status differences become entrenched, and a hierarchy is established (Clark and Blake 1994).

The earliest pottery known from Colombia dates to 5900 BP, and remained largely unchanged for almost 600 years. Located in a small, alluvial plain of northwestern Colombia, with access to freshwater streams, the mobile inhabitants of San Jacinto I exploited shellfish, hunted game, and collected seeds. The thin-walled, fiber tempered, and decorated pottery that they made showed no evidence to support its use as a tool for cooking (Oyuela-Caycedo 1995; Pratt 1999). Though organic temper is usually associated with indirect methods of cooking, pottery from San Jacinto I had relatively small orifices that would make the transfer of hot stones in and out of the

vessels impractical; in addition, Oyuela-Caycedo (1995) demonstrates that almost none of the fire cracked rock (associated with indirect cooking) is associated with pottery at San Jacinto I. There is also no sign on the outside of the containers, such as charring or soot, that indicates the ceramics were ever placed directly on the fire. Pottery from the site was highly decorated, often with shapes representing living creatures, and displayed elaborate handles. After evaluating its use in terms of the three most often cited purposes for ceramics (cooking, storage, or feasting), researchers posit that San Jacinto I pottery served a social function for feasting and serving, and possibly as small storage vessels for collected seeds (Pratt 1999).

Hoopes (1995) explores the idea of competitive feasting as a model for the adoption of ceramic technology in the Central American isthmus. Early pottery archaeological sites in Panama, Costa Rica, and Nicaragua are associated with root crops, such as manioc, and tree crops, such as palm. In Panama, the earliest use of ceramics (Monagrillo pottery dated to 4800 BP) is not associated with an intensification of any type of crop; however, the earliest maize phytoliths appear at the same time as Monagrillo pottery, and coastal settlements become larger at this time. Hoopes (1995) presents a model whereby prehorticultural, hunter-gatherer groups develop ceramic technology as a way to enhance social relationships and exchange between groups, both sedentary and non-sedentary, that further enriches the subsistence base of each participating population. The author especially notes the positive subsistence and exchange relationship that could exist between coastal and inland populations, whereby a surplus of animal protein would have “motivated hunters and fishers to utilize ceramics

to prepare and transport protein resources for exchange” with a horticultural population (Hoopes 1995:195).

Hoopes (1995) notes that his model is similar to the competitive feasting model presented by Hayden (1990), which is based on the principle that individuals with access abundant resources, such as shellfish, fish, fruit, and seeds, are able to accumulate resources and participate in competitive feasting activities without risk to the overall well-being of the group, and that these resource-rich groups are also more likely than marginal societies to develop horticulture. In a further discussion of the emergence of prestige, Hayden (1995) asserts that the initial development and spread of pottery likely developed among complex hunter-gatherer groups and horticultural groups that practiced competitive feasting, and for whom social inequality was already established or in the process of being established. Rice (1999), when discussing one of the main roles cited for pottery, storage, astutely observes, “from the viewpoint of the feasting and social models of pottery origins, it may be more appropriate to think in terms of pottery containers for short term “accumulation” rather than long term “storage””. Further, she suggests that, due to the small size of pottery and the general lack of sooting on the exterior of these vessels, people likely used early pottery to serve drinks, stews, soups and oils at community gatherings (Rice 1999).

Sedentism and the Adoption of Pottery

One of the strongest correlations of pottery-bearing societies is that they are sedentary; in fact, some semi-nomadic and nomadic groups did made pottery (Arnold 1985; Rice 1999). Conversely, some sedentary groups, such as some in the Pacific

Northwest, do not ever adopt or develop ceramics. Arnold (1985) argues that, though sedentism allows for the time necessary to go through the steps of making pottery, such as forming, drying, and firing, a sedentary population may lack the natural resources to do so effectively; water and appropriate clay need to be locally available to a group, and the climate needs to be dry enough to support its manufacture. Some semi-sedentary pottery-making groups, such as those in the Great Basin, took advantage of excellent climate conditions and made pottery seasonally, when resources were available. Non pottery-bearing sedentary groups, such as those mentioned in the Pacific Northwest, experienced unfavorable environmental conditions for making pottery (Arnold 1985). Therefore, the groups most likely to manufacture pottery are fully sedentary (which provides the most positive feedback relating to time), have access to the appropriate natural resources, and live in a climate with low relative humidity.

For Crown and Wills (1995), sedentism, the adoption of pottery, and the intensification of plant resources are inextricably linked. Using archaeological and ethnographic data from the American Southwest, the authors support a model whereby the subsistence base creates a demand for a more efficient tool for processing food: pottery. In the Southwest, the cultivation of maize and squash, for example, occur at least 1000 years before the introduction of pottery; therefore, it is not with the advent of cultigens, but with the intensive use of cultigens and increasing sedentism that pottery-making occurs. The shift to a greater reliance on cultivated foods, food processing, and pottery-making likely fell on the shoulders of women, whose burdens also included planting and daily care of crops (about two hours a day), the harvesting of crops, the

grinding of corn (up to three hours daily), and the boiling, cooking, and serving of food. Crown and Wills (1995) conclude that, at least for the Southwest, the “functional superiority” of pottery was not the driving force for its adoption, but that the cost of planting and processing plant foods was worth the investment in adding a new technology.

A survey of the earliest post-Pleistocene pottery found throughout the world demonstrates a variety of social and ecological contexts in which pottery may developed or adopted. However, Rice (1999) notes that early ceramic technology tends to be found in tropical or sub-tropical riparian environments with access to coastal or estuarine resources. Though the author is quick to point out that this bias may be attributable to preservation processes, and low fired pottery may be better preserved in low acidic deposits that shell mounds provide, a consistent environmental and archaeological pattern of early pottery nevertheless emerges. Coastal environments in the tropics and sub-tropics are particularly productive in terms of the amount of biomass available to human populations, both from the water and from the land, and offer a stable and predictable resource base from which they can be exploited (Rice 1999). Such rich environments encourage and support larger semi-sedentary or sedentary populations, who do not have to experience large vacillations in seasonality or famine related to failed cereal crops.

Complex Hunger-Gatherers: What Defines Complexity?

The term ‘complex’ when applied to hunter-gatherer populations may vary depending upon the researcher or the group under analysis, but common traits include

sedentism, the large-scale use of storage, high population density, and evidence for inequality, particularly heritable inequality.

For Testart (1982), large-scale storage, sedentism, abundance and seasonality of resources, and efficient techniques for acquiring food were necessary for the development of complexity among hunter-gatherer populations. He places the focus on seasonal storage in direct opposition to “simple” hunter-gatherer groups who are highly mobile, maintain low population numbers, and meet their daily needs on an immediate basis. Complex societies also engage in socioeconomic inequalities, the root of which lies not in agricultural production, as V. Gordon Childe (1951) would argue, but in the production of surplus foods that can be stored (Testart 1982). Sedentism is crucial to the author’s model of complexity because, while mobile groups must carry what they own, sedentary groups may build and maintain permanent technology, such as granaries, basketry, pottery, and storage pits, that aid in food production and storage. Importantly, surplus goods in such societies may also be exchanged with neighboring groups, and trading relationships help maintain the subsistence economy.

Price and Brown (1985) acknowledge that defining the “conditions, causes and consequences” of the development of complexity among hunter-gatherer groups is in itself complex, due to the number of variables, such as environment and available resources, that must be considered for each population. For these authors, population growth in a defined and restricted (but productive) area of subsistence causes populations-wide stress. The response to this stress is to react by intensifying the available food supply and developing new technologies that facilitate the exploitation of

existing and new resources; in addition, social organization must shift to focus on the organization of labor, and stratified groups, acknowledged and empowered through ritual, emerge. Price and Brown (1985) note the limits of this model in determining exactly how technological innovations are developed, and recognize that specific details regarding how intensification begins are lacking.

Cohen (1985) also cites population pressure as a driving source for the organization of people and resources among increasingly resource-restricted hunter-gatherer groups. This author sees population aggregates as forming from necessity and competition for resources, rather than as choice. Foods such as shellfish and seeds would fall low on the list of more desirable resources, such as meat and vegetables (Cohen 1985). The author invokes Kent Flannery's (1969) model of the "broad spectrum revolution", whereby hunter-gatherer populations are forced to rely on such "marginal" foods due to competition for resources; in turn, people begin cultivating crop foods to alleviate the pressures of competition and the reliance on marginal foods. Cohen (1985) describes the attributes of complexity in hunter-gatherer groups to include the emergence of "big men", regional alliances, formal reciprocal exchanges, management of storage, accumulation of wealth, luxury goods, and social and economic prestige.

Keeley (1988) offers ethnographic evidence to support his argument that the development of complex hunter-gatherer groups can only begin with significant population pressure. The researcher examined ethnographic groups using variables that might correlate with one another, including demographic information, geographic location, storage, and diet, and found that population density and the availability of

resources are highly correlated with economic complexity among hunter-gatherers. And, it appears, the greater the population pressure on available resources, the greater the likelihood for complex traits. Significantly, Keeley (1988) found that complexity was far more likely to arise (through population pressure) in environments with abundant and reliable resources rather than “poorer, more variable” regions. Abundant and reliable resources include those with fish, while poorer, more variable regions include a greater reliance on terrestrial animals for subsistence (Keeley 1988).

When discussing the emergence of complexity among foragers, researchers often cite as examples the North American archaeological and ethnographic populations from the Pacific Northwest and Southern California. Ames (1991) describes the prehistory of the southern Northwest Coast, spanning from the northern tip of Vancouver Island to Cape Mendocino in Northern California. This region has been home to hunter-gatherer groups whose settlement strategies vary from mobile to sedentary, and socioeconomic organization from egalitarian to hierarchical. Though hunter-gatherers have populated this area of abundant resources for upwards of 11,000 years, Ames (1991) focuses his attention on the emergence of complex foragers during the Pacific period (5500-270 BP) in this region.

Ames (1991) lists the features of complexity that he observes for this period, including: sedentism or semi-sedentism, heavy reliance on storage, household-based subsistence economies, broad-based diet but focused on only a few main food resources, manipulation of the environment, specialized technologies, high population densities, and vertical social hierarchies. Ames (1985; 1994) sees the emergence of social

hierarchy largely resulting from environmental circumscription. In response to abundant coastal resources and population growth, the mobility of Northwest Coast populations became reduced (Ames 1985). Large, rectangular plank houses appeared along the coastal areas at roughly 3200 BP, and later (and larger) plank houses were maintained for several hundred years, housing generations of families. In the interior areas of the Northwest region, large pithouses were used during the same time period. Longhouses, some large enough at more than 60 meters in length to house several hundred people, were more common after 1000 BP in the southern interior. All of these permanent structures suggest a high degree of sedentism, and possibly large-scale storage.

The subsistence base for this region included shellfish, fish (especially salmon), mammals, and many species of plants; the intensification of salmon fishing is related to the development of social inequality. Northwest Coast populations also engaged in long-distance trade, created elaborate artwork, and decorated themselves with labrets and tattoos (the presence and/or markings of which were linked with social position and group affiliation). Ames (1991) stresses that, when considering the development of complexity, one must take into account the long history and local variation of every population, and realize that a particular social organization may not form in a linear manner or uniformly across time and space. Therefore, while ethnographic data may provide critical information, it is in itself “the result of a dynamic, even tumultuous history, and that its direct application to the past requires continual testing...”.

The Channel Islands of Southern California is another region that researchers use to understand the emergence of complex hunter-gatherer groups (Arnold 1992, 1996;

Kennett and Kennett 2000; Porcasi and Fujita 2000; Rick et al. 2005). In her research of the Chumash of the Santa Barbara Channel region, Arnold (1992) explores the social, economic, and environmental circumstances that led to the development of a complex society and the appearance of social hierarchy and inequality. The Chumash participated in a fishing-hunting-gathering economy until about 650 or 750 BP, when traits belonging to a complex society emerged. Arnold (1992) maintains a strict definition of emerging complexity that does not include “big man” levels of organization; instead, central to her definition is the presence of “ascribed, inequalitarian social organization... signs of regional integration, a degree of permanence in the power of elites, and semi-sedentary to sedentary settlement and population agglomeration”. This type of social organization has its origin in environmental stress, which may be caused by high populations with restricted resources. In the case of the Channel Islands, high sea surface temperature that reduced marine food production coincided with the emergence of complex societal features, and is therefore seen as a prime mover for the emergence of elite control of labor and production. Stress from outside forces, such as other populations or political groups, may also influence the development of complex traits.

Arnold’s (1992) definition of complex hunter-gatherers is a chiefdom, seminally defined by Service (1975), whereby labor is regulated and controlled by sources outside of the domestic sphere, and the production of food, crafts, and other goods are intensified at the behest of elite, labor-leading members of the group. Control over the production and distribution of goods by elites was pronounced. The Channel Islands were home to high quality chert, from which microblades were manufactured, as well as

Olivella shells, mussel, and abalone that were used as trading items; none of these materials were available on the mainland, and all were in high demand. These goods were transported across the channel to the mainland via plank canoe, a technology that allowed for intensive trading relationships, and required specialized knowledge with an estimated 180 to 540 days to manufacture (Arnold 1992). These characteristics, in concert with elaborate mortuary behavior and evidence for feasting activities, are in keeping with Arnold's definition of complexity, and should act as a model against which other complex hunter-gatherer societies be defined (Arnold 1996).

Arnold (1996) discusses common myths about complex hunter-gatherers, beginning with the first myth that these groups "existed only as a step along the path to agriculture" and state-level organization. In fact, the development of cereal crop agriculture is not necessary to achieve the features associated with complexity; acorns, bulbs, seeds, fish, and more were more than able to sustain complex populations in the Channel Islands and elsewhere. The second myth is that contact with farming groups or "advanced" societies is necessary to become complex. While it is possible for a hunter-gatherer group to be influenced by more stratified neighbors and their mode of subsistence, contact with such groups is not necessary for the development of complexity. The third myth is that complex hunter-gatherer societies were so uncommon that they do not necessitate including into mainstream constructions of social evolutionary theory. This myth, she argues, is a product of normative thinking that seeks to maintain the validity of previous modeling, even in the face of archaeological evidence to the contrary (Arnold 1996).

Kennett and Kennett (2000) investigated the environmental conditions under which the emergence of complexity in the Channel Islands occurred. Are hierarchical systems more likely to form under periods of environmental stress, as some researchers argue, or periods of stable environment and abundant resources? To answer this question, the authors examined the paleoclimatic history of the last 3000 years by conducting an oxygen isotope analysis of planktonic foraminifera from a sediment core off the Santa Barbara basin, as well as mussel shells taken from archaeological sites in the northern Channel Islands. The researchers found marine productivity to be high and variable during the period just prior to the emergence of complex social organization (AD 450-1300) due to a period of unusual cooling (Kennett and Kennet 2000). As the authors note, and as I summarized from Arnold (1992) above, this finding lies in direct opposition to previous research on sea surface temperatures, which suggested a warm period of low marine productivity during this time frame. This period of cooling also affected the interior, as conditions became drier, and terrestrial resources changed. The researchers hypothesize that, in response to these changes in the environment, people began to engage in more violence to control areas of valuable resources. Fishing intensified, and people began to produce items of value that could be traded to offset the unpredictability of acquiring food. Competitive behavior for resources and cooperative responses to social problems lay at the heart of this unstable period of time, say the authors, and provided the framework for the full emergence of social complexity after AD 1300 (Kennett and Kennet 2000).

Ethnohistoric and archaeological evidence for hunter-gatherer complexity is also seen among the Calusa of southwest coastal Florida (Marquardt 1986). The Calusa were a sedentary fisher-hunter-gatherer group that was organized at the chiefdom level, and maintained widespread political influence in the region. Their society was socially stratified with ‘commoners’ and ‘nobility’, and the chief collected and redistributed wealth throughout the territory. The Calusa also created markers of rank through insignia and ornamentation, and may have kept slaves. Though this group may have cultivated some root foods, and perhaps maize, they did not engage in intensive horticulture. Rather, the Calusa subsisted from abundant marine resources such as fish and shellfish. Ethnohistoric reports from the Spanish about the Calusa are valuable documents, but must also be evaluated using caution (Marquardt 1986); however, archaeological investigations do support ethnohistoric accounts that the Calusa were a populous, socially-stratified Chiefdom that relied mainly on marine and estuarine resources for subsistence, and who maintained a society as complex as ethnohistoric native groups of the Pacific Northwest of the United States (Marquardt 1986).

Sassaman (2004), in his review of complex hunter-gatherer societies in North America and the theoretical viewpoints that researchers have applied to these groups, asserts that a greater understanding of complexity is being achieved through continued archaeological investigations, especially in Southern California and the Southeast. Previous work has differed in its definition of complexity among hunter-gatherers: is it anything that lies outside of the traditional ethnographic model of mobile and egalitarian hunter-gatherer, or should the criteria be more specific? Sassaman (2004) warns against

being overly typological when investigating hunter-gatherer archaeological sites, because an existing ethnographic corollary with which to compare may not exist. As researchers become more open to considering social and historical causes for culture change, rather than relying on a strict list of environmental conditions that elicit the emergence of complexity, a fuller and broader understanding of hunter-gatherer populations can be achieved (Sassaman 2004).

Coastal Adaptations and Recent Case Studies

In an influential paper, Yesner (1980) discusses maritime hunter-gatherers and their variation throughout the world, their subsistence economies, and some attributes that they are likely to share in common. The author makes the argument that much of what the anthropological community knows about hunter-gatherers is based on archaeological research and ethnographic studies of populations living in “marginal resource zones”, and pays less attention to the fact that many kinds of hunter-gatherer groups have lived in dynamic, ever-changing social and environmental climates throughout time. Yesner (1980) lists the traits that are most commonly observed among groups subsisting on coastal resources: high resource biomass, resource diversity, environmental stability, “unearned” resources (migratory species such as seals, whales, and birds), coastal settlement, sedentism, technological complexity and cooperation in resource exploitation, lower dependency ratios, high population densities, and territoriality, resource competition, and warfare.

High resource biomass in coastal environments refers to fish, shellfish, aquatic birds, sea mammals, and anadromous fish (particularly along the Northwest Coast).

Animals that were once thought to be unlikely food sources due to assumptions of high risk/low return investments have been exploited, as in the case of dolphin hunting in prehistoric Channel Island populations (Porcasi and Fujita 2000). Yesner (1980) has found that prehistoric groups tend to favor coastlines where bays, streams, and lakes are found, due to their particularly high level of productivity. The level of technology to subsist in a coastal zone may also vary from the very basic tool, such as a digging stick for mollusks, or nets and fish hooks for deep sea prey. In addition, the very young and the very old can help harvest marine foods such as shellfish, that do not require a specialized skill set or an over expenditure of energy. Yesner (1980) argues that this greater self-sufficiency on the part of “dependent” groups leads to greater social stability, as well. In productive coastal zones (and nearby inland areas that are often rich in plant and animal resources) that sustain high population densities, any change in resource availability or duress will likely lead to complex social and economic structures to mitigate the unpredictability of the environment (Yesner 1980).

Recent archaeological research around the world continues to advance our knowledge about the development of complex hunter-gatherer groups. Iriarte et al. (2004) report on a Pre-Ceramic archaeological earth mound plaza site called Los Ajos of the La Plata river basin from southeastern Uruguay, where evidence for the cultivation of plants appears at 4190 BP. Paleoecological evidence is in keeping with a known mid-Holocene dry period that resulted in a reduction of wetland species and an increase in chenopodiums. Flotation of the excavated areas revealed phytoliths of maize cobs, starch grains of maize kernels, phytoliths of domesticated squash (*curcubita*), and palm

phytoliths dated between 4190 and 3350 BP. During the later ceramic occupations, earthen mounds in the plaza become more specialized and formalized, and the cultivars present during the Pre-Ceramic period continue during the Ceramic period. The authors suggest that social complexity emerged due to population pressure caused by the mid-Holocene dry period, which attracted large numbers of people to wetland resources (Iriarte et al. 2004).

Habu (2008) explored a Jomon period complex hunter-gatherer occupation at the Sannai Maruyama site in northeastern Japan. This particular complex of the Middle Jomon period (3900 to 2300 BC) saw the emergence of complexity among hunter-gatherer groups, with a sharp increase in permanent house structures, elaborate figurines, and a grinding stones associated with the processing of plant foods, probably nuts. Then, a decline in each of these measures followed, and population densities appeared to lower. While Habu (2008) cannot say exactly what caused the rise and decline of this complex hunter-gatherer group, he is open to hypotheses that explore both ecological and social causes. This particular pattern of the emergence and disintegration of a complex hunter-gatherer community is novel to the thinking that cultural evolution is always unilinear (Habu 2008).

Along the coastal desert of the Atacama in northern Chile and southern Peru, Chinchorro fisher-hunter-gatherers began practicing artificial mummification coincident with evidence for the development of cultural complexity between 7000 and 4000 BP (Marquet et al. 2012). The authors' definition of complexity includes sedentism, increased population density, rituals, warfare, and social differentiation. In the beginning

of this mortuary practice, infants and children were the only members of the community who were treated; this led researchers to reject their working hypothesis that artificial mummification was (at least initially) related to ancestor worship. Adults were subsequently artificially mummified, and variations developed, whereby some were painted different colors (usually red or black), or were covered in mud or reed cordage. Other individuals were not artificially mummified, but were mummified through natural processes. It is unclear whether this funerary practice was directly linked with group identity or as a way to signal control over resources (Marquet et al. 2012). After 4400 BP, the practice of artificial mummification ceased. The authors attribute this to a sharp decline in population densities during a time of water shortage, increased aridity, and low marine productivity due to warmer waters caused by El Niño events. The landscape was no longer able to support the Chinchorro culture in the way it had done for thousands of years.

Prehistoric coastal adaptations are often associated with shell mounds, and recent research along the west coast of South Africa dating from 3000 to 2000 BP discusses a population of hunter-gatherers who built “megamiddens” that suggest permanent residence and increased population densities (Jerardino 2010). In addition to shellfish remains, the majority of which consist of black mussels, vertebrate species of cormorants, penguins, fish, tortoise, and small bovids were recovered from the mounds. The intensification of marine resources and small terrestrial prey did not continue after 2000 BP, perhaps due to increasing population pressures and resource stress. In any case, the accumulation of “megamiddens” ceased after this period of time, and was

ultimately replaced with a subsistence economy based on herding; it is unclear at this time if any relationship between these two economies, or populations, existed (Jerardino 2010).

The study of shell mounds and the exploitation of marine and terrestrial resources by prehistoric groups continue to develop, as innovative, interdisciplinary methods and ideas are tested (Alvarez et al. 2011). Finstad et al. (2013) describe a geochemical technique using magnesium and calcium concentrations, as well as oxygen isotope ratios, on mussel shells that can be used to reconstruct seasonal construction patterns of shell mound sites. The researchers examined two hunter-gatherer mound sites in the San Francisco bay area (1100-250 BP) called Ellis Landing and Brooks Island to see whether they were built at the same time, and if they were part of the same cultural sphere of interaction. Excavations at the mound sites reveal evidence for burials, housing, and refuse related to processing food and cooking; mound sites also tend to occur in discrete clusters, with the largest of the mounds situated closest to the bay. The authors found that Ellis Landing and Brooks Island did overlap for at least some of Late Period time frame (1100-250 BP), and geochemical signatures suggest that the harvesting of mussel shells occurred at the same time of year (late spring, summer, and fall, but rarely in the winter time). This pattern does not suggest short term sedentism by hunter-gatherers with each site being used sporadically, but long term, stable use with multi-site occupation.

In this chapter, I have provided an overview of the theoretical thought regarding the adoption of ceramic technology, the emergence of complex hunter-gatherer societies,

and the manner in which coastal environments can provide the stable and productive resources necessary for large populations to thrive for millennia. For the coastal *sambaqui* foragers of the Atlantic coast of Brazil, the adoption of pottery occurred after subsisting for thousands of years without the use of such technology, and under the conditions of a stable, productive marine environment. This research seeks to understand whether these coastal inhabitants adopted pottery as a utilitarian means to process food for subsistence purposes, or whether pottery was adopted for symbolic or social use associated with a prestige economy. Related to this question is the intersection of theories of social organization surrounding complex hunter-gatherers. Though definitions of what constitute ‘complexity’ among a group of foragers may differ among researchers, it is important to keep in mind the wide range of socioeconomic strategies that are possible when examining the archaeological record, and to remain open to types of social organization that may not fit into neat typologies. In addition, it is necessary to remember that defining ‘prestige’ is a complex issue that cannot be accurately described in a simplistic manner. The *subsistence* and *prestige* models I describe in this chapter are useful for purposes of analysis and exploration, but I also realize that a great deal of cultural variation exists for prestige economies. While I present these models in dichotomous terms, many of the traits described in each model are not mutually exclusive for many cultures.

CHAPTER III

PALAEOENVIRONMENTAL RESOURCES OF SOUTHERN BRAZIL

This chapter describes palaeoenvironmental conditions of the Atlantic coast of Brazil, and the manner in which fluctuations in sea-level during the Holocene impacted fisher-hunter-gatherers who occupied the region. This chapter also considers archaeological data that intersect with evidence for climatic and vegetation changes during the study period. Marine and terrestrial food resources of the Atlantic forest are also discussed, along with descriptions of the archaeological contexts from which flora and fauna were recovered. Though sea-level fluctuated several times during the Holocene, the impact on overall climate was minimal. However, evidence suggests that *sambaqui* foragers responded to changes in groundwater levels by migrating toward the coast during regressive periods. This allowed *sambaqueiros* to continue to exploit fish, mollusks, and crustaceans from lagoon, bay, and estuarine environments, as well as land mammals from the Atlantic rainforest. As vegetation profiles and climate remained stable from the Mid-Holocene to the present, the coastal foragers were able to exploit steady, predictable, and diverse resources for thousands of years. Finally, this chapter reviews evidence for the origin and dispersal of maize and manioc into South America, and the timing and proximity of plant domestication to the prehistoric populations under study.

Description of the Study Area

The archaeological sites used in this study are located along the Atlantic coastline of southeastern Brazil, in the modern-day states of Santa Catarina and Rio de Janeiro. These regions form part of the Atlantic Forest (*Mata Atlântica*), a sub-tropical and tropical rainforest that defines the entire eastern coast of Brazil, and is comprised of deciduous and semi-deciduous trees, mangrove swamps, and a diverse array of flora and fauna. The southern sub-tropical climate of Santa Catarina is warm-temperate, with an average low temperature of 61.9° and a high of 74.5°; the rainiest months are April, May, September, and October. In contrast, centrally-located and tropical Rio de Janeiro has an average low temperature of 69° and a high of 79.5°. Months December through March represent the rainiest periods of the year for this region.

The state of Santa Catarina is divided between the mainland and its smaller island counterpart upon which the capitol, Florianópolis, is located. The largest island belonging to the state of Santa Catarina, the island of Santa Catarina measures about 50 miles in length and ranges in width between 5 and 10 miles. The archaeological sites for this study are located on mainland Santa Catarina, Santa Catarina island, and the smaller island of São Francisco do Sul. Therefore, coastal environmental resources from inlets, bays, lagoons, estuaries, and mangrove swamps played a large role in the diet of the prehistoric populations who occupied the islands. The mainland coastline, though narrow along the entire eastern border of Brazil, provides the same rich resources that can be found in the islands. Interior plateau resources of mainland Santa Catarina include plants and animals that thrive in the rich temperate forests of the Serra Geral

mountains, an extension of the Serra do Mar mountain range. For example, *Araucária angustifolia* pine forests, found in the plateau of Santa Catarina and other states in the southern region, constituted an important part of the pre-contact Atlantic Forest biome, but have since been impacted by large, industrialized populations. The seed from this tree, *pinheiro brasileiro*, is still enjoyed as a “typical” southern Brazilian food, and offered great nutritional benefits for indigenous populations.

Palaeoenvironment of Coastal Southern Brazil

Studies of past climate and ecology provide insight into the manner in which prehistoric groups interacted with their environment and exploited resources. Because the coastal populations in this study subsisted on plants and animals from the Atlantic forest and its marine environment for thousands of years, documenting oscillations in sea level is helpful for reconstructing the environment in which these cultures developed and sustained themselves. For example, archaeologists have uncovered *sambaquis* located 30 to 35 km from present-day coastal waters (Suguio et al. 1993; Martin et al. 1996); relative sea level has a profound impact on the creation of important resources, such as lagoons and estuaries, and it is therefore necessary to understand its effect on the subsistence economies of the past. Palaeoenvironmental reconstruction also requires an investigation of vegetation and its change through time. Since vegetation type and distribution largely depend upon local precipitation and temperature, microscopic and macroscopic remains of plants inform a great deal about past climate. Similarly, faunal remains may indicate local climate and seasonality, and may signify their availability for humans as food, shelter, and/or clothing. In sum, environmental conditions largely

determine which plant and animal resources were available for prehistoric groups, and at what time of the year.

In a palaeoenvironmental study conducted in the southeastern state of São Paulo, Brazil, Ybert and colleagues (2003) discussed a Mid-to-Late Holocene decline in sea level from a maximum height of 3.5 to 4 m above modern sea-level. Sea level reached this maximum at 5800 cal yr BP, and declined to 2 m above the present-level by 3470 cal yr BP. Thereafter, sea-level continued to decline at a steady rate until it reached its present-day level. Marine diatoms from sediment cores from the coastal plain peat bog Fazenda Boa Vista revealed that the area was once a resource-rich lagoon of the Atlantic Pluvial Rainforest from 4900 to 3470 cal yr BP, where prehistoric groups built shell mounds and consumed aquatic and terrestrial foods. Ybert et al. (2003) characterized the environment as open forest consisting largely of herbaceous plants. After 3470 cal yr BP, the drop in water level transformed the lagoon into a swamp, and the area was abandoned. Evidence of marine resources vanished, and a humid tropical forest replete with fern took over the open-forested lagoon. The change in sea-level after 3470 cal yr BP had a dramatic effect upon groundwater levels and lagoon and estuarine environments, but overall climatic conditions, with the exception of three minor oscillations in humidity, remained stable from 4900 cal yr BP to the present. Because the authors found no evidence of human activity after the decline in sea level, they speculate that the *sambaqui* occupants followed the receding waters towards the shore to continue the exploitation of aquatic food sources (Ybert et al. 2003).

A palaeoenvironmental study from the coastal plain of Santa Catarina (from the Cape of Santa Marta to Ponta de Itapirubá), reported a lower sea-level during the Holocene. Using the vermetid, a species of gastropod, as an indicator species for ancient intertidals, Angulo et al. (1999) estimated palaeosea levels and determined radiocarbon dates and palaeotemperatures through ^{14}C and $\delta^{18}\text{O}$ isotope analyses, respectively. Angulo et al. (1999) found that maximum Holocene sea-level was “at least 1 m lower than those observed in the states of São Paulo, Paraná and north of Santa Catarina” at 5410 BP, instead of the estimated 3.5 to 4 m relative sea level reported by Ybert et al. (2003) for the state of São Paulo. Although Angulo et al. (1999) and Ybert et al. (2003) agreed that maximum sea-level for the Atlantic coast was reached during the mid-Holocene, and that a gradual decrease in relative sea level from maximum to modern levels occurred, Angulo et al. (1999) assert that maximum sea-level only reached 2.10 m above modern level. Sea levels were higher during the last 2000 years until very recently, perhaps until as late as 190 +/- 65 years BP, and oxygen isotope analyses of vermetid gastropods revealed that the Middle to Late Holocene absence of these organisms south of Cabo Frio (22°S) may have been caused by a steady lowering of sea temperatures for that region. The disagreement among studies regarding maximum sea level estimates for the Atlantic coast of Brazil may be related to changes in geomorphology, methodological problems, or other causes (Angulo et al. 1999).

The greatest disagreement about sea-level fluctuations along the Atlantic coast of Brazil concerns whether the decline from the Holocene maximum was gradual and steady, or whether repeated oscillations raised and lowered the sea-level throughout the

Middle to Late Holocene. In their study of palaeoshorelines, Suguio et al. (1991) argue that sea-level decline was not steady, but fluctuated between periods of “submergence” (rise in sea-level) and periods of “emergence” (drop of sea level). Periods of submergence occurred from 7000 to 5100 B.P., 3800 to 3600 B.P., and 2700 to 2500 B.P. During the last two submergence phases, sea-level attained a height varying between 2 to 3.5m above current shorelines. Their conclusions are based on a study of gastropods excavated from *sambaqui* sites in the state of São Paulo. The authors employed radiocarbon dating and an analysis of $\delta^{13}\text{C}$ ratios to discover the respective age and local environments under which these organisms developed. Gastropods removed from lagoon waters will display a range of carbon isotope values between freshwater and saltwater, and those exhibiting lower $\delta^{13}\text{C}$ ratios will have developed in the inner part of the lagoon, where they absorbed carbon from terrestrial plants. However, gastropods that lived on the cusp of lagoon and sea will have the highest carbon isotope ratios, due to their distance from terrestrial plant carbon (Suguio et al. 1991). Using these data, the authors determined oscillations in the lagoon waters and, in turn, estimated fluctuations in sea level for the time period spanning the use of the archaeological sites in the area.

As oscillations in sea-level altered the manner in which prehistoric groups interacted with their environment in the coastal region of Santa Catarina (Ybert et al. 2003), Barbosa and colleagues (1994) argued that shoreline fluctuations also affected the occupation of *sambaqui* sites in the state of Rio de Janeiro. The Ilha de Boa Vista sites, called IBV I through IV, form a subset of the São João grouping of *sambaquis* located in the São João coastal plain. The IBV *sambaquis* are similar in age to those in the rest of

the area, but are smaller in scale, averaging 50m x 40m in length and width, and 2m in height (Barbosa et al. 2004). A total of six radiocarbon dates were assayed from charcoal and nuts recovered from different stratigraphic layers of IBV-4, and a long, but discontinuous, occupational history of the site was discovered. Comparing the radiocarbon dates with artifact density counts, Barbosa et al. (2004) argued that the site was first occupied from 4500 to 3000 cal yr BP, and then abandoned; the site was reoccupied from about 2100 to 1700 cal yr BP, but this settlement appeared to be smaller and less intense than the previous settlement. The authors suggested that each occupation of the Boa Vista *sambaquis* corresponded to time periods when sea-level was favorable for the development and maintenance of resource-rich lagoons and estuaries. Sea-level was high at roughly 4000 to 3500 BP, when levels began to steadily decline; at roughly 2500 BP, sea-level rose once more and then gradually declined until its present location was reached. Barbosa et al. (2004) concluded that the fisher-hunter-gatherers who built and lived on the shell mounds were intimately connected to the pulses in sea-level, and subsisted largely on plant and animal resources that high groundwater levels could provide.

Vegetation and Climate Change

Studies of palaeovegetation also offer important information regarding past climate history. Through the study of the palynological record, Behling and Lichte (1997), Behling (1998), and Behling and Negrelle (2001) described the Late Quaternary vegetation history of southern Brazil. In general, the shift in climate from the Late Glacial Maximum (LGM) to the Early Holocene meant that formerly cool and dry

conditions gave way to the warmer and wetter climate of the Holocene. From 14,000 to 10,000 ^{14}C yr B.P., the lowlands of Santa Catarina were characterized as “subtropical with the occurrence of frosts,” and the highlands as cold and dry (Behling 1998). From 10,000 to 3000 ^{14}C yr B.P., lowland climate consisted of tropical rainforest vegetation, and highland climate was warm and dry. From 3000 ^{14}C yr B.P. to the present, lowland climate remained tropical, while highland vegetation reflected a cool, but moist, environment (represented by the spread of *Araucaria* pine into grassland regions). Today, the coastal highlands and lowlands of Santa Catarina contain *Araucaria* forests and *campos* vegetation; the former requires an annual precipitation rate of at least 1400mm, and exists in high humidity environments without a dry season, while the latter occurs more often at higher elevations and is composed of grasslands and shrubs. At transitional areas, both types of vegetation are seen together (Behling 1998).

Analysis of charcoal from coastal *sambaquis* in Rio de Janeiro, Cabo Frio and Arraial do Cabo regions, led Rita Scheel-Ybert (2000) to conclude that overall vegetation profiles remained unchanged from 5500 to 1400 B.P. By examining charcoal recovered from prehistoric archaeological contexts, this study offers direct evidence for the variety of resources that existed at each locale, as well as insight into the manner in which different woody plants and vegetation were selected for consumption. According to Scheel-Ybert (2000), the vegetation profile of coastal Rio de Janeiro is defined as *restinga*, and is typical for the sandy beach ridges of Brazil. It also used as a general term for vegetation that grows close to the coastline (Morellato et al. 2002). *Open restinga* consists of “herbaceous and scrub formations” that grow on low, external sand

barriers, and marshy plants that grow in the low-lying areas between beach ridges or dunes; the *restinga forest*, which is composed of lush evergreens, develops along inner sand barriers. The dominant vegetation type for *restinga* environments is Myrtaceae (myrtle), a family of flowering, berry-producing trees and shrubs that include the pineapple guava, grumichama (“Brazilian cherries”), eucalyptus, and the jaboticaba fruit tree. These flowering trees and shrubs produce fruit throughout the year, and therefore are aseasonal (Morellato et al. 2002). Though Scheel-Ybert (2000) found that the vegetation profiles for this study period mirror those of today, the author identified two ‘transgressive’ (encroaching) and two ‘regressive’ (receding) fluctuations in mangrove vegetation, which she attributed not to climate change, but changes in local humidity and soil salinity levels. Overall, coastal environments are edaphically buffered against large-scale climate, meaning that conditions of the soil have a greater impact on vegetation than external climatic conditions.

Through an examination of the annual developmental stages of plant life and their relationship to climate, Morellato et al. (2002) discovered that the flowering and leaf patterns of coastal Atlantic rainforest vegetation are highly seasonal due to annual changes in day-length and temperature, while fruiting occurs throughout the year without seasonal variation. Flowering and leaf growth are at their peak during the transition from the dry (and cold) to wet (and warm) season, which spans September to November. Among the four areas selected for this study (two classified as Atlantic rain forest and two as coastal plain forest), little variation in the cycles of plant growth occurred. Taken with other palaeoenvironmental studies that argue for regional climatic

and vegetation stability from the Mid-Holocene, this information indicates that the southeastern shoreline was a largely favorable and predictable environment for *sambaqui* groups, who lived along the coast for thousands of years. Though this investigation was performed in the state of São Paulo rather than Santa Catarina or Rio de Janeiro, the Atlantic coastal forest biome remained remarkably similar through time along the central, southeastern, and southern shores.

Plant Resources

In addition to the palaeoenvironmental information that Scheel-Ybert's (2000) analysis of charcoal provided about Mid-to-Late Holocene vegetation profiles for the Rio de Janeiro coastline, a related article based on the same study provided a thorough description of carbonized plant remains, including palm fruit shells, seeds, and tubers recovered from six *sambaqui* archaeological sites. These carbonized plant foods offer a rare glimpse into the past diet of *sambaqui* fisher-hunter-gatherers, as tubers had never before been identified at a Brazilian archaeological site (Scheel-Ybert 2001). Though the absolute number of tuber remains was small, a wide variety of the root foods was represented in the archaeological assemblage, including Gramineae/Cyperaceae (flowering grass/sedge), *Dioscorea* sp. (yams), and perhaps *Typha domingensis* (southern cattail). Though not found in the analysis, Scheel-Ybert (2000) noted that other plant foods were available to *sambaqui* groups, including a variety of fruits, drupes and berries belonging to the families Myrtaceae (grumichama, guava, and araçá-peba), Anacardiaceae (a drupe similar to the mango, caju), Bromeliaceae (pineapples), Cactaceae (columnar cacti), Celastraceae (staff vine), Chrysobalanaceae, Malpighiaceae,

Moraceae (fig, uvilla), Palmae (palm drupes or fruits), Passifloraceae (passion fruit), and Sapotaceae (zapotes, abiu). Interestingly, Martins (1994) argues that many of these species, specifically Palmae, Sapotaceae, Myrtaceae, Moraceae, Bromeliaceae, and Anacardiaceae, show a degree of variability that is partly due to the hybridization and propagation efforts of humans. These fruit-bearing trees produce year-round and, along with a wide variety of legumes and tubers in the region, formed an important part of *sambaqui* paleodiet.

At the site Forte Marechal Luz, Ilha de São Francisco, Santa Catarina, Bryan (1993) notes that, though few plant remains survived, researchers uncovered charred seeds and shells belonging to Palmae, Sapotaceae (zapotes), Myrtaceae, Meliaceae, and Myristicaceae (of the nutmeg family). Bryan (1993) does not report much evidence for domestication of plant foods at the site, with the exception of one type of stone artifact that may have been used as a digging stick blade (a bitted tool) to plant seeds.

At Morro de Ouro and Rio Comprido, *sambaqui* archaeological sites analyzed in this study, grains of *Discorea*, or yams, were recovered from the teeth of human skeletal remains (Wagner et al. 2011).

One of the most important plant resources for prehistoric groups throughout the New World was the palm, for which at least 50 species have been recovered from 130 archaeological sites “from the southern United States to southern Uruguay” (Morcote-Rios and Bernal 2001). Archaeologists have discovered palm remains through analyses of carbonized endocarps or fruits, pollen, phytoliths, and tools, including palm mats, spears, and darts. These authors report that palm is not only used as a food, but can also

be processed for its oil, which works as a source of fuel. In the state of Rio de Janeiro, at least 5 different species of palm represented by *Acrocomia*, *Allagoptera*, *Astrocaryum*, *Bactris setosa* Mart., *Bactris*, and *Syagrus* have been excavated from *sambaqui* archaeological sites. Several archaeological sites from the Cabo Frio region (reported by Scheel-Ybert 1998) contained 4 of these species. Other sites in coastal Rio de Janeiro with palm remains include: Sernambetiba, Corondó, and Zé Espinho (see Table 3.1). According to Morcote-Rios and Bernal (2001), the oldest examples of *Acrocomia* palm are located in South America, where it likely originated and spread northwards to Central America. The spread of this particular type of palm may have been intentional, as one can eat the mesocarp directly without having to process the oils by roasting (as in other types of palm), the tough shell is easy to remove, and the flesh and seed of the palm survive for a long period of time without spoiling (Morcote-Rios and Bernal 2001). Detailed ethnographic or prehistoric uses for other species of palm are scarce, but each species of plant produces edible fruits, seeds, oils, stalks, and leaves that can help nutritionally and technologically sustain human populations.

Table 3.1 Palm Remains Found at Coastal Archaeological Sites in Rio de Janeiro

Palm	¹⁴C B.P.	Archaeological Site, Rio de Janeiro
<i>Acrocomia</i>	1960 ± 70	Sernambetiba (Heredia and Beltrão 1980)
cf. <i>Allagoptera</i> , cf. <i>Astrocaryum</i> , cf. <i>Bactris</i> cf. <i>Syagrus</i>	5520 ± 120 3940 ± 140 2240 ± 70	Cabo Frio: Forte (Scheel-Ybert 1998)
cf. <i>Allagoptera</i> , cf. <i>Astrocaryum</i> , cf. <i>Bactris</i> cf. <i>Syagrus</i>	4340 ± 70 1800	Cabo Frio: Salinas Peroano (Scheel-Ybert 1998)
cf. <i>Allagoptera</i> , cf. <i>Astrocaryum</i> , cf. <i>Bactris</i> cf. <i>Syagrus</i>	4160 ± 90	Saquarema: Beirada (Scheel-Ybert 1998)
cf. <i>Allagoptera</i> , cf. <i>Astrocaryum</i> , cf. <i>Bactris</i> cf. <i>Syagrus</i>	3760 1430	Cabo Frio: Boca da Barra (Scheel-Ybert 1998)
cf. <i>Allagoptera</i> , cf. <i>Astrocaryum</i> , cf. <i>Bactris</i> cf. <i>Syagrus</i>	2080 ± 70	Arraial do Cabo: Ponta da Cabeça (Scheel-Ybert 1998)
<i>Astrocaryum</i> , <i>Bactris</i>	4260 ± 75 3010 ± 80	Corondó (Carvalho 1984)
<i>Bactris setosa</i> Mart.	2260 ± 60 1780 ± 170	Zé (Kneip and Pallestrini 1987)

Animal Resources

Though direct evidence for the use of plant resources is difficult to obtain from the humid environment of southeastern coastal Brazil, the remains of marine and terrestrial animals are far more abundant in the archaeological record. Mollusks were a

particularly ubiquitous food resource for the inhabitants of these shores, and were also used as material to build large, earthen mounds. Bryan (1993) reports that remains of the “giant oyster (*Ostrea arborea*), which lives on the roots of mangrove trees,” was found at the Santa Catarina site of Forte Marechal Luz, but that it was never as common as smaller varieties of mollusks. Smaller oysters and mussels were abundant, but were too difficult to identify at the species level. Likely candidates among oysters include *Ostrea brasiliiana* and *Ostrea stentina*, and mussels *Mytilus perna* and *Modiolus brasiliensis*. Bryan (1993) noted that the clam *Anomalocardia brasiliiana*, known by its common name *berbigão*, was the most ubiquitous mollusk for all stratigraphic levels at the site. In addition to these plentiful bivalves, other bivalve species were sometimes seen. However, the shells of barnacles (*Barnea costata*), teredo worms (also known as “shipworms”, class bivalve), W. Indian fighting conchs (*Strombus pugilis*), sea urchin spines, crab pincers, and the remains of other sea creatures, including the occasional land snail, occurred with some regularity throughout the archaeological deposits (Bryan 1993).

Nineteen species of fish were uncovered at Forte Marechal Luz, and it is clear that they formed an important part of *sambaqui* diet (Bryan 1993). The common names for the identifiable species are: catfish (a species that dwelt in the bay), grunt, bluefish, croaker, smooth puffer, porcupine fish, porgy, sea chub, spadefish, jack, snakefish, sea bass, ray, and shark. These data support the results of a recent examination of the biomolecular components of residue recovered from *sambaqui* pottery, in which Hansel (2004) discovered animal fats, carbon isotope values, and amino and fatty acids that

indicated a marine, or fish, origin for the residue. In his report on Forte Marechal Luz, Bryan (1993) notes that most of the fish species lived in relatively shallow water and were medium-sized, and were likely caught with baited fishhooks. The author doubts that the fisher-hunter gatherers engaged in any major open sea voyages to obtain marine resources, with the possible exception of sea turtle. Rather, he speculates that fish were caught with fishhooks, seals were captured as they lay on the beach, and whales scavenged or killed after beaching.

Mammals, birds, and reptiles also formed a large part of the diet at Forte Marechal Luz, and some remains occurred in nearly every occupational level (Bryan 1993). Of these, likely sources of food include peccary, tapir, deer, agouti, whale, sea turtle, and many unidentifiable remains of land mammals, sea mammals, birds, and turtles. Also present, but few in number, were the remains of jaguar, puma, raccoon, capivara, dolphin, and caiman. Compared to the quantity of marine animal remains, however, the remains of terrestrial mammals were scarce. Bryan (1993) speculates that much of the bony material from land mammals may have been harvested for projectile points and tools, rather than broken up and consumed, although he reports finding very little in the way of refuse or detritus from the manufacturing of such tools.

A similar diversity of fauna was recovered from Cosipa-3, a *sambaqui* located in the state of São Paulo (Figuti 1989). Though not part of this particular study, Cosipa-3 is located along the Atlantic coast, and contains similar terrestrial resources of the Atlantic forest as those sites located in Rio de Janeiro and Santa Catarina. The site has one radiocarbon date of 3790 ± 110 B.P., taken on a charcoal sample, and is located on the

Ilha de Casqueirinho (23° latitude S and 46° longitude W). Identified faunal remains included several species of fish, including the sand tiger shark, blue shark, catfish, croaker, drum, snook, mullet, and sheepshead. Oysters, clams, mussels, crab, howler monkey, and coatimundi were also recovered.

Origin and Spread of Cassava and Maize into South America

The origin and early distribution of maize throughout South America is widely debated (Freitas et al. 2003; Freitas and Martins 2000; Piperno 2003; Staller and Thompson 2002; Staller 2003). Maize has been found in archaeological contexts from Panama from 7000-4800 BP (Freitas et al. 2003) and western Mexico from about 5400 BP (Staller 2003). In a genetic study of primitive and modern maize from South America, Freitas and colleagues (2003) discovered that two allele groupings of maize were carried to Atlantic coastal Brazil through lowland river systems originating in Panama. The earliest known date for cultivated maize in South America is disputed; some researchers place a date at no earlier than about 4500 BP (Freitas et al. 2003; Staller and Thompson 2002; Staller 2003), while others argue for an earlier presence at 7000 BP in Ecuador (Piperno 2003).

Like maize, there is considerable discussion about the origin of domesticated cassava, or manioc (Allem 2002). Manioc is an ancient cultigen (9000-7000 BP) from Central America (Piperno and Holst 1998) and South America (Olsen and Schall 2001), with many varieties of wild ancestor species. Many argue for a Brazilian Amazonian origin of the domesticated variety *Manihot esculenta* (Allem 2002; Olsen and Schall 2001), and note its economic importance for ethnohistoric groups throughout South

America. Manioc has great practical value as a food crop because it provides nutritional benefits as a source of calories and carbohydrates, can be harvested year-round, and can retain viable seeds, buried underground, for 25 years (Martins 1994). Macrobotanical evidence demonstrates that coastal *sambaqui* groups in the state of Rio de Janeiro (5500-1400 BP) consumed root foods such as manioc, yams, sweet potato, and arrow-root (Scheel-Ybert 2000). Root foods formed a major part of the diet for many pre-contact groups throughout South America (Martins 1994), and remain important for settled horticultural groups, like the Yanomami, today.

Turner and Machado's (1983) analysis of dental wear and caries rates from the Corondó *sambaqui* site (4200 to 3000 BP) in Rio de Janeiro indicated that abrasive and starchy plants were an important part of coastal forager diet (Turner and Machado 1983). Sixty percent of the adult inhabitants of the pre-ceramic coastal site exhibited dental caries, and 84.8% of adults a distinctive form of dental wear on the lingual surface of the maxillary teeth. This particular type of dental attrition, which Turner and Machado termed "LSAMAT" (lingual surface attrition of the maxillary anterior teeth), increases with the age of the individual, and appears only on the lingual surface of the upper teeth, and never lower teeth. Dentine exposure of the incisors, canines, premolars, and occasionally molars is complete by 18 years of age, and children as young as 10 to 12 years of age had dentine exposure on their upper teeth. It is suggested that an abrasive, grit-containing plant like manioc, or other starchy tuber such as cattail, was raked or pulled in an apical-cervical direction along the lingual maxillary surface of the teeth. The plants may have even been sucked or held in the mouth between the teeth and tongue.

Turner and Machado (1983) concluded that the *sambaqui* fisher-hunter-gatherers may have used this particular dental surface to either extract food for consumption and/ or process plant material for an “industrial” purpose. The authors noted the rarity of finding such high rates of caries and this form of dental wear associated in one population, and surmised that one behavioral activity caused each trait to occur. In a later study by Irish and Turner (1997), the authors described the presence of LSAMAT (along with a high rate of dental caries) in a historic Senegalese population that was known to consume manioc, as well as sugar cane. Turner and others have also reported the occurrence of LSAMAT in populations from Panama and Puerto Rico.

A microscopic study of crystallized starches from prehistoric maize kernels and manioc root from an archaeological site in the state of Minas Gerais, west of Rio de Janeiro, represents some of the earliest evidence for the harvesting of manioc and maize crops in Brazil (Freitas and Martins 2000). Boquete, located in a valley of the São Francisco River, enjoyed a long history of human occupation beginning about 11,000 BP. The area is marked by limestone rockshelters that contained lithic and ceramic artifacts, and are decorated with rock art; groups also carved silo-like cavities into the rocky formations for plant food storage, ritual significance, or for some other unknown purpose (Freitas and Martins 2000). Within “silos” uncovered at Boquete, researchers found the remnants of manioc root and maize cobs, along with guariroba palm fruit; these vegetal remains were bundled in palm leaves and covered with charcoal ash and soil. The discovery of manioc root at Boquete is especially remarkable since the plant, which is friable and decays quickly, is rarely identifiable in the archaeological record.

However, due to the alkaline micro-environment in which the manioc was stored, and the subsequent development of calcite crystals within its structures, the manioc survived the destructive influence of time. Radiocarbon dating of palm fruit associated with the manioc root revealed a date of 860 ± 60 BP, and dates for maize ranged from 570 ± 60 BP to 2040 ± 70 BP (Freitas and Martins 2000). Freitas and Martins (2000) noted that the manioc root dated in their study is the oldest confirmed example in South America. Of further import is the discovery of maize as a crop food as early as 2040 ± 70 BP in Minas Gerais, Brazil.

Other evidence for maize as a prehistoric food crop in Brazil comes indirectly, from a vessel recovered from the *sambqui* archaeological site O Sitio da Praia das Laranjeiras, Santa Catarina. The vessel shows decorative impressions of maize kernels, which suggests either trade or cultivation of maize in southeastern coastal Brazil between 1000-600 BP (Prous 1991). Researchers postulate that maize cultivators from the highlands of Santa Catarina may have brought ceramics and possibly maize agriculture to *sambaqui* foragers at 1000 BP (Bryan 1993; De Masi 1999; Neves and Cocilovo 1988; Prous 1991).

As part his study of settlement strategy and seasonality among Pre-Ceramic coastal foragers in Santa Catarina, De Masi (1999) employed an oxygen isotope analysis of oyster shells to test whether occupation of coastal sites were seasonal or permanent (camp sites or residential sites). He found that two of the three sites on the island of Santa Catarina, along a lagoon called Lagoa Conceição, were residential, wherein the inhabitants consumed oysters on a year-round basis; the remaining site was determined

to be seasonally occupied. In addition, De Masi (1999) used stable carbon and nitrogen isotope analysis to compare the diet of these coastal populations to that of highland populations in mainland Santa Catarina. To complete his analysis, he also took prehistoric and modern faunal samples for carbon isotope analysis, including wild pig, deer, tapir, capibara, turtle, shark, American harvestfish, bluefish, mullet, roughneck grunt, whitemouth croaker, sea lion, dolphin, whale, penguin, and the flesh of clams (*Anomalocardia brasiliiana*). After measuring the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ ratios of human collagen in highland and coastal groups, he found that coastal groups overwhelmingly relied on marine resources as a dietary base. Of four coastal sites sampled (ranging in age from 4070 B.P. to 1300 B.P.) and 19 individuals studied (14 adults, 4 children, and 1 age indeterminate), De Masi (1999) found carbon isotope ratios of collagen ranging from -9.2 to -13.3‰ and nitrogen isotope ratios ranging from 18.4 to 12.3‰. Average $\delta^{13}\text{C}$ measured -11.8‰ and average $\delta^{15}\text{N}$ measured 15.7‰, \pm sd 1.0 and 1.7, respectively. For the highland population, average carbon isotope ratios of collagen measured -16.9‰, and average nitrogen isotope ratios measured 8.6‰ \pm sd 2.9 and 0.9, respectively. Significantly, DeMasi also documented possible maize consumption in one highland individual by 1182 BP, whose $\delta^{13}\text{C}$ measured -10.7‰, and $\delta^{15}\text{N}$ measured 7.6‰. The *sambaqui* populations of the Pre-Ceramic and Ceramic time periods had access to a wide variety of plant and animal foods from the Atlantic Ocean and its bays, estuaries, and rivers, as well as from the rich Atlantic Forest. For thousands of years, the inhabitants of the Atlantic coastline enjoyed a stable environment and a wealth of nutritional resources that allowed for the development of communities based on fishing,

hunting, and gathering. In addition to maintaining a coastal subsistence strategy with significant cultural markers for such a long period of time, it is also possible that *sambaqui* groups achieved a relationship with horticultural groups that lived further inland in the highlands of Santa Catarina. *Sambaqui* subsistence will be explored through the analysis of stable carbon and nitrogen isotopes and dental microwear analysis in later chapters of this work, where it is hoped that the relationship between subsistence and culture can be elucidated.

CHAPTER IV

SAMBAQUI ARCHAEOLOGY

In this chapter, I describe the archaeological sites used in this study, and offer a history of the research that has been conducted on coastal *sambaquis* since the 1970s. I also discuss the archaeological material that has been recovered from *sambaqui* sites, and pay particular attention to pottery, stone tools, fish hooks, bone tools, and other artifacts. These materials inform this study's objective: to test whether the adoption of pottery by *sambaqui* fisher-hunter-gatherers is associated with a change in subsistence related to cooking and/or food processing. This evidence will also help determine if pottery appeared in response to the development of a prestige economy, or some other social process. I present history of theoretical thought regarding the introduction of pottery into the southern coast of Brazil at 1000 BP, including evidence related to migration, diffusion, post-marital residence patterns, patterns of health, and genetic relationships between *sambaqui* archaeological populations. After incorporating *sambaqui* archaeological data into previous models for the adoption of ceramic technology and the emergence of complex societies, I hope to present a more complete analysis of the social and economic context of these coastal foragers.

Sambaquis were built by settled fisher-hunter-gatherers from at least 5000 BP to 600 BP. The word *sambaqui* has its origins in a Tupi Guarani word, *tamba-ki*, literally translated to *shell-hill* (Figuti 1999). These mounds contain a wide array of faunal and vegetal material, including the remains of mollusks, fish, whale, terrestrial animals, and

charred seeds and fruits. In addition, *sambaqui* mounds frequently contain hearths, floors, postholes, groundstone tools, flaked tools, bone fish hooks, pottery and human burials. These coastal shell mounds vary in size from 2 to 30 meters in height (De Blasis et al. 1998), and have been studied since the 1950s (Araújo 1970; Beck et al. 1970; Bryan 1977, 1993; Chmyz 1976; Figuti 1993; Tiburtius et al. 1949; Tiburtius and Bigarella 1953). Many of these investigations provide chronological dating, stratigraphic sequencing, burial descriptions, artifact illustrations, and provide a crucial base from which theoretical questions have been derived. Investigations of the 1980s and early 1990s emphasized the analysis of faunal and vegetal food remains from *sambaqui* sites in an effort to understand the subsistence strategy and social organization of populations who resided on the coast (Kneip 1987). Archaeologists reached a general consensus that shell moundbuilders were fisher-hunter-gatherers organized at the band level. In recent years, however, researchers have begun to reassess conclusions regarding the socio-political complexity of these prehistoric coastal groups, and suggest that they may have been organized into a hierarchical system, perhaps at the chiefdom level (Gaspar 1998). Once widely described as trash mounds, the shell mounds may have served as monumental architecture, living space, and/or elite burial grounds (Barreto 2005; De Blasis et al. 1998; Fish et al. 2000; Gaspar 2000).

Archaeological Sites of the Study Area

Twelve archaeological sites from the modern states of Santa Catarina and Rio de Janeiro, southern Brazil, were used in this study. Each site is a *sambaqui*, or shell mound site, located on or near the Atlantic coast, and each has a long history of prehistoric

occupation and unique environmental position to coastal and interior resources. I used ten archaeological sites from the state of Santa Catarina for this study: Base Aérea, Cabeçuda, Enseada I, Espinheiros II, Forte Marechal Luz, Itacoara, Laranjeiras I and II, Morro de Ouro, Rio Comprido, and Tapera. Two archaeological sites in this study are located in the state of Rio de Janeiro: Geribá II and Zê Espinho. Table 4.1 provides information about the location of each site, available radiocarbon dates, time period, and where each collection is currently housed.

Table 4.1 Archaeological Sites of the Study Area and Their Location, Radiocarbon Dates (BP, uncalibrated), Time Period, and Museum Collection

Site	Location ¹	Radiocarbon Dates (BP)	Reference	Time Period ²	Museum Collection ³
Base Aérea	SC Island	800±70	Schmitz 1999	C	CC
Cabeçuda	SC	4120±220	Lima 1999-2000	PC	MN (UFRJ)
Enseada I I	SF do Sul Island	1390±40	Weselowski et al. 2010	PC/C	UFSC and MASJ
Espinheiros II	SC	2970±60 1270±60 1160±45	Castilho 2008	PC	MASJ
Forte Marechal Luz	SF do Sul Island	4290±130 3660±130 1440±110 880±100 640±10 620±100	Bryan 1993	PC/C	MN (UFRJ)
Itacoara	SC	1570±20 1250±20	Weselowski et al. 2010	C	MASJ
Laranjeiras I	SC	4900±210 3815±120	Castilho 2008	PC	CC
Laranjeiras II	SC	n.d.	--	C	CC
Morro de Ouro	SC	4030±40	Castilho 2008	PC	UFSC and MASJ

Table 4.1 Continued.

Site	Location ¹	Radiocarbon Dates (BP)	Reference	Time Period ²	Museum Collection ³
Rio Comprido	SC	4815	Neves and Weselowski 2002	PC	MASJ
Tapera	SC Island	1140±180 1030±180 550±70	Weselowski et al. 2010	C	CC
Geribá II	RJ	5160±110	Tenório 1998	PC	MN (UFRJ)
Zé Espinho	RJ	2260±160 1920±150 1860±160 1780±170 1650±170 1510±160 1180±170	Marinho et al. 2006	PC	MN (UFRJ)

1: SC Island: Santa Catarina Island; SC: Santa Catarina; SF do Sul Island: São Francisco do Sul Island; RJ: Rio de Janeiro

2: C: Ceramic Period; PC: Pre-Ceramic Period

3: CC: Colégio Catarinense, Florianópolis, Santa Catarina; MN, UFRJ: Museu Nacional, Universidade Federal de Rio de Janeiro, Rio de Janeiro; UFSC: Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina; MASJ: Museu Arqueológico de Sambaqui Joinville, Joinville, Santa Catarina

Figures 4.1, 4.2, and 4.3 display maps of the study area. Cabeçuda, a site in Santa Catarina that is not shown in Figure 4.3, is located about 120 kilometers south of Santa Catarina Island in the Laguna region. The other two archaeological sites, Geribá II and Zé Espinho, are located in the modern state of Rio de Janeiro in the Armação de Buzios and Guaratiba regions, respectively.



Figure 4.1: São Francisco do Sul Island, Santa Catarina



Figure 4.2: Santa Catarina Island, Santa Catarina

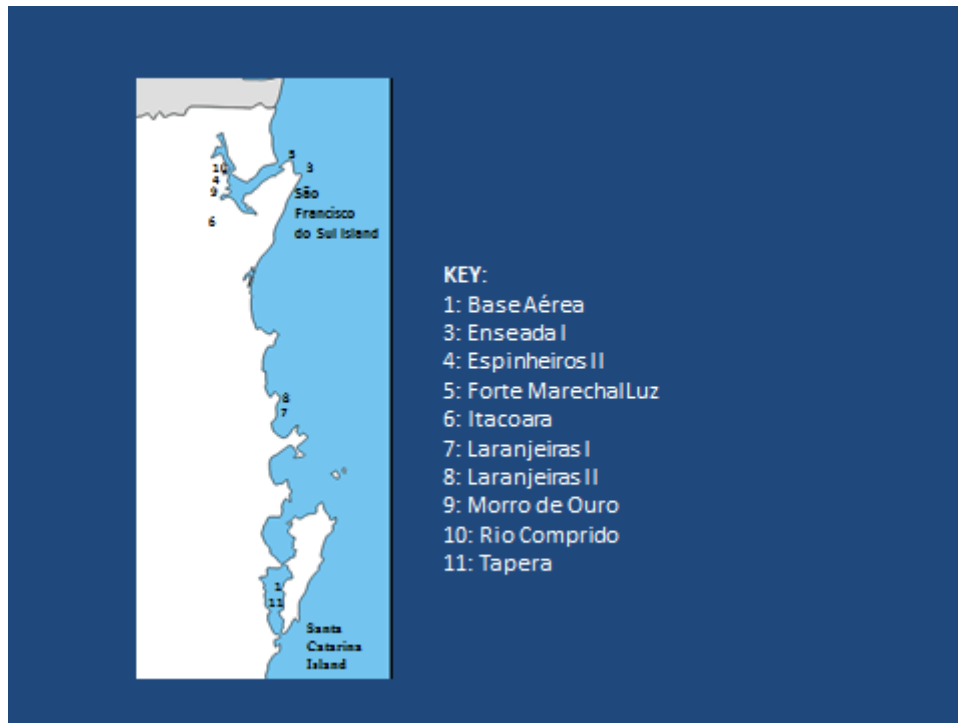


Figure 4.3: Sites from the Study Area

Pottery Recovered from Sambaqui Sites

The ceramic technology recovered from *sambaqui* archaeological sites has been described as small, simple, utilitarian, and undecorated ware (Beck et al. 1970; Schmitz et al. 1993). In addition, researchers describe a uniform appearance to the pottery occurring at all *sambaqui* sites and that, even though one may see variations in the quantity of a particular vessel form, or color, at any given site, the collection as a whole remains comparable at each location (Prous 1991; Schmitz et al. 1993; Silva et al. 1990). The number of pottery fragments and/or vessels found at *sambaqui* sites also varies, so that one Ceramic occupation site may have more than 10,000 fragments, as at Forte Marechal Luz, while another has less than 200 (Base Aérea); the majority of pottery-

bearing sites have an average of 4000 and 5000 pieces of pottery each. In this section, I will refer to this pottery by its type name Itararé; a full discussion of this name designation and cultural affiliation implication appears later in the chapter.

At Laranjeiras II, the researchers describe the Itararé fragments in terms of temper and the percentage of the collection it represented: fine sand (78.6%), coarse sand (19.3%), or mica (2.1%). The unslipped pottery fragments were found to be the colors red (6.5%), black (48.4%), red/black (23.2%), and brown (21.9%). The artifacts displayed a high surface polish, which is characteristic of Itararé pottery, and appear to have been fired in a reduced oxygen environment (Schmitz et al. 1993). The pottery at Laranjeiras II, which was manufactured by coiling, showed a variety of forms, from shallow, flat bowls to deep, straight-walled vessels. The walls of the pottery are thin, and range between 3 and 9 mm of thickness; the walls with the fine sand temper tend to have the thinner walls than those with coarse sand temper. Vessels have either a flat or concave bottom, but rarely convex (Schmitz et al. 1993).

The same varieties, forms, tempers, and colors of Itararé pottery were discovered at Tapera; in addition, the authors note that pottery with convex, or rounded, bases were almost always associated with simple bowls and plates (Silva et al. 1990). Ceramics with flat or concave bases, meanwhile, were more often seen in taller pieces of pottery, or those with a pronounced spherical shape. Significantly, soot can sometimes be observed on the base fragments of the pottery (indicating cooking over direct fire), as well as evidence for food remains on the inside of some of the fragments (Silva et al. 1990). They suggest that the pottery was used for food preparation or serving, perhaps fish, but

that the quantity and type of vessels recovered leads them to doubt that cultivation played an important role at the site (Silva et al. 1990). Archaeologists working at the Base Aérea site, located very close to Tapera, only recovered 180 pottery fragments from excavations there. However, the overall form, colors, and appearance of the pottery is in the tradition of Itararé, and is identical to that recovered from Tapera (Schmitz et al. 1993).

Beck et al. (1970) briefly describe the pottery recovered from Enseada I as small, utilitarian, thin-walled, and for the domestic sphere. Due to the presence of black soot on some of the fragments, the ceramics from Enseada I appeared to have been placed over an open fire, and the colors included shiny black, dull grey, red-orange, and brown. All of the fragments appear to be well-polished, both on the inside and on the outside of the vessels. About 4500 undecorated pottery fragments were recovered from the site, and they were all constructed by coiling (Beck 1974).

In his discussion of the ceramic period at the *sambaqui* sites of Tapera, Forte Marechal Luz, and Itacoara, Prous (1991) remarks that the pottery at each of these sites is identical to one another, as well as to the Itararé pottery from the nearby highland interior of Santa Catarina. He further interprets the swift, sudden, and abundant appearance of the technology at Forte Marechal Luz as evidence of not only an adoption of pottery, but of a migration of potters. At the same time, he is quick to add, everything else about the *sambaqui* way of life appears to have stayed the same. The author describes the vessels as measuring between 6 and 25 cm at the mouth, with the shape

being reminiscent of a gourd (Prous 1991). See Figure 4.4 for examples of reconstructed Itataré pottery.



Figure 4.4 A Collection of Reconstructed Itataré Pottery from Laranjeiras II (Schmitz et al. 1993).

At least 500 years before ceramic technology appeared at Forte Marechal Luz, inhabitants at this site were using unfired clay basins to cook food (Bryan 1993). The author describes a group of 13 of these vessels as red, irregular in shape, and about 10 to 15 cm in depth. Boiling stones were found nearby, as were the remains of fish. One of the basins held charcoal and fish bones, and another held the remains of calcined whale bone fragments. However, even though people had been using unfired clay vessels to cook food for centuries, Bryan (1993) asserts that the well-formed pottery that appears at about 1000 BP is most likely to have been introduced by outsiders, either through marriage or trade. Like the pottery described before, the vast majority of the ware at Forte Marechal Luz is dark in color, and ranges from dark brown to grey, to reddish-orange. The other type of pottery is black (about 5%), which sometimes displays a shiny slip (Bryan 1993). “Water-worn flattened ovoid pebbles with polished faces” were commonly found in the ceramic layers of the site, and are thought to have been used to polish the surface of pottery before firing (Bryan 1993: 24). Encrustations that may be food were also observed on the interior parts of the pottery fragments. Bryan (1993) reports that angular quartz temper was used for the production of most of the vessels, whereas fine and coarse sand temper was reported elsewhere (Schmitz et al. 1993).

At Laranjeiras II, the authors note that the pottery was found “many times with crusty food remains on the inside”, but do not elaborate any further on the subject (Schmitz et al. 1993). Silva et al. (1990) also note the presence of encrustations on pottery from Tapera, and posit that the vessels may have been used for serving fish. In fact, an organic residue analysis of Itataré pottery (Hansel 2004), including samples from

Enseada I and Tapera, showed evidence of degraded animal fats from marine animals and plant residues. Hansel (2004) notes that his finding of plant residues is particularly significant, as evidence for vegetal remains at *sambaqui* sites is often lacking.

The ceramic technology that appeared about 1000 years ago at coastal *sambaqui* sites is now most commonly referred to as Itataré, or Itataré/Taquara pottery. Taquara refers to the same pottery found in the state of Rio Grande do Sul (Chmyz 1976). This ceramic tradition, which is found in the modern states of Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Rio de Janeiro and Espírito Santo, shares the same morphological characteristics across all *sambaqui* sites containing a ceramic occupation. While some argue that greater cultural and genetic affinity exists between *sambaqui* sites of the south and southeastern part of Brazil, specifically Rio Grande do Sul and the southern part of Santa Catarina (Neves and Cocilovo 1989), all *sambaqui* archaeological sites share the presence of shell mounds, which act as places of human burial, habitation, and collected animal remains (Wagner et al. 2011).

Stone Tools, Fish Hooks, Bone Tools, Net Weights, and Perforated Teeth

In addition to the description of the pottery found at *sambaqui* sites, I briefly discuss the artifact assemblage that relates to subsistence. Archaeologists have noted that the type and quantity of these tools did not change between the Pre-Ceramic and Ceramic periods (Neves and Weselowski 2002). The materials available to the coastal inhabitants are similar across sites, and a wide variety of tools were made from (in order from most common to least common) basalt, quartz, granite, schist, chalcedony, and quartz crystal (Silva et al. 1993). Stone artifacts directly related to the processing and

cooking of food at *sambaqui* sites include hammerstones (likely used to crack open palm nuts) and net weights (Bryan 1993; Schmitz et al. 1993). Net weights appear as small pebbles with an engraved groove by which it attaches to the fishing net (Schmitz et al. 1993). Many of the tools, such as stone axes, adzes, and reused flakes are attributed mainly to woodworking (Bryan 1993). Stone anvils, polishers, worked flakes, pebbles, hammerstones, scrapers, and knives made up the assemblage at Forte Marechal Luz, Itacoara, Laranjeiras II, Tapera, Morro de Ouro and Zé Espinho (Bandeira et al. 2013; Beck 1972; Bryan 1993; Kneip 1987; Schmitz et al. 1993; Silva et al. 1990).

One category of artifact that is not discussed in much, if any, detail across the archaeological record for *sambaqui* sites is fire cracked rock. Though hearths are described at *sambaqui* sites, they are usually done so in the context of the mortuary record, as these features occur (or are found) in the context of a burial. The addition of this information to site reports would be enormously helpful for the reconstruction of past diet, as would more complete zooarchaeological analyses for *sambaqui* sites. Many of these sites were excavated during the 1960s and 1970s, when a high level of attention to feature detail and the systematic collection of faunal remains was not common.

In his study of inland and coastal sites in Santa Catarina, De Masi (1999) mentions that the small coastal sites SC-PRV-01 (5020 to 3987 BP) and SC-PRV-02 (1735 to 1067 BP) contain fire cracked rock “as the predominant artifacts with 75% and 74% each, respectively...” (p.76). This information would indicate that, of the lithic assemblage recovered at these sites, fire cracked rock was a prominent feature. De Masi (1999) goes on to describe other site structures excavated at these sites, such as

fireplaces and unfired clay containers. Three types of fireplace include 1. fire cracked rocks piled together 2. spread-out fire cracked rock and 3. ash pits without fire cracked rock (containing only shells and ash). The first two types of fireplaces are often associated with the remains of fish and marine mammals, as well as charred plant remains, such as seeds. The author also posits that the unfired clay containers found at the coastal sites served as places of storage, though he admits that a specific function for these containers has not yet been established (De Masi 1999). Clearly, prehistoric populations along the coast of Santa Catarina were cooking food well before the introduction of ceramic technology; however a lack of systematic data for these features, as well as faunal analyses, remain lacking for many such sites.

The coastal inhabitants of southern Brazil also used bone to create a variety of tools for subsistence, including projectile points (from birds, the spines of rays, and mammals) and fish hooks made out of mammal bone (Bandeira et al. 2013; Beck et al. 1970; Bryan 1993; Kneip 1987; Schmitz et al. 1993; Silva et al. 1990; Tiburtius and Bigarella 1951). At Tapera, 1284 projectile points made from mammalian and bird bone were recovered (Silva et al. 1993). Bryan (1993) lists 23 fish hooks and fish hook fragments for the entire occupation of the site. Six fish hooks and two fragments, also made from mammalian bone, were recovered from Laranjeiras II (Schmitz et al. 1993), 28 fish hooks and 36 fragments were recovered from Enseada I (Beck et al. 1970), and 8 fish hooks were found at Itacoara (Bandeira et al. 2013). Figures 4.5 and 4.6 demonstrate examples of bone projectile points and fish hooks that have been excavated at *sambaqui* sites.

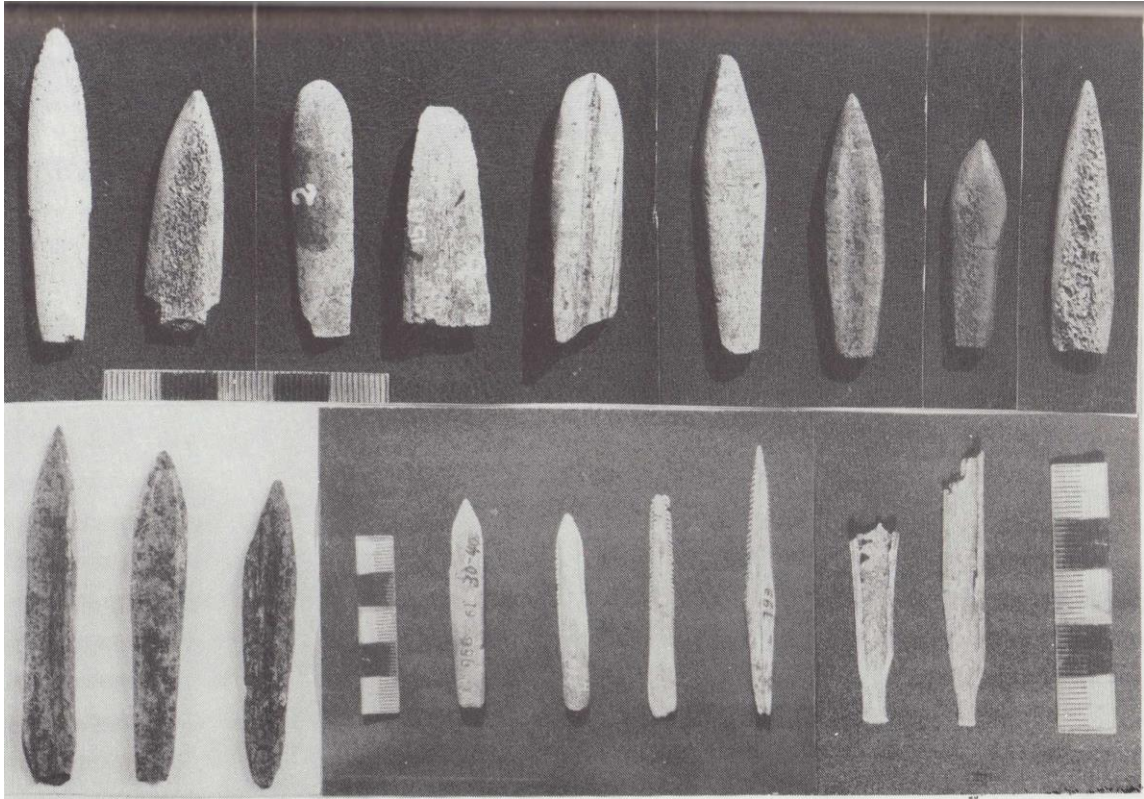


Figure 4.5 Bone Projectile Points from Tapera (Silva et al. 1993)

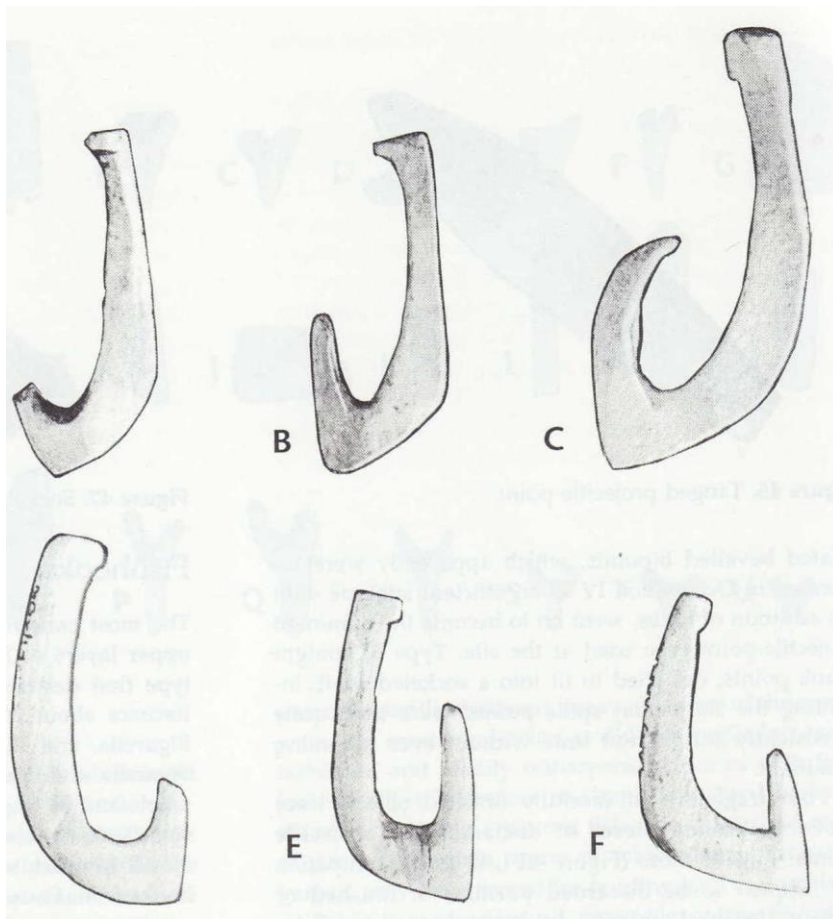


Figure 4.6 Fish Hooks Made out of Mammalian Bone from Forte Marechal Luz (Bryan 1993)

Worked and unworked teeth from mammals and fish (including sharks) are also widely reported at *sambaqui* sites (Beck et al. 1970; Bryan 1993; Kneip 1987; Schmitz et al. 1993; Silva et al. 1993). These specimens were likely worn as adornments, along with pendants made from marine shell. Bryan (1993) speculates that the shark teeth were likely extracted from animals that had washed onto shore, rather than actively hunted, as there is no archaeological evidence that would suggest a technology advanced enough

for this type of fishing. However, perforated teeth of these shark species are commonly found at *sambaqui* sites in Santa Catarina. Figure 4.4 illustrates the manner in which teeth were perforated, and the variety of species that were worn. Though only the shark species are listed in Figure 4.7, mammalian teeth belonging to ocelots, jaguar, opossum, brown howler monkey, peccary, and seals were also perforated and worn as ornamentation (Silva et al. 1990).

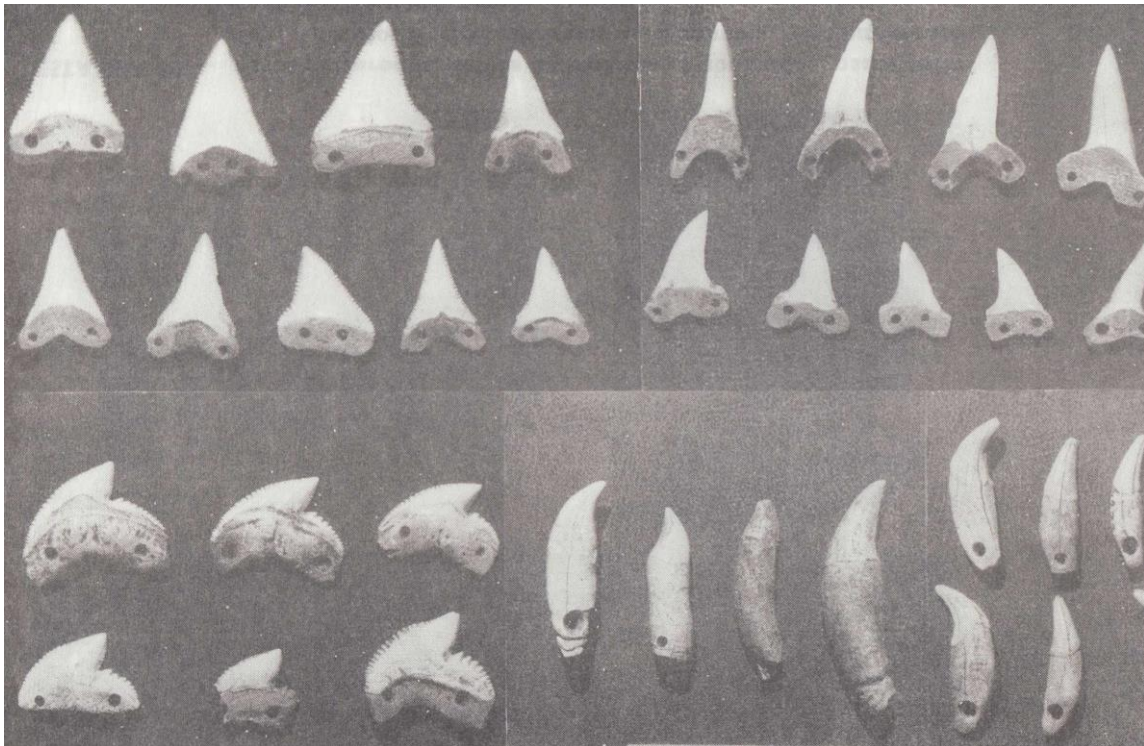


Figure 4.7 Perforated Shark and Mammal Teeth from Tapera, Including (*Galeocerdo cuvier* (Tiger shark), *Odontaspis Taurus* (Sand Tiger shark) and *Carcharodon carcharias* (Great White shark) (Silva et al. 1990)

Theoretical Debates and Recent Research

The manner in which ceramic technology came into being at coastal *sambaqui* sites has been the subject of much debate, speculation, and investigation (Araujo 2007; Bandeira 1992; Bandeira et al. 2013; Gonzalez 1998; Beck et al. 1970; Bryan 1993; Chmyz 1976; Neves and Cocilovo 1989; Neves and Weselowski 2002; Prous 1991; Schmitz 1987; Schmitz 1999; Tiburtius and Bigarella 1953). Did coastal fishers-hunters-gatherers develop this ceramic tradition independently, or does the appearance of pottery indicate a migration of people or ideas? If people migrated to the area, was it a friendly or unfriendly exchange? Where did the migrants come from? Did the appearance of pottery signify the adoption of horticulture, or was the pottery used for other purposes? So, too, defines the question of this work: does a change in subsistence and/or food processing occur with the appearance of ceramic technology at *sambaqui* sites?

Early investigations of *sambaquis* in Santa Catarina began in the 1950s and 1960s, most notably with Guilherme Tiburtius, who emigrated from Germany to Brazil, and geographer João José Bigarella (Prous 1991). Tiburtius, along with Bigarella, excavated Itacoara and other sites in Paraná and Santa Catarina; the artifacts from the excavations remain housed in the Museu do Sambaqui de Joinville. Though not professional archaeologists, and widely criticized for excavating sites without professional credentials, they are also credited with preserving artifacts and amassing data for *sambaqui* archaeological sites. Another key figure for the region during this time is Wesley Hurt, who attempted to establish seven different cultural phases for four *sambaquis* of Santa Catarina based on their relationship with each other and to the

environment (Bandeira 1992). In the early years of research and excavation, archaeologists placed emphasis on identifying different cultural phases with which pottery and other artifacts, such as lithics and bone tools, could be associated, and demarcating these phases through space and time (Beck et al. 1970; Bigarella 1954; Chmyz 1976; Hurt 1974; Piazza 1974). For example, André Prous established two cultural phases for *sambaqui* groups: setentrional and meridional. The first describes the area from Paraná to Joinville in northern Santa Catarina, and the second describes the area from southern Santa Catarina to Rio Grande do Sul (Prous 1991). Prous (1991) argues that the artifact assemblage differed slightly between the regions, with the northern section having a more refined bone tool technology than the southern region.

The observation that differences exist between northern and southern *sambaquis* has also been supported by genetic evidence (Neves and Cocilovo 1989). However, with additional excavation of *sambaqui* sites, the names for many of the phases established by early researchers began to seem arbitrary and highly localized (Bandeira 1992), and are not often used in contemporary analyses. Beginning in the late 1980s and continuing to the present day, archaeologists have moved away from descriptive work and have applied testable models to research questions, some related to human interaction with the environment and the manner in which people exploited the faunal resources available to them (Araujo 2007; Bandeira 1992; De Masi 1999; Scheel-Ybert et al. 2003).

Anthropologists have also focused a great deal of energy into the ways in which bioarchaeological research questions can tackle problems related to the interrelationships of *sambaqui* inhabitants, the adoption of agriculture, and the health status of these

populations. Recent research topics include paleopathology and indicators of health (Eggers et al. 2008; Lessa 2011a; Lessa 2011b; Mendonça de Souza 1995; Neves and Weselowski 2002; Okumura 2013; Rodrigues 1997; Weselowski 2008), paleodiet (DeMasi 1999; Eggers et al. 2011; Weselowski et al. 2010), biodistance (Bartolomucci 2006; Hubbe et al. 2009; Neves and Cocilovo 1989), and migration (Bastos et al. 2011).

Mendonça de Souza (1995) examined health indicators in a skeletal sample from the *sambaqui* site of Cabeçada, Santa Catarina, and found elevated incidents of cribra orbitalia, periostitis in the femora and tibiae, and Harris lines throughout the body. These results indicate that the population experienced an elevated degree of physiological stressors and infectious disease processes (Mendonça de Souza 1995). Rodrigues (1997), in a study of the same site, found a low occurrence of dental pathologies in the Cabeçada population, and a complete absence of dental caries. When pathologies were found, males tended to display more dental problems than females; the author also suggests that, due to missing mandibular incisors among males, that this group likely wore lip ornaments (Rodrigues 1997).

Neves and Weselowski (2002) explore whether health indicators of skeletal remains from *sambaqui* archaeological sites of northern Santa Catarina support the idea that plant cultivation was introduced at the same time as pottery. After examining the occurrence of dental caries, tooth wear, linear enamel hypoplasia, and cribra orbitalia, the authors found no evidence that these populations experienced the pathological diseases associated with cultures that practice intensive agriculture (Cohen and Armelagos 1984). In fact, the *sambaqui* groups experienced overall good health and a

high quality of life (Neves and Weselowski 2002). Interestingly, Morro de Ouro and Rio Comprido, both of the Pre-Ceramic period, showed a significant incidence of dental caries. The presence of cavities is typically associated with the consumption of starchy foods, such as grains and/or plant foods, so this finding was unexpected, given the population (Neves and Cocilovo 2002). This result suggests that the use of carbohydrates was actually higher among some Pre-Ceramic *sambaqui* populations than at Ceramic occupation sites. The Ceramic occupation groups of Enseada I, Itacoara, and Forte Marechal Luz showed few, if any, carious lesions. In addition, the incidence of porotic hyperostosis was higher at Morro de Ouro and Rio Comprido than at Ceramic occupation sites. These results support a surprising relationship between the presence of pottery and improved markers of health, in some cases (Neves and Weselowski 2002). As for the other indicators of health used in this study, no significant differences between the Pre-Ceramic and Ceramic populations were found. Of course, interpreting the health of an archaeological population from skeletal remains is complex, as the presence of skeletal lesions for some individuals (and groups) may indicate a greater resistance to disease processes, not greater weakness (Wood et al. 1992). Accurate paleodemographic profiles aid in assessing population-wide health, but other factors, such as selective mortality and hidden heterogeneity remain real problems for the paleopathologist to consider (Wood et al. 1992).

De Masi (1999) made a significant contribution to understanding settlement strategy, subsistence patterns, and paleodiet of *sambaqui* populations by demonstrating, through an oxygen isotope analysis of modern and prehistoric shells, that coastal groups

in the modern state of Santa Catarina maintained residency on a year-round basis. This finding is critical, because it addresses sedentism, one of the correlates of the adoption of ceramic technology. His stable carbon and nitrogen isotope study of human collagen in 19 Pre-Ceramic skeletons from the Santa Catarina archaeological sites of SC-PRV-01, SC-PRV-02, and SC-CL-01(4070-1300 BP), which contain average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-11.8 \pm 1.04\text{‰}$ and $15.7 \pm 1.71\text{‰}$, respectively, reflects a diet rich in marine resources (De Masi 1999).

In another study, Weselowski et al. (2010) extracted microfossils (mainly phytoliths and starch grains) from the dental calculus of skeletons from Pre-Ceramic occupation sites of Morro de Ouro and Forte Marechal Luz, as well as Ceramic occupation sites Enseada I I and Itacoara. The authors describe a technique for the recovery of dental calculus from museum collections that yields accurate results. Weselowski et al. (2010) found *Ipomoea batatas* (sweet potato) and *Dioscorea* (yam) starch grains at Morro de Ouro. Sweet potato starch, *Araucaria angustifolia* (Paraná pine) and altered *Zea mays* (maize) microfossils were also found at Enseada I I. The authors note that starch can become altered through cooking, and it is not likely that alteration occurred through diagenetic processes (Weselowski et al. 2010). *Zea mays* starch grain was also discovered at Itacoara, as well as sweet potato. At Forte Marechal Luz, sweet potato and Paraná pine were recovered, and the investigators suspect that a higher meat intake at this location may be responsible for the large calculus deposits they observed. The presence of Paraná pine starch in the dental calculus of some individuals at Enseada I I and Forte Marechal Luz indicate a possible seasonal

exploitation of edible seed resources (pinhão) in the nearby highlands during the winter time (Weselowski et al. 2010).

A principal components analysis of cranial metric traits shows genetic differentiation between populations of *sambaqui* sites, such that groups living in the modern states of Rio de Janeiro and Espírito Santo correlate more closely with one another than do groups from Paraná and Santa Catarina (Neves and Cocilovo 1989). This is a geographical split, as the first two states are located together in the northern part of the study area, while the latter sites are located to the south. The authors hypothesize that each of these areas were populated by two distinct biological groups. Along with the introduction of ceramic technology about 1000 BP, craniometric changes are also seen, particularly in individuals from Forte Marechal Luz and Enseada I I. According to the authors, one cannot be certain whether these changes are due to gene flow from groups originating in the interior, or whether the changes are due to natural processes of selection (Neves and Cocilovo 1989).

A more recent craniometric analysis of *sambaqui* sites from the states of Paraná and Santa Catarina (including Enseada I I, Itacoara, Laranjeiras II, Base Aérea, and Tapera) examines whether the arrival of pottery from the interior correlates with a shift in social structure, specifically post-marital residence patterns (Hubbe et al. 2009). To test the hypothesis, the authors employed two types of analyses: a within-group variation of each sex and a between-group variation each sex. In the former, the sex with the higher level of variation is the one that leaves the natal group upon marriage; in the latter, the sex that shows greater affinity between groups is the one that leaves its natal

group. The within-group test found no significant levels of variation for either sex; however, the between-group test shows evidence for a matrilineal system during the Pre-Ceramic period, followed by a patrilineal social system during the Ceramic period (Hubbe et al. 2009). Therefore, a change in social structure, according to this research, accompanied the arrival of ceramic technology at these sites. Due to the apparent shift in social structure that occurs alongside the appearance of pottery, the authors favor the idea that the Pre-Ceramic populations did not simply co-opt a technological tradition, but were coerced into adopting a new social organization from an outside population. Hubbe et al. (2009) recognize that this particular interpretation is speculative, but cite research regarding conflict between South American tribal groups whose outcomes involve a reorganization of social and political structure on the part of the “subdued group”.

Bastos et al. (2011), in an effort to elucidate theoretical problems related to migration and diffusion, tested the dental enamel of 32 human skeletal remains from Pre-Ceramic (n=21) and Ceramic (n=11) occupations at Forte Marechal Luz using strontium isotope analysis. Marine and terrestrial fauna of the local area were also collected and tested for reference. After calculating the mean $^{87}\text{Sr}/^{86}\text{Sr}$ for the local environment, the investigators discovered three non-local individuals at Forte Marechal Luz, one from the Pre-Ceramic period (Burial 11, used in the skeletal sample for the present study) and two from the Ceramic period. Because the authors used dental enamel for their analysis, and dental enamel is formed during the early years of life and does not remodel, these non-local individuals spent their infancy and/or childhood in a different

geographic location. The $^{87}\text{Sr}/^{86}\text{Sr}$ values for non-locals ranged from 0.70761 to 0.70835, and the local strontium isotope values measured between 0.70905 and 0.71064 (Bastos et al. 2011). Of course, Burial 11 indicates that there was contact with outsiders before the introduction of pottery. The place of origin for the non-local individuals, based on low strontium isotope values, may be the Santa Catarina plateau roughly 250 km from Forte Marechal Luz. As I detailed earlier, archaeologists have speculated for years that the plateau is also the origin of Itataré pottery. Closer plateau sites in the state of Paraná, at 130 km distance, are also possible origins of the non-local individuals. Based on the number of individuals tested, it is difficult to assess exactly how much interaction occurred between outside groups and Forte Marechal Luz. However, tremendous strides toward understanding mobility and social change may be implemented using this powerful tool for future studies.

In recent years, researchers have begun to reassess conclusions regarding the socio-political complexity of these prehistoric coastal groups (Barreto 2005; De Blasis et al. 1998; Fish et al. 2000; Gaspar 1998; Gaspar et al. 2008). Once widely described as trash mounds, shell mounds of the Atlantic coast share three important things in common: they were a living space, an area where faunal remains were collected, and a place to bury the dead. While the size and shape of *sambaquis* may vary, and the dead may be positioned in different ways and occasionally be subjected to secondary burial and post-mortem alteration, these characteristics unify these markers on the landscape (Gaspar 1998).

Beyond these characteristic lies questions regarding the symbolic significance of the shell mounds, and their purpose on the landscape. Researchers have begun to regard some of these as structures as mortuary monuments to the dead, in a manner similar to (if not the same as) the practice of ancestor worship (Gaspar et al. 2008). At Jabuticabeira II in Santa Catarina, for example, the dead were sometimes painted with red ochre, and may have been desiccated and stored off-site in order to be interred with other family members at a later date. When buried, it was not unusual to remove a few bones from the deceased and replace the bones with those belonging to other individuals. Small grave offerings of bone and shell were sometimes made, and sometimes large stone plaques would be found near the head of the deceased. Covering several burials with a thick layer of shell may have been a way to close the burial ground for a particular family group, and the author reports evidence of feasting (the presence of a fire and food remains) within the context of the burials themselves (Fish et al. 2000; Gaspar et al. 2008).

Bryan (1993) also discusses evidence for secondary burials at Forte Marechal Luz, but found only one phalange that was painted with hematite at this site. Grave goods, including whale bone, perforated shark and mammalian teeth, potsherds, polished stones, bone projectile points, hammerstones, shells, and worked stone were recovered in a wide variety of mortuary contexts, and Bryan (1993) recorded evidence for feasting at the grave site, as well.

The presence of such large architecture carries more social meaning than practical meaning, and for some indicates a complex, possibly hierarchical system of

organization (De Blasis et al. 1998). Evidence from mortuary patterning suggests that differences in social status may have occurred, but no systematic analysis of this has been completed to date. Thus far, archaeologists do not report a distinguishable mortuary pattern at burial sites. Population size for many of the *sambaqui* sites is estimated to be large, and evidence has shown that these groups were stable for hundreds of years; therefore, territorial circumscription, and a socio-political structure to oversee the territory, may have developed (De Blasis et al. 1998; Fish et al. 2000). De Blasis et al. (1998) argue that a more systematic research approach be taken toward *sambaqui* archaeological sites, so greater evaluation of the data and its social meaning can be determined.

The archaeological data from *sambaqui* sites is rich and varied, and deserves a systematic and complete examination. The past decade has witnessed a huge growth in the number of studies addressing such important issues as faunal analysis, paleodiet, social complexity, and migration, particularly. Each scientific report and examination of the data aids in the understanding of these prehistoric groups, and the manner in which they interacted with each other and their environment. The paleodietary analysis conducted in this work will add to the growing body of knowledge about the people who populated the Atlantic coast, and will generate new research questions for the future.

CHAPTER V
**STABLE CARBON AND NITROGEN ISOTOPE ANALYSIS: RESEARCH
METHODS AND LITERATURE REVIEW**

Stable carbon and nitrogen isotope analysis has been an important part of paleodietary research since the 1970s and 1980s, when methods and techniques involving the use of human bone apatite and collagen were developed and employed for the purposes of understanding humans' interaction with the environment, society, and subsistence needs and practices (Ambrose 1986; De Niro and Epstein 1978, 1981; Krueger and Sullivan 1984; Lee-Thorp et al. 1989; Schoeninger and DeNiro 1983, 1984; Sullivan and Krueger 1981; Walker and DeNiro 1986). In this study, I examine the relationship between the adoption of ceramic technology and the diet of a coastal, hunting-fishing-gathering people who occupied the Atlantic coast of southeastern Brazil from 5000 to 600 BP. I hypothesize that the appearance of pottery at *sambaqui* archaeological sites coincides with a change in diet that is associated with a greater reliance on cultivated C₃ or C₄ plants. To test this hypothesis, I conducted an analysis of stable carbon and nitrogen isotopes from Pre-Ceramic and Ceramic *sambaqui* archaeological sites, the results of which are reported in the following chapter. In this chapter I review how stable carbon and nitrogen isotope ratios inform on past diet and biology, and will review the relevant literature regarding research methods and bioarchaeological applications that apply to the present study.

Carbon and Nitrogen Isotope Fractionation and the Relationship to Diet

The elements of carbon and nitrogen contain stable, i.e. non-radioactive or non-decaying, isotopes that vary in neutron number and therefore mass. Carbon has two stable isotopes, ^{12}C and ^{13}C , and one radioactive isotope, ^{14}C . ^{12}C is the most abundant and lightest stable isotope of carbon, and makes up 98.9% of the carbon found in nature. ^{13}C has one more neutron than carbon-12, and is far less abundant at about 1.1%. Nitrogen also has two stable isotopes, ^{14}N and ^{15}N . ^{15}N contains one more neutron than the more abundant ^{14}N . Nitrogen-14 is the most abundant isotope, and represents over 99% of the element, while nitrogen-15 represents only 0.36% (Ambrose 1993; Fry 2006; Katzenberg 2000).

Fractionation of isotopes occurs during a kinetic or biochemical process in which one isotope is preferentially enriched over another isotope. In the case of carbon, ^{12}C is preferentially taken up during the biochemical process of photosynthesis because it is lighter than stable isotope ^{13}C . $\delta^{13}\text{C}$ represents the ratio of ^{12}C to ^{13}C compared to the standard Pee Dee Belemnite (PDB), a marine limestone originally found in South Carolina that has an isotopic value of 0. The formula for calculating $\delta^{13}\text{C}$ is as follows (all stable isotope ratios are reported in units per mil (‰)):

$$\delta^{13}\text{C}\text{‰} = \left[\left(\frac{^{13}\text{C}/^{12}\text{C}_{\text{sample}}}{^{13}\text{C}/^{12}\text{C}_{\text{standard}}} \right) - 1 \right] * 1000\text{‰}$$

Carbon isotope ratios reflect the degree to which individuals consume different types of plants, specifically C_3 , C_4 , and CAM plants (Ambrose et al. 2003; Katzenberg 1992; O'Leary 1981). Calvin-Benson plants, or C_3 plants, employ a 3-carbon molecule that reacts with carbon dioxide using the enzyme ribulose biphosphate during

photosynthesis, and discriminate against the slower-moving ^{13}C isotope relative to the lighter ^{12}C isotope. C_3 plants include tubers, legumes, and most shrubs and trees found in temperate environments. C_3 plants have an average $\delta^{13}\text{C}$ value of -26.5‰ . Plants that utilize the Hatch-Slack photosynthetic pathway, or C_4 plants, include tropical grasses such as maize, as well as millet, sorghum, and sugar cane. These plants use a 4-carbon molecule that reacts with carbon dioxide from the atmosphere through carboxylation of phosphoenolpyruvate. C_4 plants have a $\delta^{13}\text{C}$ of roughly $-12.5\text{‰}_{\text{PDB}}$, and discriminate less against the heavier ^{13}C isotope of carbon. Paleodietary studies have used stable carbon isotopes to investigate the adoption and consumption of maize by New World prehistoric groups (Katzenberg et al. 1995; Schwarcz et al. 1985; Vogel and van der Merwe 1977). Crassulacean Acid Metabolism plants, or CAM plants, have an isotopic value that lies in an intermediate range between C_3 plants and C_4 plants. CAM plants may employ either a 3-carbon molecule or 4-carbon molecule to fix carbon from the atmosphere, and their isotopic values depend upon which carboxylation process is used, and whether it occurs in darkness or light. These plants tend to exist in xeric environments, and include succulents and cacti (Ambrose 1993; Katzenberg 2000; O'Leary 1981; Tieszen 1991).

As people and animals consume plants and other animals and/or marine and freshwater life, they incorporate carbon dietary signals into their tissues. However, dietary inferences based on carbon isotope ratios must take into consideration the source of the biological tissue analyzed. Hydroxyapatite (bone apatite) is a “poorly crystalline” carbonated calcium phosphate that comprises the inorganic, mineral fraction of bone and dental enamel, and is expressed chemically as $\text{Ca}_{10}(\text{PO}_4)_6\text{OH}_2$ (Ambrose 1993; Krueger

and Sullivan 1984). Carbonate exists in two forms within apatite: structural and adsorbed. Structural carbonate can replace PO₄ within the crystal, and adsorbed carbonate occurs on the surface of the crystal; adsorbed carbonate is easily solubilized, while structural carbonate may be better protected against the effects of diagenesis, as it has a lower turnover rate (Ambrose 1993). Carbon isotope values derived from bone apatite reflect the whole diet, as carbohydrates, proteins, and lipids are incorporated from the circulatory system as dissolved bicarbonate. Bone collagen, an organic fraction of bone that consists of a long, fibrous protein made of the amino acids glycine, alanine, proline, and hydroxyproline, contains carbon and nitrogen; hence, δ¹³C and δ¹⁵N values are derived from bone collagen (Krueger and Sullivan 1984). This organic fraction of bone mainly reflects the protein portion of the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993).

Nitrogen isotope ratios are similarly expressed as ¹⁵N to ¹⁴N compared to the standard of AIR. The equation for arriving at δ¹⁵N is as follows:

$$\delta^{15}\text{N}\text{‰} = \left[\left(\frac{^{15}\text{N}/^{14}\text{N}_{\text{sample}}}{^{15}\text{N}/^{14}\text{N}_{\text{standard}}} - 1 \right) \right] * 1000\text{‰}$$

When used in conjunction with stable carbon isotopes, nitrogen isotopes allow the researcher to determine the trophic level of dietary protein, as δ¹⁵N values become enriched by 3‰ at each trophic level of the protein source (Schoeninger and DeNiro 1984; Schwarcz et al. 1985). Because a wide range of carbon sources contribute to marine plants, marine organisms have δ¹³C values that fall between C₃ and C₄ terrestrial plants. Using nitrogen and carbon isotopes together, therefore, marine sources of dietary protein, such as fish, can be distinguished from terrestrial sources of protein (Katzenberg

1992; Schoeninger and DeNiro 1984; Schwarcz and Schoeninger 1991). These dietary distinctions are crucial for studies involving prehistoric groups that, like the coastal foragers of Brazil, exploited marine and terrestrial resources.

Bone collagen and apatite from archaeological contexts are subject to contamination by organic and inorganic sources, and may become chemically and physically altered through a process called diagenesis. Researchers can treat bone samples in the laboratory to remove contaminants, but each sample must be evaluated to be sure it is suitable for analysis. Possible sources of organic contamination that bone might encounter post-deposition include insect remains, fungus, root hairs, and humates (decayed organic matter in the soil). After contaminants have been removed from bone collagen samples and they are processed for stable carbon and nitrogen isotope ratios, their quality can be determined by looking at the ratio of carbon to nitrogen concentrations. If the ratio of C/N falls between 2.9 and 3.6, then the quality of the bone sample has not been compromised by post-depositional processes, and may be used for paleodietary interpretation (De Niro 1985). Samples that fall outside of this range are far more likely to display significant and errant shifts in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ dietary signals.

Ambrose (1990) discusses the preservation quality of bone collagen further in his description of C/N ratios of human and mammalian samples from prehistoric and historic sites in East Africa. He confirms previous studies regarding the acceptable C/N ratio range of 2.9 to 3.6, and notes that concentrations of carbon and nitrogen drop off quickly in bone samples outside of this range. The author also prescribes a treatment protocol that will remove the majority of inorganic and organic contaminants found in

post-depositional sediments, and recommends demineralization in a weaker acid to preserve as much of the collagen as possible. Ambrose (1990) also suggests the use of NaOH for the removal of humic acids. Neglecting treatment procedures will result in poor collagen retrieval, and samples that either underestimate or overestimate the contribution of marine, C₄, or C₃ foods.

van Klinken (1999) points out the distinction between degradation and contamination of bone collagen; degradation most often occurs in tropical climates with low collagen concentrations, while contamination from outside sources is more of a concern in temperate areas. Another way to examine sample quality is to calculate the % yield of collagen. Twenty-two percent of fresh bone is collagen by weight, but this figure declines quickly once burial occurs. When the percent yield of collagen drops to 0.5%, the sample should not be used; to be conservative, the author prefers to use a cutoff of 1% collagen yield (van Klinken 1999). In any case, any sample that has a percent yield less than 2% should be examined for any other indicators of degradation or contamination. van Klinken (1999) uses a C/N ratio that is more restricted than that described by Ambrose (1990), and only accepts samples in the range of 3.1 to 3.5. %C (weight % of C in the combusted sample) also provides information regarding sample quality. Intact collagen samples usually contain 35% weight in carbon; higher values may indicate organic contamination, while lower values inorganic contamination. Intact nitrogen isotope samples will have a %N of between 11 and 16% (van Klinken 1999).

Bone apatite may be contaminated in the post-depositional environment by calcium carbonate (delivered through groundwater or rainwater), and the subsequent

deposition of calcite (Krueger and Sullivan 1984; Sillen et al. 1989). Adsorbed (non-structural) carbonate can be removed with pre-treatments using a 1.5% solution of sodium hypochlorite (to remove organic material) and a 1 M solution of acetic acid to remove calcite and other inorganic contaminants from the sample (Lee-Thorp et al. 1989).

Koch et al. (1997), in a study of diagenetic alterations of hydroxylapatite in bone and teeth, found that a modified pre-treatment program consisting of dilute sodium hypochlorite and a 1 M buffered acetic acid solution (or a .1 M acetic acid solution) removed contaminants from a sample without damaging or altering the isotopic composition of the sample. Treatment with lower pH solutions caused a significant increase in oxygen isotope ratios, and a decrease in carbon isotope ratios. The authors found that, due to its structural properties, tooth enamel retained a more faithful isotopic signature than bone apatite and or dentin. Due to the wide variation of isotope measurements observed in the bone apatite and dentin samples, the authors do not regard these fractions of bone suitable for paleodietary analysis (Koch et al. 1997).

Wright and Schwarcz (1996) employ the use of Fourier transform infrared spectroscopy (FTIR) analysis to examine the structural properties of bone apatite samples that have been pre-treated, yet show evidence for isotopic alteration. Thirty-three femoral samples from the Late/Terminal period Maya site of Dos Pilas were pre-treated using a 1.5% solution of sodium hypochlorite and a 1 M acetic acid solution. In addition, 2 mg of finely ground bone powder from each sample was combined with 200mg of potassium bromide and made into 12mm pellets to be analyzed using FTIR. A

crystallinity index (CI) for each sample was produced for each sample, as well as C/P (carbonate to phosphate) ratios. A high CI indicates that recrystallization and significant diagenetic alteration of the sample has occurred, and a low C/P ratio signifies samples do not retain a biogenic signal suitable for paleodietary analysis. FTIR allows for the examination of the structural integrity of bone apatite samples to ensure that diagenetically altered material is not being used to infer past diet.

Carbon Isotope Analysis: Early Research and Current Applications

Early investigations into the manner in which carbon isotopes are incorporated into bodily tissues involved the use of feeding experiments and reported stable carbon isotope data from the remains of modern animals with known diets. DeNiro and Epstein (1978) devised a controlled feeding experiment of lab animals, including shrimp, nematodes, flies, moths, snails, grasshoppers, weevils, milkweed bugs, and mice, and conducted a carbon isotope analysis of the animal remains. The researchers then compared the $\delta^{13}\text{C}$ values to the isotopic composition of each of the diets that were given to the animals. Through these experiments, DeNiro and Epstein (1978) concluded that stable carbon isotopes could be used to distinguish between broad classes of plants, such as C_3 and C_4 carbon sources, and that this methodology could be applied to dietary analyses of fossil animals.

Sullivan and Krueger (1981) supported the use of bone apatite to analyze past diet, and conducted a comparative analysis using the organic and inorganic fractions of modern and archaeological bone. Modern bone samples included the use of giraffe, buffalo, gazelle, domestic cow, deer, and warthog, while archaeological samples

included human, bison, ox, mastodon, and domestic cow. The authors noted the greater isotopic fractionation that occurred between bone apatite and diet, but praised the use of this fraction of bone for its ability to be used more reliably on older specimens. A later article by Krueger and Sullivan (1984) explores different models for bone apatite and collagen fractionation based on the diets of omnivores, carnivores, and herbivores. The authors state that bone apatite incorporates carbon from blood bicarbonate, and its isotopic value reflects the carbohydrates that are used in energy metabolism. This research also found a 5‰ enrichment between bone collagen and diet in carnivores.

Following this study, Lee-Thorp et al. (1989) also analyzed the bone apatite and collagenous fractions of bone in their examination of modern faunal remains from southern Africa, and compared these results to archaeological samples from the same region. The researchers selected a mix of modern material from herbivores, carnivores, and omnivores, which included baboons, felids, and jackals, zebra, and giraffe.

Archaeological human remains came from coastal burials and shell middens on the southwestern Cape. The results showed mean differences in collagen-apatite spacing based on diet, with herbivores having the greatest difference between fractions of bone at 6.8‰, omnivores at 5.2‰, and carnivores at 4.3‰. The authors also observe different fractionation patterns of carnivores and herbivores in their bone collagen and apatite to diet spacing ($\Delta d\text{-co}$ and $\Delta d\text{-ap}$) at 5‰ and 12‰, respectively. They also note the small isotopic difference in bone apatite and collagen ratios of the coastal archaeological sample (2.6‰), and propose that this small difference may be due to their coastal diet.

More experimental studies with laboratory animals helped clarify the relationship between stable carbon isotope ratios of collagen and apatite to dietary protein and energy, as well as the isotopic relationship with each other (Ambrose and Norr 1993; Tieszen and Fagre 1993). In their experimental study, Tieszen and Fagre (1993) fed laboratory mice diets of varying isotopic value (based on C₃, C₄, and mixed strategies) to understand the spacing in $\delta^{13}\text{C}$ that is observed between diet and collagen/apatite. The researchers also considered the isotopic values and proportion of carbohydrates, lipids, and protein for each diet in order to understand how the body assimilates ¹³C into its different tissues. Tieszen and Fagre (1993) discovered that bioapatite is strongly correlated with bulk diet than collagen, and that protein provides the most significant amount of carbon to collagen.

Ambrose and Norr (1993) also conducted an experimental feeding program using rats fed various diets based on C₃, C₄, and mixed plant and protein sources. The purpose of the study was to explore the manner in which carbon is routed to different tissues of the body. The results indicate that dietary protein is routed to collagen, and that it takes very little C₄ protein added to a C₃ energy diet (5%) to significantly enrich the $\delta^{13}\text{C}$ value of collagen. Therefore, the authors conclude that $\delta^{13}\text{C}$ values of collagen “substantially underestimate the isotopic composition of the non-protein portion of the diet, even at extremely low levels of dietary protein” (Ambrose and Norr 1993: 31). In addition, Ambrose and Norr (1993) found that the isotopic values of bone apatite are representative of the whole diet, and that the mean diet to tissue difference for bone carbonate equals 9.4‰. This value remains the same, regardless of the protein

contribution of the diet. When dietary protein and energy have the same ^{13}C value, then the difference between diet and bone collagen is 5‰. Given the differences in isotopic composition between collagen and apatite, the best dietary analyses will be those that incorporate both bone fractions in their research models. The contribution of these feeding experiments facilitated the interpretation of future studies involving the use of stable carbon isotope analysis, and their value to paleodietary research cannot be overstated.

Drawing on the results of research examining the contributions of stable carbon isotopes to dietary interpretation, Harrison and Katzenberg (2003) explored the dietary spacing of bone collagen and apatite ($\Delta^{13}\text{C}_{\text{CA-CO}}$) to test whether it can be used to identify the introduction of C_4 plants into a C_3 diet, as well as investigate the role of protein in the subsistence practices of prehistoric populations. The authors use a group of prehistoric burials from southern Ontario, whose diet included animal C_3 protein and freshwater fish, and another set of burials from British Columbia and San Nicolas Island off the coast of California. These latter populations had a diet high in marine foods, and in the case of British Columbia, salmon (an anadromous fish). Harrison and Katzenberg use a model of examining the dietary contributions of carbon whereby $\Delta^{13}\text{C}_{\text{CA-CO}}$ equals 4.4‰ when the $\delta^{13}\text{C}$ value of protein is the same as that of the whole diet. 9.4‰ represents the spacing between bone apatite and diet, and 5‰ represents the spacing between bone collagen and diet when the ^{13}C values of energy and protein are the same; subtract the two, and the difference equals 4.4‰. Collagen and apatite spacing greater than 4.4‰ indicates that the protein portion of the diet is less enriched in ^{13}C than the

whole diet; conversely, spacing less than 4.4‰ indicates that the protein portion of the diet is more enriched in ^{13}C than the whole diet. This latter example would be the case, for instance, in a population that relied heavily on a combination of ^{13}C enriched proteins, such as marine foods, and C_3 plant foods for energy. Where $\Delta^{13}\text{C}_{\text{CA-CO}}$ is greater than 4.4‰, a diet of C_4 carbohydrates and C_3 proteins is suggested. By analyzing both bone apatite and collagen carbon isotope ratios plotted against time, Harrison and Katzenberg (2003) discovered that southern Ontario populations began consuming maize earlier than previously thought, as evidence for the consumption C_4 carbohydrates appears in isotope ratios of bone apatite earlier than in bone collagen. It takes a much greater threshold of C_4 carbohydrate consumption to be seen in bone collagen alone.

In 2007, Kellner and Schoeninger also examined the ways in which carbon isotope ratios from bone apatite and collagen could inform on diet, and offered a critical analysis of using absolute values from $\Delta^{13}\text{C}_{\text{CA-CO}}$ to make dietary interpretations. Using published data of stable carbon and nitrogen isotope ratios from a wide range of archaeological populations and modern free range faunal species, the authors assert that dietary interpretations can be more accurately made by plotting carbon isotopes from bone apatite and collagen against one another, and calculated a regression line along which one can determine the degree to which groups consumed C_3 and C_4 proteins and carbohydrates. Archaeological populations were chosen based on reported isotope data, and their disparate diets that would lend themselves to this kind of modeling. While some dietary expectations held up with the bivariate model, others displayed a greater reliance on unexpected C_3 or C_4 food sources. For example, at Grasshopper Pueblo, the

carbon isotope plots show that domestic maize-fed turkeys, not mule deer, made up a much larger portion of the protein intake than previously thought. The model also distinguishes marine versus terrestrial sources of protein in paleodietary data, and shows whether the source of energy in the diet is C₃ or C₄. The bivariate plots allow for greater interpretive power, as they show more detailed and subtle aspects of diet within and between populations (Kellner and Schoeninger 2007).

Understanding the manner in which plants extract carbon from the atmosphere is crucial to the interpretation of carbon isotope ratios, as well. The concentration of CO₂ in the atmosphere affects fractionation in plants. With high CO₂ levels, plants may discriminate against the heavier isotope of carbon, and significant growth can occur; however, in atmospheres with limited CO₂, plants will discriminate less against ¹³C, and growth is more restricted (O'Leary 1981). Plants that photosynthesize in a dense, forested area with a heavy canopy will display more negative δ¹³C ratios than open forest plants, because CO₂ is recycled and re-fixed. In such canopied forests, a gradient in carbon isotope ratios occurs whereby leaves and plants near the ground are less enriched than those at the top of the canopy. The δ¹³C of the air in such forests measures 5 to 6‰ lighter than air outside of this type of heavily forested environment (van der Merwe and Medina 1989). Therefore, animals that consume plants in this type of environment will incorporate these less enriched carbon isotope ratios into their bodily tissues, and into the tissues of humans who eat those animals (Krigbaum 2003; Tieszen 1991; van der Merwe and Medina 1991).

Nitrogen Isotope Analysis: Early Research and Current Applications

Early research of stable nitrogen isotope ratios also involved the use of controlled feeding experiments. DeNiro and Epstein (1981), in a study similar to their 1978 experiment involving carbon isotope ratios, raised various insects, shrimp, and mice on diets of known nitrogen isotope value, and then analyzed their tissues. The researchers found that ^{15}N of animal tissues is enriched relative to the diet; however, the authors also found that $\delta^{15}\text{N}$ of different animals of a species raised on the same diet can differ, and that two species fed the same diet can have large differences in their level of ^{15}N enrichment over diet. DeNiro and Epstein (1981) also found that tissues of mice fed different diets also had different stable nitrogen isotope ratios. Analyses using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ together may help solve paleodietary problems in archaeology, as bone collagen preserves dietary signals that may not be as readily apparent in the archaeological record. In the Tehuacan Valley of Mexico, the use of these isotopes revealed that prehistoric populations consumed corn and beans as part of their diet much earlier than previously believed. The researchers caution that plant sources of nitrogen must be taken into consideration in paleodietary interpretation, as nitrogen fixing plants (which fix nitrogen from symbiotic soil bacteria), such as legumes and algae, have lower nitrogen isotope ratios than plants that use inorganic sources of nitrogen to grow. Conversely, aquatic sources of protein have higher nitrogen isotope values than terrestrial protein sources, and this may be useful to distinguish different dietary practices of the past.

Schoeninger and DeNiro (1983) also discussed the higher nitrogen isotope values of marine resources compared to terrestrial sources, and examine the diets of historic and

prehistoric populations with divergent subsistence practices in order better characterize this relationship. The diet of historic Alaska Eskimo consists primarily of marine mammals (85% of the diet), and average $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ of bone collagen measures between 17 and 20‰, and -12 and -14‰, respectively. Prehistoric populations from the Bahamas have lower nitrogen isotope values than expected given their reliance on marine resources; however, this is due to their dependence on reef fish that consume nitrogen fixing plants. Agricultural groups had significantly lower nitrogen isotope ratios (ranging from $\delta^{15}\text{N}$ 6‰ to 12‰) than groups who relied on marine mammals and/or salmon for their subsistence. The authors note a 3‰ enrichment of nitrogen at each trophic level along the food chain, such that carnivorous fish and mammals had higher nitrogen isotope ratios than their vegetarian or herbivorous terrestrial counterparts. Schoeninger and DeNiro (1983) caution that it may not be possible to detect freshwater fish in the diet using nitrogen isotope ratios, as these measurements often overlap with those from terrestrial resources. However, Schwarcz et al. (1985) did not experience difficulty distinguishing freshwater fish in the diet of southern Ontario populations, as $\delta^{15}\text{N}$ values for fish measured -16.5‰, well outside the isotopic range that would be expected for herbivores.

Early research into the manner in which stable nitrogen isotope values reflect diet also had to consider their possible variation in the environment. Heaton et al. (1986) report the $\delta^{15}\text{N}$ values from prehistoric groups of southwest South Africa and Namibia. Though nitrogen isotope ratios from South African coastal people confirm their reliance on marine resources, the $\delta^{15}\text{N}$ of interior groups (as well as herbivorous mammals of the

same region) is wildly variable and, at times, high enough to cross over into the lower threshold of a marine dietary signal. As none of the sampled individuals relied on marine resources, the authors suggest that variations in climate, particularly aridity, are responsible for the range of values. Plants sampled from the interior do not show variations in $\delta^{15}\text{N}$; therefore, the authors posit that the nitrogen isotope enrichment is being accomplished by the tissues of the animal proper.

To investigate this problem further, Heaton (1987) collected and analyzed 140 terrestrial plants from different habitats and climates in South Africa and Namibia. At the majority of sites, $\delta^{15}\text{N}$ values of the plants measured between -1 and 6‰. However, coastal plants had consistently higher nitrogen isotope values than plants found inland. After excluding differences in photosynthetic pathway and the effects of salinity as possibilities for high $\delta^{15}\text{N}$ values, Heaton (1987) could draw no definitive conclusions from his research, other than noting that aridity and high nitrogen isotope values are correlated with one another, and that observed values may be associated more with water consumption and the metabolism of nitrogen by animals in arid areas.

Ambrose (1987) suggests that Heaton et al. (1986) are premature in their initial paleodietary analysis of prehistoric groups from South Africa, and hypothesizes that urea excretion among water-conserving herbivores with high protein diets is the cause of the anomalously high nitrogen isotope ratios described by the researchers. Particular animals, such as the impala, sheep, dikdik, and others expel a highly concentrated urea that is depleted in ^{15}N relative to the diet. The remaining nitrogen in the tissues of these animals becomes enriched, and is passed on to human beings who consume the enriched

tissues. Ambrose (1991) examines environmental causes for variation in nitrogen isotope ratios, and concludes that at least some of the variation can be attributed to climate. Soil profiles offer much of the variation, as nitrogen concentrations can vary due to the age, degree of disturbance, aridity, and makeup of the soil (clay having higher $\delta^{15}\text{N}$ than sands and silts). Plants with the highest $\delta^{15}\text{N}$ values tend to occur in arid locales and marine coastal environments. The author again asserts that urea recycling amongst water-stressed herbivores remains a possible source of nitrogen enrichment, but admits that more work needs to be done on this problem. As far as paleodietary analyses are concerned, it is important to understand the local resources before interpretations are made, and that it may also be difficult to compare populations that hail from distinct environmental regimes.

Further investigation of this problem asserts that nitrogen isotope ratios are indeed higher in arid regions, and that a relationship between low rainfall rates and high nitrogen isotope ratios has been observed (Schwarcz et al. 1999). The authors present $\delta^{15}\text{N}$ data from archaeological fauna, plants, and human remains from Dakhleh Oasis, Egypt, a place with very low annual precipitation, and found highly enriched nitrogen isotope ratios, particularly in the plants (fig, olive, date, grape, barley, wheat, and others). The authors exclude the possibility that urea recycling is responsible for this phenomenon, and indicate that high ^{15}N of desert soils may instead be the greatest contributing factor. A feeding experiment conducted by Ambrose (2000) using rats fed varying amounts of protein and given differing amounts of water to drink, with some being water-stressed and exposed to greater temperatures, revealed no significant

difference in the manner in nitrogen isotope ratio values of bone collagen were expressed. The author concludes that, for rats at least, neither low protein diets nor exposure to heat and water stress cause an increase in nitrogen isotope ratios.

In another controlled feeding study, Sponheimer et al. (2003) examine the $\delta^{15}\text{N}$ values of herbivores to determine if digestive anatomy (hindgut fermenters versus foregut fermenters) or dietary protein levels influenced the variations in nitrogen isotope ratios that has been observed between herbivores. The researchers included llamas, alpacas, goats and cattle (all foregut fermenters), as well as horses and rabbits (hindgut fermenters) in their experimental study. Hair, instead of bodily tissue, was used for the nitrogen isotope analysis. The results found that $\delta^{15}\text{N}$ varied significantly between herbivores fed the same diet, even those that had not been exposed to heat and water stress (Sponheimer et al. 2003). The authors cite support, though weak, that some of the difference may be due to foregut versus hindgut digestion processes. However, their results indicate greater nitrogen isotope enrichment with herbivores fed high protein diets. This is largely due to matters of efflux, the ridding of nitrogen isotopes in urine and fecal matter, which vary depending upon the consumption of a low protein versus high protein diet. On a high protein diet, herbivores rid most of their enriched ^{15}N through urine, not fecal matter; the converse is true for herbivores eating low protein diets. Herbivore fecal matter is enriched compared to diet by .5 to 3‰ (Sponheimer et al. 2003).

Warinner and Tuross (2009) examine tissue-diet spacing for bone collagen and apatite samples taken from the humerus and mandible of pigs raised in a controlled

feeding experiment to determine if alkaline cooking of maize affects $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values of these tissues after the treated food is digested. While previous research had shown no isotopic change in maize after it was treated with lime, Warinner and Tuross (2009) found that alkaline treatments released amino acids during the digestion process that, in fact, did contribute to the alteration of carbon and oxygen isotope values in the tissues of the pigs. The pigs fed alkaline-treated corn, rather than raw corn, showed enrichment in $\delta^{13}\text{C}$ collagen values of 0.9‰, which represents a significant shift in $\Delta_{\text{tissue-diet}}$ values. $\delta^{18}\text{O}$ values also showed a significant enrichment in tissue-diet spacing of 0.3‰. Carbon isotope values of tooth enamel were enriched over those of bone apatite for both the raw maize diet and the alkaline-treated diet in pigs, at 2.3‰ and 2.2‰, respectively. Oxygen isotope values of tooth enamel apatite also showed significant enrichment compared to bone apatite, at 1.7‰ for the raw diet, and 1.6‰ for the alkaline-treated diet. In addition, the authors discovered no significant difference in carbon and oxygen isotope values between the mandible and humerus, which is welcome news for researchers who use various bones from archaeological contexts in their paleodietary reconstructions. However, paleodietary interpretations for those populations that use alkaline treatments to process food may need to be reassessed, as do studies that employ the use of enamel apatite to infer diet (Warinner and Tuross 2009).

Stable nitrogen isotopes from bone collagen are useful for determining relative dependence on marine and terrestrial food sources, as well as identifying the trophic level relationship between plants, animals, and humans in a given environment. Schoeninger and DeNiro (1984) contributed significant understanding of how these two

isotopes can function together in their analysis of marine and terrestrial birds, fish, and mammals. Their results also demonstrated a 3‰ enrichment of $\delta^{15}\text{N}$ for each trophic level along the food chain; for example, they showed that marine animals that ate fish had a $\delta^{15}\text{N}$ measuring 16.5‰, while animals that ate invertebrates, such as marine mollusks, had a nitrogen isotope ratio of 13.3‰, on average (Schoeninger and DeNiro 1984). This study showed a $\delta^{15}\text{N}$ range of exclusive marine feeders to be between 9.4 and 23‰, with an average of $14.8\text{‰} \pm 2.5\text{‰}$; however, the highest nitrogen isotope value for terrestrial feeders was reported at 10‰. Freshwater fish, aquatic migratory birds, and anadromous fish are the only categories of animal that overlap between the nitrogen isotope values of marine and terrestrial feeders, so caution must be made in paleodietary reconstructions where these food sources are common. With the exception of these crossover groups, nitrogen isotope ratios are particularly useful in distinguishing between terrestrial and marine diets, especially in regions where C_4 plants are available for consumption.

Stable Carbon and Nitrogen Isotope Analysis and Bioarchaeology

The study of carbon and nitrogen isotope ratios, and their relationship to diet, allows paleodietary researchers to use $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ comprehensively. The efficacy of using stable carbon and nitrogen isotopes together for the purpose of dietary interpretation was explored in early research by Ambrose (1986) and Walker and DeNiro (1986). In the first study, Ambrose (1986) examined the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of modern herbivores and carnivores in the central Rift Valley of Kenya, and used additional published data of grazers, browsers, and caprines from a previous co-authored

study with DeNiro (1986). Ambrose (1986) also conducted a C and N isotope analysis using 97 human remains housed in museum collections from historic, proto-historic, and archaeological sites in Kenya, Tanzania, and Capte Town, South Africa. Among the non-human bones tested, carbon isotope ratios from bone collagen were able to separate non-forest grazers, browsers, and mixed feeders. Carbon and nitrogen isotope values for the human subjects were consistent with available ethnographic accounts of their diet, and pastoralists who depend heavily on animal protein were distinguishable from farmers who rely more heavily on plants. In addition, prehistoric populations generally fit expectations based on dietary reconstructions of archaeological remains.

In a study examining interior and coastal prehistoric populations in Southern California, Walker and DeNiro (1986) demonstrate that stable carbon and nitrogen isotope ratios can distinguish groups that relied on marine versus terrestrial resources, as well as show changes in subsistence practices through time. The authors used bone collagen samples from archaeological sites in the Santa Barbara Channel area, which include three different ecological zones: the Channel Islands, coastal mainland, and coastal interior. The differences in resource availability between these areas of close proximity is of particular interest, as archaeological evidence indicates that Channel Island groups imported scarce terrestrial foodstuffs, such as acorns, to the islands. The carbon and nitrogen isotope results support evidence provided by archaeological evidence and ethnohistorical accounts: Channel Island occupants subsisted on a large quantity of marine resources, particularly fish, but terrestrial plant and animal resources were not nearly as abundant. The authors also assert that dependence on marine

resources among mainland and interior Santa Barbara Channel area increased from the early prehistoric period to the late prehistoric period (Walker and DeNiro 1986).

Early studies such as these set the stage for tremendous scholarship related to archaeological populations and diet, and over the next twenty-five years this area of study has continued to grow. Through research designs involving herbivores, carnivores, mammals, insects, water-dependent and water conserving animals, and creatures fed specific diets while raised in the laboratory, researchers have gained a much better understanding of the ways in which carbon and nitrogen isotopes are incorporated into the body's tissues through diet. Compiling and analyzing already published data has also led to breakthroughs in the interpretations of past diet (Harrison and Katzenberg 2003; Froehle et al. 2012; Kellner and Schoeninger 2007).

Bioarchaeological studies employ stable carbon and nitrogen isotope ratios to investigate not only what people ate, but also to help answer a wide range of anthropological problems, including those related to social status (Ambrose et al. 2003; Cox et al. 2001; Jay and Richards 2006; Kellner and Schoeninger 2008; Privat and O'Connell 2002; Ubelaker et al. 1995; White et al. 1993; White et al. 2001; Yoder 2012), infant weaning practices (Choy et al. 2010; Dupras et al. 2001; Fuller et al. 2006; Herring et al. 1998; Katzenberg et al. 1996; Nitsch et al. 2011; Pearson et al. 2010; Schurr 1997; Schurr and Powell 2005; Wright and Schwarcz 1998; Wright and Schwarcz 1999), the introduction of a crop food (Gil et al. 2009; Hard et al. 2008; Hutchinson et al. 1998; Katzenberg et al. 1995; Schoeninger 2009; Schwarcz et al. 1985), resource use/intensification/depletion (Beasley et al. 2013; Emery et al. 2000;

Larsen et al. 1992; Larsen et al. 2008; Tomczak 2003; White et al. 1993; Yesner et al. 2003), and health (Ambrose et al. 2003; Papathanasiou et al. 2000; White and Armelagos 1997; Wright and White 1996).

Studies that employ stable carbon and nitrogen isotope analysis also investigate nuances of diet and social interaction among populations, and offer a foundation for ongoing research. The bioarchaeological questions for the *sambaqui* populations of the Atlantic coast of Brazil in this study are related to many of the above subject areas, particularly social status, the introduction of a crop food, and resource use/intensification/depletion. To identify a baseline of foods that these coastal groups ate is also important, so that future studies can incorporate these data into other research questions.

CHAPTER VI
PALEODIETARY ANALYSIS USING STABLE CARBON
AND NITROGEN ISOTOPES:
DATA COLLECTION, RESULTS AND DISCUSSION

To test the hypothesis that the adoption of ceramic technology among coastal *sambaqui* populations is associated with a change in diet, I conducted an analysis of stable carbon and nitrogen isotopes. Stable carbon and nitrogen isotope ratios of human skeletons allow for the investigation of changes in marine and terrestrial resource procurement through time. I expect $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ collagen values from Pre-Ceramic occupations in Santa Catarina to indicate a heavy reliance on marine resources, as well as to closely correspond to the average isotope values that have been reported for Pre-Ceramic *sambaqui* occupations in this region ($\delta^{13}\text{C}$ of $-11.8 \pm 1.04\text{‰}$ and $\delta^{15}\text{N}$ of $15.7 \pm 1.71\text{‰}$) (De Masi 1999). If coastal *sambaqui* foragers of southeastern Brazil began intensifying new resources concurrent with the adoption of pottery, then the subsistence model for the adoption of ceramic technology would be supported; conversely, if no significant change in diet is seen with the adoption of pottery, then the *prestige model* for the adoption of ceramic technology must be considered.

Research Expectations

If coastal groups began consuming maize, a C_4 plant, at the same time as the adoption of ceramic technology, I would expect $\delta^{13}\text{C}$ ratios of bone apatite to become more enriched in the heavier isotope of carbon. I would expect $\delta^{13}\text{C}$ ratios of collagen

from Ceramic occupation skeletons to stay the same, as marine sources of protein have isotope ratios that are similar to C₄ plants. Through the analysis of $\delta^{15}\text{N}$ ratios, I will be able to identify changes in the trophic level of the protein source, and determine whether the consumption of marine foods changed through time. A significant decrease in $\delta^{15}\text{N}$ ratios through time would reflect a greater reliance on terrestrial sources of protein versus marine protein. If $\delta^{15}\text{N}$ ratios decrease or remain stable through time, and $\delta^{13}\text{C}$ ratios become significantly less enriched after the introduction of pottery, then one can argue that coastal foragers intensified the use of a C₃ plant, such as manioc.

Examination of the difference between collagen and apatite carbon isotope values ($\Delta^{13}\text{C}_{\text{CA-CO}}$) allows for greater distinction between marine and terrestrial sources of carbon (Harrison and Katzenberg 2003). When carbon isotope ratios from dietary protein and the whole diet are roughly the same, the $\Delta^{13}\text{C}_{\text{CA-CO}}$ should equal 4.4‰. I expect the $\Delta^{13}\text{C}_{\text{CA-CO}}$ of Pre-Ceramic occupation skeletons to be less than 4.4‰, as this value reflects a diet rich in marine protein and C₃ terrestrial plants. If coastal groups began consuming maize concomitant with the adoption of pottery, then bone apatite would become more enriched in the heavier isotope of carbon and the $\Delta^{13}\text{C}_{\text{CA-CO}}$ of Ceramic occupation groups should approach 4.4‰. If coastal groups began consuming a greater amount of terrestrial protein than marine protein through time, and the $\Delta^{13}\text{C}_{\text{CA-CO}}$ exceeds 4.4‰ after the introduction of pottery, then it is reasonable to infer that coastal foragers began intensifying the use of C₄ plants.

The Dataset

For this study, I sampled bone collagen of 86 individuals for stable carbon and nitrogen isotope analysis, and the bone apatite fraction of 104 individuals. I collected data from the following sites in Santa Catarina: Cabeçuda, Enseada I, Forte Marechal Luz, Laranjeiras I, Laranjeiras II, Morro do Ouro, Rio Comprido, Tapera, and Espinheiros II. Two other sites, Zé Espinho and Geribá II, are located in the state of Rio de Janeiro. Table 6.1 provides detailed information about the skeletal data set and stable carbon and nitrogen isotope ratios that I used for this paleodietary analysis. All measurements of stable carbon and nitrogen isotope ratios are reported in permil (‰).

Table 6.1: Skeletal Sample Information and Data

Site ¹	Burial	Age ²	Sex ³	Period ⁴	Bone ⁵ Sample	$\delta^{13}\text{C}_{\text{CO}}$	$\delta^{13}\text{C}_{\text{CAP}}$	$\Delta^{13}\text{C}_{\text{CA-CO}}$	$\delta^{15}\text{N}$
Cabeçuda	1707	Adult	M	PC	Hum	--	-8.29	--	--
Cabeçuda	1708	YA	I	PC	Fibula	-11.31	-6.96	4.35	16.53
Cabeçuda	1709	Adult	F	PC	Hum	-11.29	-7.31	3.98	17.70
Cabeçuda	1710	Adult	M	PC	Femur	-11.14	-7.21	3.93	17.36
Cabeçuda	1711	Adult	F	PC	Hum	--	-8.17	--	--
Cabeçuda	1712	Adult	M	PC	Femur	-11.21	-7.42	3.79	19.11
Cabeçuda	1716	Adult	M	PC	Tibia	-11.47	-7.83	3.64	19.84
Cabeçuda	1721	Adult	M	PC	Hum	-10.95	-7.45	3.5	19.46
Enseada I	1	Adult	I	C	Hum	-12.87	-7.70	5.17	14.65
Enseada I	7	Adult	M	C	Rib	-12.68	-7.58	5.10	14.72
Enseada I	10	Adult	PM	C	Hum	-12.58	-9.92	2.66	17.03
Enseada I	14*	Adult	M	PC	Rib	-10.84	-6.03	4.81	17.84
Enseada I	15*	YA	M	PC	Radius	-10.72	-6.86	3.86	13.87
FML	7	Adult	I	C	Femur	-13.68	-10.86	2.82	15.36
FML	10	Adult	I	PC	Tibia	-11.64	-9.05	2.59	14.51
FML	11	Adult	I	PC	Hum	-12.43	-9.80	2.3	15.64

Table 6.1 Continued.

Site ¹	Burial	Age ²	Sex ³	Period ⁴	Bone ⁵ Sample	$\delta^{13}\text{C}_{\text{CO}}$	$\delta^{13}\text{C}_{\text{AP}}$	$\Delta^{13}\text{C}_{\text{CA-CO}}$	$\delta^{15}\text{N}$
FML	12*	Adult	I	PC	Radius	-19.49	-12.80	6.69	11.18
FML	13	Adol	I	PC	Fibula	-11.69	-8.12	3.57	14.76
FML	22	Adult	I	PC	Femur	-12.69	-10.86	1.83	14.59
FML	28	Adult	PF	C	Tibia	-14.45	-12.04	2.41	13.92
FML	30	Adult	I	C	Radius	-12.82	-10.50	2.32	16.42
FML	33	Adult	I	C	Tibia	-13.92	-10.83	3.0	14.47
FML	40	Adult	I	PC	Hum	-14.78	-11.78	3.0	12.70
FML	46	Adult	I	PC	Radius	-10.81	-8.67	2.14	14.11
FML	49	Adult	I	PC	Fibula	-14.76	-11.49	3.27	12.88
FML	52	Adult	I	C	Fibula	-13.32	-11.77	1.55	16.29
FML	53	Adult	M	C	Scapula	-13.34	-11.02	2.32	15.50
FML	56	Adult	I	C	Fibula	-13.47	-11.52	1.95	14.17
LJ I	118	Adult	M	PC	Ulna	-12.19	-8.04	4.15	14.23
LJ I	119	Adult	F	PC	Ulna	-12.74	-10.42	2.32	16.54
LJ I	126	Adult	I	PC	Tibia	-13.13	-10.92	2.21	16.19
LJ I	134*	Adult	I	PC	Misc	-23.39	-10.29	13.1	8.00
LJ I	136	Adult	F	PC	Rib	-14.93	-12.17	2.76	14.98
LJ I	138*	Adult	I	PC	Hum	-29.83	-10.57	29.59	.24
LJ I	139	Adult	I	PC	Radius	--	-10.37	--	--
LJ I	140	Adult	I	PC	Ulna	-19.79	-14.08	5.71	10.70
LJ I	141	Adult	M	PC	Rib	-12.72	-10.33	2.39	15.77
LJ I	144	Adult	F	PC	Rib	-13.85	-9.80	4.05	15.29
LJ I	146	Adult	F	PC	Fibula	-13.64	-10.70	2.94	15.52
LJ I	152	Adult	M	PC	Fibula	-13.71	-9.23	4.48	16.94
LJ II	22	YA	I	C	Ulna	-19.15	-12.27	6.88	10.88
LJ II	30	Adult	F	C	Femur	-15.73	-12.94	2.79	15.83
LJ II	35	Adult	I	C	Hum	-14.55	-12.32	2.23	16.63
LJ II	36	Adult	I	C	Fibula	-16.72	-11.89	4.83	13.56
LJ II	37	Adult	F	C	Ulna	-16.29	-14.46	1.83	14.95
LJ II	45	Adult	M	C	Ulna	-15.70	-11.70	4.0	16.10
LJ II	50	Adult	I	C	Rib	-14.71	-11.96	2.75	14.87
LJ II	59	Adult	M	C	Radius	-13.69	-10.73	2.96	17.12
LJ II	62	Adult	I	C	Fibula	-14.36	-11.07	3.29	17.23
LJ II	73	Adult	I	C	Fibula	-13.77	-13.14	.63	17.42
LJ II	78	Adult	F	C	Tibia	-14.79	-13.22	1.57	16.34
LJ II	89	Adult	F	C	Femur	-14.63	-11.26	3.37	15.93

Table 6.1 Continued.

Site ¹	Burial	Age ²	Sex ³	Period ⁴	Bone ⁵ Sample	$\delta^{13}\text{C}_{\text{CO}}$	$\delta^{13}\text{C}_{\text{AP}}$	$\Delta^{13}\text{C}_{\text{CA-CO}}$	$\delta^{15}\text{N}$
LJ II	94	Adult	I	C	Fibula	-15.81	-13.17	2.64	14.69
LJ II	107*	Adult	M	C	Fibula	-16.55	-10.52	6.03	12.79
LJ II	108	Adult	I	C	Fibula	-15.09	-12.01	3.08	14.41
LJ II	112	Adult	M	C	Hum	-12.45	-10.48	1.97	17.64
MO	1	Adult	I	PC	Fibula	--	--9.82	--	--
MO	2	Adult	F	PC	Misc	--	-9.23	--	--
MO	5	Adult	I	PC	Fibula	-15.03	-11.50	3.57	11.98
MO	9	Adult	F	PC	Misc	--	-11.38	--	--
MO	10	Adult	M	PC	Misc	--	-9.23	--	--
MO	22*	Adult	M	PC	Misc	-13.07	-10.35	2.72	12.80
MO	25*	Adult	M	PC	Rib	-19.58	-12.65	6.93	9.84
MO	31	Adult	M	PC	Misc	--	-9.89	--	--
MO	33	Adult	F	PC	Misc	-18.20	-12.23	5.97	10.70
MO	44A	Adult	I	PC	Misc	-12.47	-9.14	3.33	14.10
MO	52	Adult	M	PC	Misc	--	-10.07	--	--
MO	59	Adult	F	PC	Misc	-21.23	-13.77	7.46	8.81
MO	60A	Adult	M	PC	Rib	--	-11.67	--	--
MO	80	Adult	M	PC	Hum	-11.87	-8.97	2.90	12.97
MO	83	Adult	M	PC	Tibia	--	-11.00	--	--
MO	84A	Adult	F	PC	Misc	-12.62	-11.45	1.17	13.79
MO	86A	Adult	M	PC	Femur	--	-13.04	--	--
RC	16*	Adult	I	PC	Fibula	-18.95	-10.90	8.05	9.54
RC	22	Adult	I	PC	Misc	-12.50	-10.70	1.80	13.54
RC	37	Adult	PF	PC	Fibula	-13.40	-10.05	3.35	13.55
RC	40	Adult	PM	PC	Femur	-11.70	-9.66	2.04	14.52
RC	53	Adult	I	PC	Misc	-12.71	-9.51	3.20	14.19
Tapera	7	Adult	F	C	Fibula	-12.31	-7.25	5.06	16.21
Tapera	9	Adult	M	C	Ulna	-10.89	-6.12	4.77	17.35
Tapera	14	Adult	F	C	Rib	-12.60	-9.14	3.46	15.85
Tapera	16	Adult	I	C	Rib	-11.46	-9.26	2.20	17.03
Tapera	26*	Adult	M	C	Rib	-9.58	-5.42	4.16	16.74
Tapera	28	Adult	M	C	Fibula	-11.33	-6.48	4.85	15.29
Tapera	41	Adult	F	C	Rib	-11.49	-9.38	2.11	16.27
Tapera	43	Adult	F	C	Ulna	-11.73	-9.12	2.61	16.34
Tapera	49	Adult	I	C	Radius	-10.58	-7.92	2.66	15.06
Tapera	67	Adult	F	C	Rib	-10.99	-8.34	2.65	16.02

Table 6.1 Continued.

Site ¹	Burial	Age ²	Sex ³	Period ⁴	Bone ⁵ Sample	$\delta^{13}\text{C}_{\text{CO}}$	$\delta^{13}\text{C}_{\text{AP}}$	$\Delta^{13}\text{C}_{\text{CA-CO}}$	$\delta^{15}\text{N}$
Tapea	72	Adult	F	C	Rib	-11.95	-7.58	4.37	16.59
Tapera	73	Adult	F	C	Radius	-11.71	-9.66	2.05	16.30
Tapera	125	Adult	M	C	Rib	-10.67	-8.90	1.77	16.53
Tapera	126	Adult	I	C	Radius	-11.29	-8.98	2.31	15.67
Tapera	152	Adult	F	C	Fibula	-11.84	-6.94	4.90	16.36
Tapera	155	Adult	M	C	Rib	-10.48	-7.13	3.35	15.47
Tapera	156	YA	M	C	Rib	--	-6.61	--	--
Tapera	158	YA	M	C	Rib	-10.50	-5.70	4.80	15.99
ZE	2055	Adult	I	PC	Fibula	--	-16.05	--	--
ZE	2057	Adult	PF	PC	Fibula	--	-12.05	--	--
ZE	2059	Adult	I	PC	Fibula	-13.80	-11.32	2.48	13.89
ZE	2061	Adult	PF	PC	Rib	--	-13.90	--	--
ESP II	6	Adult	PM	PC	Fibula	-11.12	-9.48	1.64	14.43
ESP II	9	Adult	PM	PC	Misc	-11.97	-9.91	2.06	13.07
Geribá II	2151	Adult	I	PC	Misc	--	-10.96	--	--
Geribá II	2152	Adult	F	PC	Rib	--	-11.83	--	--

1: FML= Forte Marechal Luz; LJ I=Laranjeiras I; LJ II=Laranjeiras II; MO=Morro de Ouro; RC=Rio Comprido; ZE=Zé Espinho; ESP II=Espinheiros II

2: YA=Young Adult

3: M=Male; F=Female; I=Indeterminate; PM=Probable Male; PF=Probable Female

4: PC=Pre-Ceramic; C=Ceramic

5: Hum=humerus; Misc=miscellaneous long bones

* Excluded from the data set

During the summer of 2006, I traveled to the southern state of Santa Catarina, Brazil, to acquire bone samples for stable carbon and nitrogen isotope analysis.

Permission to use skeletal remains from *sambaqui* archaeological sites was obtained through IPHAN (National Institute of Historical and Archaeological Heritage), an organization established in 1937 to protect the cultural resources of Brazil, and to

safeguard the ethical use of human remains from archaeological sites (iphan.gov.br). Foreign archaeologists who wish to remove skeletal remains from Brazil must comply with strict measures delineated by IPHAN; for example, a foreign researcher must show that the lab analysis of bones cannot be conducted at a location in Brazil, and the researcher must also maintain a formal collegial relationship with a university in Brazil in order to obtain permission to remove human remains from the country (Mendonça 2011). Currently, no skeletal remains from archaeological sites have been subject to reburial; rather, they are curated in Brazilian museums, and inventoried along the guidelines offered by IPHAN (Mendonça 2011).

I visited museums housed at the Universidade Federal de Santa Catarina, as well as the Colégio Catarinense, in the city of Florianópolis. I also visited the Museu Arqueológico de Sambaqui de Joinville in Joinville, Santa Catarina, and the Museu Nacional housed at the Universidade Federal de Rio de Janeiro in Rio de Janeiro, Brazil. For each isotopic analysis, I selected a small piece of bone or bones weighing approximately 3 grams, for isotope analysis. Half of the 3 gram sample would be devoted to the collagen portion of the isotopic analysis, while the other half was reserved for bone apatite analysis. I preferentially chose bone fragments to preserve the intact skeleton; therefore, many of the bone samples listed in Table 6.1 come from various parts of the skeleton, or are labeled ‘miscellaneous’, meaning that the sample contains more than one or two fragments of long bone. Though the state of skeletal preservation varied with each collection, the overall quality of conservation, curation, and preservation of the *sambaqui* skeletal remains was adequate for isotopic analysis.

Collagen Sample Preparation

In the physical anthropology laboratory at Texas A&M University, I began to process each sample by mechanically cleaning the outer cortex and cancellous bone (if present) from a 1 to 1.5 gram piece of bone with a long file or diamond-studded Dremel drill. This removed any dirt or residue clinging to the surface of the bone was physically removed. I then placed each sample into a labeled centrifuge tube and sonicated the specimen in four separate washes of three minutes each with deionized water (run through a Barnstead filter), 95% ethanol, 100% ethanol, and acetone. I dried the bone fragment for 24 hours underneath a fume hood, and then weighed the sample on a mass balance.

To obtain the collagen fraction of bone, I demineralized the bone sample with a .025M HCl solution containing 979 ml of distilled water and 20.7 ml of concentrated hydrochloric acid. I placed the sample in a clean fritted tube within the centrifuge tube, and allowed the HCl solution to drip over the sample until it was completely covered. I replaced the HCl solution twice per day, until the resulting pseudomorph was free of hard mineral. Once demineralized, I decanted the HCl from the sample and rinsed the organic fraction using distilled water until a neutral pH was established.

I soaked the sample for 24 hours in a .0125M solution of NaOH (5 grams of sodium hydroxide pellets mixed into 1000ml of distilled water) to remove humic contaminants (Ambrose 1990). I decanted the NaOH from the pseudomorph by placing it in the centrifuge for two minutes, and rinsed the sample five times with deionized water using the same procedure. After checking the pH to make sure that it measured no

greater than 7, I transferred the pseudomorph and collagen into a glass vial to be solubilized in pH3 water for three days in a 90 degree Celsius oven. At the end of each day of solubilization, I transferred the liquid portion from the glass vial into a silicon cup to dry. When all of sample was solubilized after three days, I added a little bit of deionized water to the dried collagen in the silicon cup to redissolve the collagen. I transferred the liquid into a weighed and labeled glass vial. I then freeze dried the sample and weighed the vial.

I sent thirty-five of the collagen samples used in this study to Dr. Cassady Yoder at Radford University. There, Dr. Yoder processed the bone samples in her laboratory, using exactly the same procedures and equipment described above. After the samples were solubilized, Dr. Yoder sent the samples to Dr. Eric Bartelink at California State University Chico to be freeze dried. Dr. Yoder's freeze drier had stopped functioning, and she had no other access to a freeze drier at her university's campus. Dr. Bartelink had been trained in the same stable isotope laboratory methods as Dr. Yoder and the author, and ran his own stable isotope lab at California State University, Chico.

All of the collagen samples were sent to Dr. Tom Boutton in the Department of Rangeland Ecology and Management at Texas A&M University, where the stable isotope ratios in the bone collagen was measured using a Carlo Erba EA-1108 interfaced with a ThermoFinnigan Delta Plus isotope ratio mass spectrometer operating in continuous flow mode.

Evaluation of the Collagen Sample

To evaluate the quality of the collagen sample, I calculated the C/N ratio and, when possible, calculated the percent collagen yield (weight percent) for each sample. The C/N ratio is calculated by taking the percent carbon divided by 12 and dividing that number by the percent nitrogen divided by 14. Ratios that fall between 2.9 and 3.6 are considered to be of sound quality, meaning that they have not undergone the deleterious effects of diagenesis (De Niro 1985). Collagen yield weight percent is another way to evaluate the quality of a collagen sample. It is calculated by taking the number produced by dividing the pre-weight glass vial (empty) by the post-weight glass vial (with processed collagen sample inside), and dividing it by the original cleaned sample weight multiplied by 100. Quality of the collagen sample is considered to be possibly compromised when the percent collagen yield dips below the threshold of 1%, according to one study (van Klinken 1999), and 3.5% based on the results of a different study (Ambrose 2000).

While I have C/N ratios for all of my collagen samples, I am missing the percent collagen yield for 52 of the samples. For 35 of the samples, the final collagen vials were weighed with different mass balances (the pre-weight vial at Radford University, and the post-weight vial at California State University Chico). Because of the differences in the mass balances, the percent collagen yield could not be calculated. Eighteen of the remaining samples have anomalous weight data (the post-weight vial is lighter than the pre-weight vial), or some missing value, such as the original weight of the bone sample, that is necessary to calculate the percent yield.

I evaluated each bone sample according to its C/N ratio, percent carbon and nitrogen that the samples contained, percent collagen yield by weight, and $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Anomalous stable carbon isotope values, such as very negative $\delta^{13}\text{C}$, are also a good indication that collagen samples are altered (van Klinken 1999). In addition, the percent carbon in the sample should not vary greatly from 35% (under 30% indicates poorly preserved bone, but I excluded any sample below 35%), nor should the percent nitrogen stray too far out of the range of 11 to 16% (van Klinken 1999). I removed ten bone collagen samples from the dataset due to unfavorable quality indicators, including the C/N ratio, % carbon, % nitrogen, % collagen yield by weight, and anomalous $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Excluded bone samples are marked with an asterisk next to the burial number in Tables 6.1 and 6.2, and the reason for the exclusion is indicated by the bolded number. Bone samples whose C/N ratios measured over 3.6 were evaluated on a case by case basis. However, if two indicators of sample quality were problematic, they were automatically excluded.

In Tables 6.1 and 6.2, if the burial number has an asterisk next to it, I excluded it from the data set. If a number is bolded as having a questionable indicator of quality, but does not have an asterisk, I concluded that the quality of the collagen sample was acceptable. In all, I removed ten collagen samples from the dataset, leaving me with a total of 76 bone samples from which to glean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

Table 6.2: Sample Quality Indicators for Bone Collagen, Including C/N Ratio, % C, % N, and % CY (Collagen Yield)

Site ¹	Burial ²	Age ³	Sex ⁴	Period ⁵	Bone Sample ⁶	C/N Ratio	%C	%N	% CY ⁷
Cabeçuda	1708	YA	I	PC	Fibula	3.44	39.03	13.26	--
Cabeçuda	1709	Adult	F	PC	Hum	3.49	37.26	12.51	--
Cabeçuda	1710	Adult	M	PC	Femur	3.55	39.09	12.89	.48
Cabeçuda	1712	Adult	M	PC	Femur	3.56	39.70	13.07	.31
Cabeçuda	1716	Adult	M	PC	Tibia	3.57	40.23	13.18	.54
Cabeçuda	1721	Adult	M	PC	Hum	3.66	40.71	13.00	.63
Enseada I	1	Adult	I	C	Hum	3.21	38.01	13.86	6.02
Enseada I	7	Adult	M	C	Rib	3.19	40.47	14.81	--
Enseada I	10	Adult	PM	C	Hum	3.28	39.28	14.02	--
Enseada I	14*	Adult	M	PC	Rib	2.53	32.18	14.92	4.04
Enseada I	15*	YA	M	PC	Radius	2.75	34.84	14.83	--
FML	7	Adult	I	C	Femur	3.61	39.60	12.72	--
FML	10	Adult	I	PC	Tibia	3.61	42.42	13.64	--
FML	11	Adult	I	PC	Hum	3.62	41.73	13.50	3.53
FML	12*	Adult	I	PC	Radius	3.64	40.48	13.03	3.24
FML	13	Adol	I	PC	Fibula	2.98	42.13	16.55	3.15
FML	22	Adult	I	PC	Femur	3.60	41.77	13.56	--
FML	28	Adult	PF	C	Tibia	3.60	41.40	13.44	--
FML	30	Adult	I	C	Radius	3.25	42.63	15.36	2.47
FML	33	Adult	I	C	Tibia	3.22	41.83	15.02	--
FML	40	Adult	I	PC	Hum	3.63	40.68	13.12	1.72
FML	46	Adult	I	PC	Radius	3.29	43.59	15.53	--
FML	49	Adult	I	PC	Fibula	3.26	40.97	14.68	--
FML	52	Adult	I	C	Fibula	3.29	41.68	14.83	--
FML	53	Adult	M	C	Scapula	3.32	43.16	15.22	--
FML	56	Adult	I	C	Fibula	3.31	42.20	14.89	--
LJ I	118	Adult	M	PC	Ulna	3.25	41.70	14.99	2.94
LJ I	119	Adult	F	PC	Ulna	3.23	40.49	14.67	10.5
LJ I	126	Adult	I	PC	Tibia	3.30	39.17	13.89	--
LJ I	134*	Adult	I	PC	Misc	13.63	36.59	3.14	--
LJ I	136	Adult	F	PC	Rib	3.40	39.67	13.66	--
LJ I	138*	Adult	I	PC	Hum	8.08	52.90	7.66	6.37
LJ I	140	Adult	I	PC	Ulna	3.23	38.04	13.78	--
LJ I	141	Adult	M	PC	Rib	3.21	39.56	14.46	--
LJ I	144	Adult	F	PC	Rib	3.22	39.44	14.33	--
LJ I	146	Adult	F	PC	Fibula	3.44	41.23	14.02	--

Table 6.2 Continued.

Site ¹	Burial ²	Age ³	Sex ⁴	Period ⁵	Bone Sample ⁶	C/N Ratio	%C	%N	%CY ⁷
LJ I	152	Adult	M	PC	Fibula	3.26	40.26	14.41	--
LJ II	22	YA	I	C	Ulna	3.44	41.69	14.17	--
LJ II	30	Adult	F	C	Femur	3.44	42.17	14.34	11.5
LJ II	35	Adult	I	C	Hum	3.17	40.06	14.76	12
LJ II	36	Adult	I	C	Fibula	3.46	40.29	13.63	--
LJ II	37	Adult	F	C	Ulna	3.45	42.14	14.28	7.31
LJ II	45	Adult	M	C	Ulna	3.25	39.01	14.01	--
LJ II	50	Adult	I	C	Rib	3.39	41.36	14.1	--
LJ II	59	Adult	M	C	Radius	3.49	40.97	13.76	--
LJ II	62	Adult	I	C	Fibula	3.50	41.68	13.96	4.39
LJ II	73	Adult	I	C	Fibula	3.25	39.94	14.38	--
LJ II	78	Adult	F	C	Tibia	3.24	40.07	14.47	4.62
LJ II	89	Adult	F	C	Femur	3.51	41.43	13.85	--
LJ II	94	Adult	I	C	Fibula	3.22	40.73	14.81	--
LJ II	107*	Adult	M	C	Fibula	4.43	18.62	4.91	--
LJ II	108	Adult	I	C	Fibula	3.21	38.82	14.15	8
LJ II	112	Adult	M	C	Hum	3.50	40.57	13.59	--
MO	5	Adult	I	PC	Fibula	3.27	38.33	13.74	--
MO	22*	Adult	M	PC	Misc	3.12	12.68	4.77	3.13
MO	25*	Adult	M	PC	Rib	3.21	26.68	9.72	--
MO	33	Adult	F	PC	Misc	3.37	37.29	12.96	--
MO	44A	Adult	I	PC	Misc	3.25	40.98	14.72	--
MO	59	Adult	F	PC	Misc	3.31	38.22	13.51	7.70
MO	80	Adult	M	PC	Hum	3.50	38.67	12.92	--
MO	84A	Adult	F	PC	Misc	3.24	35.68	12.88	1.75
RC	16*	Adult	I	PC	Fibula	3.34	33.98	12.01	--
RC	22	Adult	I	PC	Misc	3.27	35.24	12.63	--
RC	37	Adult	PF	PC	Fibula	3.32	39.60	13.95	--
RC	40	Adult	PM	PC	Femur	3.30	37.54	13.30	--
RC	53	Adult	I	PC	Misc	3.30	38.62	13.69	--
Tapera	7	Adult	F	C	Fibula	3.54	41.31	13.63	--
Tapera	9	Adult	M	C	Ulna	3.33	39.31	13.80	--
Tapera	14	Adult	F	C	Rib	3.50	42.29	14.16	12.60
Tapera	16	Adult	I	C	Rib	3.39	42.33	14.59	--
Tapera	26*	Adult	M	C	Rib	3.30	31.32	11.09	--
Tapera	28	Adult	M	C	Fibula	3.41	42.36	14.56	6.06
Tapera	41	Adult	F	C	Rib	3.42	43.35	14.83	4.96
Tapera	43	Adult	F	C	Ulna	3.13	39.98	14.98	--

Table 6.2 Continued.

Site ¹	Burial ²	Age ³	Sex ⁴	Period ⁵	Bone Sample ⁶	C/N Ratio	%C	%N	%CY ⁷
Tapera	49	Adult	I	C	Radius	3.42	41.58	14.24	--
Tapera	67	Adult	F	C	Rib	3.44	42.98	14.61	4.28
Tapea	72	Adult	F	C	Rib	3.28	43.47	15.53	3.39
Tapera	73	Adult	F	C	Radius	3.29	44.24	15.77	--
Tapera	125	Adult	M	C	Rib	3.24	41.55	14.98	1.13
Tapera	126	Adult	I	C	Radius	3.51	43.16	14.41	--
Tapera	152	Adult	F	C	Fibula	3.30	41.47	14.71	--
Tapera	155	Adult	M	C	Rib	3.52	42.90	14.25	6.21
Tapera	158	YA	M	C	Rib	3.32	42.09	14.81	.69
ZE	2059	Adult	I	PC	Fibula	3.30	42.39	15.03	3.31
Esp II	6	Adult	PM	PC	Fibula	3.20	36.10	13.24	--
Esp II	9	Adult	PM	PC	Misc	3.24	38.74	13.97	1.91

1: FML=Forte Marechal Luz; LJ I=Laranjeiras I; LJ II=Laranjeiras II; MO=Morro de Ouro;

RC=Rio Comprido; ZE=Zé Espinho

2: all burial numbers with asterisks have been removed from analysis

3: YA=Young Adult

4: M=Male; F=Female; I=Sex Indeterminate; PM=Probable Male; PF=Probable Female

5: PC=Pre-Ceramic; C=Ceramic

6: Hum=Humerus; Misc=Miscellaneous

7: % CY= Percent Collagen Yield

Apatite Sample Preparation

The initial mechanical and chemical cleaning of the bone apatite sample is identical to the bone collagen sample preparation. I mechanically cleaned the outer cortex and cancellous bone (if present) from a 1 to 1.5 gram piece of bone with a long file or diamond-studded Dremel drill. This ensured that the any dirt or residue clinging to the surface of the bone was physically removed. I then placed each sample into a labeled centrifuge tube and sonicated the specimen in four separate washes of three

minutes each with distilled water (run through a Barnstead filter), 95% ethanol, 100% ethanol, and acetone. I dried the bone fragment for 24 hours underneath a fume hood, and then weighed the sample on a mass balance.

I then ground the bone sample to a fine powder using an agate mortar and pestle, and sieved the powder through a 50 micron screen. After weighing the powder with a mass balance, I returned the sample to the labeled centrifuge tube and soaked the powder in a 1.5% sodium hypochlorite (bleach) solution for 48 hours to remove organic contaminants (Koch 1997). I shook the sample every few hours to ensure that all of the bone powder was exposed to the bleach solution. After 48 hours, I centrifuged and rinsed the bone sample three times in distilled water to remove any remnant of the bleach solution.

To remove diagenetic contaminants, I placed the bone powder sample in a 1M solution of buffered acetic acid (to a pH of 4.5) for a total of 24 hours (Koch 1997). After the first 12 hours, I centrifuged the sample and removed the acetic acid solution, replacing it with fresh solution for the next 12 hours. I then rinsed the bone powder sample three times with distilled water and dried the sample in a 60 degree oven for 24 hours. I weighed the sample, and sent them to Dr. Ethan Grossman in the department of Geology and Geophysics at Texas A&M University. There, the samples (n=104) were reacted with phosphoric acid at 70 degrees Celsius and the CO₂ was measured on a ThermoFinnigan Delta Plus XP isotope ratio mass spectrometer using a Gas Bench Automated Gas Handling System.

Results: Pre-Ceramic and Ceramic Occupation $\delta^{13}C$ and $\delta^{15}N$ Comparisons

Table 6.3 provides information about mean stable carbon and nitrogen isotope values from the ten *sambaqui* archaeological sites that I sampled. $\delta^{13}C$ from collagen and apatite are reported, as well as $\Delta^{13}C_{CA-CO}$ and $\delta^{15}N$. Two of the sites, Enseada I and Forte Marechal Luz, have Pre-Ceramic and Ceramic components, and are therefore listed twice in Table 6.3.

Table 6.3: Mean and S.D. of $\delta^{13}C_{CO}$, $\delta^{13}C_{AP}$, $\Delta^{13}C_{CA-CO}$, and $\delta^{15}N$ for Pre-Ceramic and Ceramic *Sambaqui* Sites

Site ¹	n ²	Period ³	$\delta^{13}C_{COL}$	SD	$\delta^{13}C_{AP}$	SD	$\Delta^{13}C_{CA-CO}$	SD	$\delta^{15}N$	SD
Cabeçuda	6,8	PC	-11.23	.176	-7.58	.47	3.87	.30	18.33	1.32
Enseada I	2,0	PC	--	--	-6.45	.59	--	--	--	--
Enseada I	3,3	C	-12.71	.147	-8.40	1.32	4.31	1.43	15.47	1.35
FML	8,7	PC	-12.69	1.55	-10.32	1.66	2.72		14.17	1.05
FML	7,7	C	-13.57	.52	-11.22	.56	2.35		15.16	1.00
LJ I	9,12	PC	-14.08	2.29	-10.58	1.48	3.45	1.21	15.13	1.85
LJ II	15,16	C	-15.16	1.55	-12.07	1.12	2.99	1.48	15.57	1.77
MO	6,17	PC	-15.24	3.76	-10.91	1.47	4.07	2.27	12.06	2.02
RC	4,5	PC	-12.58	.70	-10.16	.62	2.60	.79	13.95	.49
Tapera	16,18	C	-11.36	.65	-7.77	1.37	3.37	1.22	16.15	.60
Zé Espinho	1,4	PC	-13.80	--	-13.33	2.11	2.48	--	13.89	--
Esp II	2,2	PC	-11.55	.60	-9.70	.30	1.85	.30	13.75	.96
Geribá II	2,0	PC	--	--	-11.40	.62	--	--	--	--

1: FML=Forte Marechal Luz; LJ I=Laranjeiras I; LJ II=Laranjeiras II;

MO=Morro de Ouro; RC=Rio Comprido; EspII= Espinheiros II

2: The first number is the number of bone apatite samples; the second is the number of bone collagen samples

3: PC=Pre-Ceramic; C=Ceramic

Because these biological data are not normally distributed, I conducted a Mann-Whitney U non-parametric test to compare Pre-Ceramic and Ceramic stable carbon and nitrogen isotope values. I used all individuals from each occupation, but also tested sub-groups within those datasets, such as adults only (by excluding adolescents), females, males, and males and females together. As one can see in the following tables, the number of sex indeterminate individuals is higher than the number of sexed individuals for this dataset.

Table 6.4 displays the results of a Mann-Whitney U analysis comparing mean $\delta^{13}\text{C}$ values of bone collagen between time periods. Stable carbon isotope ratios of bone collagen reflect the protein portion of the diet, as carbon atoms from protein sources are preferentially routed to this fraction of the bone. The results for all individuals and sub-groups are not statistically significant between Pre-Ceramic and Ceramic occupation sites.

Table 6.4: Mann Whitney U Comparing $\delta^{13}\text{C}$ from Collagen between Pre-Ceramic and Ceramic Occupations

Group	Occupation	n	Mean $\delta^{13}\text{C}_{\text{COL}}$	Mean Rank	U	p
All individuals	Pre-Ceramic	35	-13.19	39.99	665.5	.588
	Ceramic	41	-13.23	37.23		
Excluding Adolescents	Pre-Ceramic	34	-13.23	39.22	655.5	.659
	Ceramic	41	-13.23	36.99		
Females	Pre-Ceramic	8	-14.81	8.12	67.00	.157
	Ceramic	12	-13.00	12.08		
Males	Pre-Ceramic	8	-11.91	9.12	43.00	.829
	Ceramic	10	-12.17	9.80		
Males and Females	Pre-Ceramic	16	-13.36	17.81	203.00	.438
	Ceramic	22	-12.63	20.73		

Table 6.5 examines the $\delta^{13}\text{C}$ values from bone apatite between time periods, and reflects the whole diet of the individual. As with the results from the analysis of bone collagen, there is no statistically significant difference between any of the tested groups. However, stable nitrogen isotope values from bone collagen reveal statistically significant differences between Pre-Ceramic and Ceramic occupations (see Table 6.6). When all individuals in the dataset are considered, the Ceramic occupation has statistically higher $\delta^{15}\text{N}$ values than the Pre-Ceramic occupation (Mann Whitney U=982, $p=.006$). When only adults are considered in the analysis, the results remained statistically significant (U=950, $p=.007$). When comparing females between the Pre-Ceramic and Ceramic time periods, the results are nearly significant at $p=.098$, with Ceramic occupation females displaying higher $\delta^{15}\text{N}$ than Pre-Ceramic females. This indicates an even greater reliance on marine foods during the Ceramic period than the Pre-Ceramic period for these groups.

Table 6.5: Mann Whitney U Comparing $\delta^{13}\text{C}$ from Apatite between Pre-Ceramic and Ceramic Occupations

Group	Occupation	n	Mean $\delta^{13}\text{C}_{\text{AP}}$	Mean Rank	U	P
All individuals	Pre-Ceramic	60	-10.25	51.62	1372.5	.730
	Ceramic	44	-9.93	53.69		
Excluding Adolescents	Pre-Ceramic	58	-10.34	50.15	1354.5	.596
	Ceramic	44	-9.9	53.28		
Females	Pre-Ceramic	12	-10.71	10.92	91.00	.291
	Ceramic	12	-9.94	14.08		
Males	Pre-Ceramic	19	-9.24	15.05	151.00	.305
	Ceramic	13	-8.34	18.62		
Males and Females	Pre-Ceramic	31	-9.81	26.06	463.00	.213
	Ceramic	25	-9.11	31.52		

Table 6.6: Mann Whitney U Comparing $\delta^{15}\text{N}$ from Bone Collagen between Pre-Ceramic and Ceramic Occupations

Group	Occupation	n	Mean $\delta^{15}\text{N}$	Mean Rank	U	P
All individuals	Pre-Ceramic	35	14.71	30.94	982.00	.006
	Ceramic	41	15.72	44.95		
Excluding Adolescents	Pre-Ceramic	34	14.71	30.56	950.00	.007
	Ceramic	41	15.72	44.17		
Females	Pre-Ceramic	8	14.17	7.75	70.00	.098
	Ceramic	12	16.08	12.33		
Males	Pre-Ceramic	8	16.96	10.75	30.00	.408
	Ceramic	10	16.17	8.50		
Males and Females	Pre-Ceramic	16	15.56	18.53	191.5	.651
	Ceramic	22	16.12	20.20		

Figure 6.1 represents a plot of the isotopic values of nitrogen and bone collagen from Pre-Ceramic and Ceramic *sambaqui* groups. It shows a positive relationship between the two indicators of diet (Pearson's $r=.620$, $p=.01$). Using the same plot, Figure 6.2 illustrates the isotopic values of nitrogen and bone collagen for plant and animal resources.

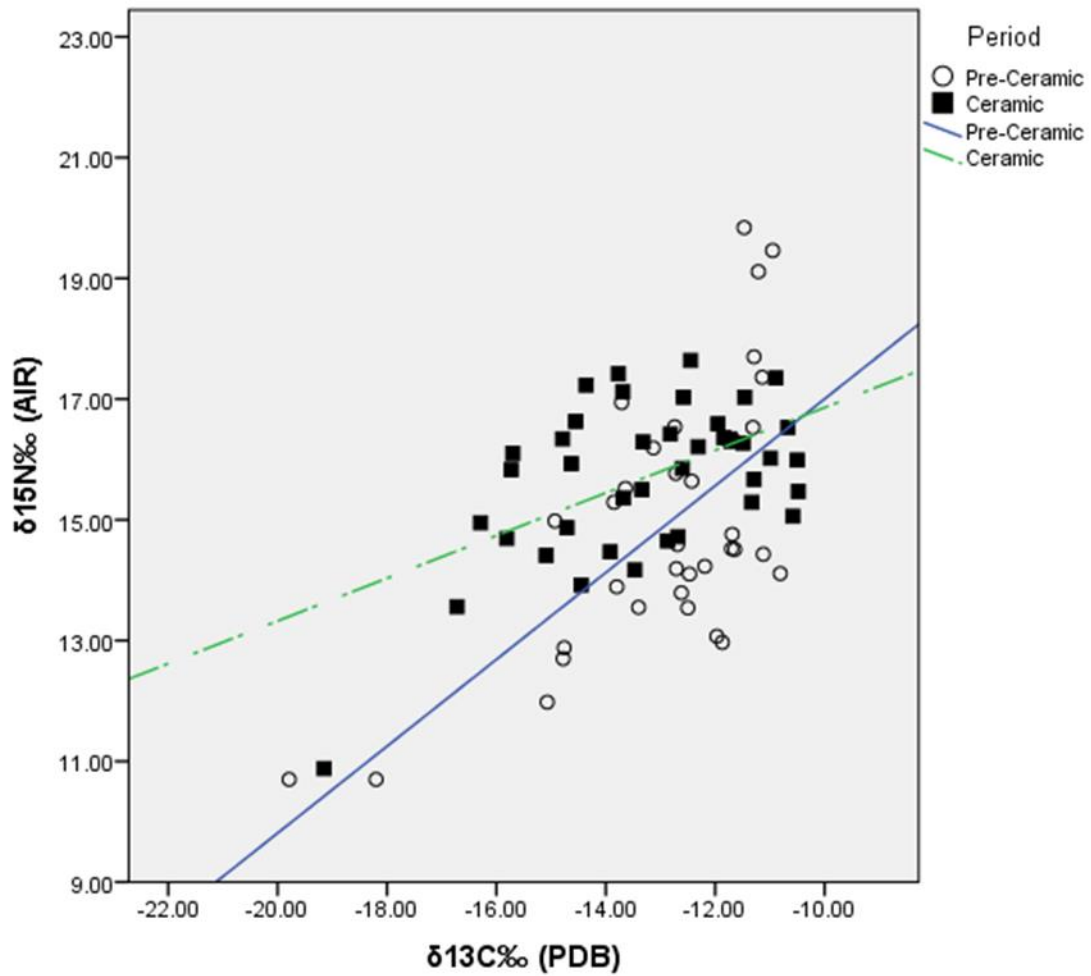


Figure 6.1: A Plot of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from Bone Collagen Shows a Positive Relationship between Isotope Signatures (Pearson's $r=.620$, $p=.01$)

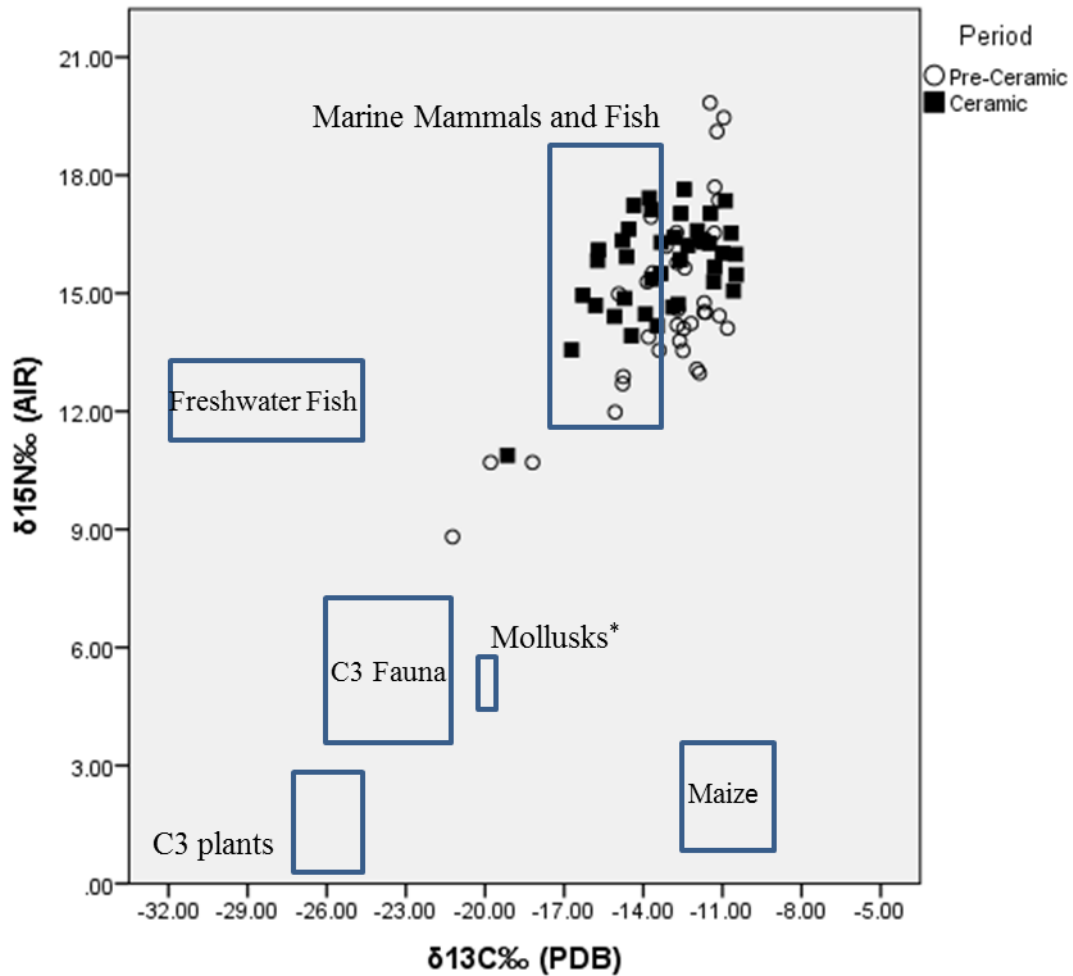


Figure 6.2: a plot of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ from bone collagen shows the isotopic values of terrestrial and faunal resources (after Tykot 2006) * *anomalocardia brasiliiana*

Examining the difference between $\delta^{13}\text{C}$ in collagen and $\delta^{13}\text{C}$ in apatite allows one to infer the degree to which a population relied on marine versus terrestrial resources. Table 6.7 illustrates that there is no statistically significant difference in $\delta^{13}\text{C}_{\text{CA-CO}}$ values between time periods.

Table 6.7: Mann Whitney U Comparing $\Delta^{13}\text{C}_{\text{CA-CO}}$ between Pre-Ceramic and Ceramic Occupations

Group	Occupation	n	Mean $\Delta^{13}\text{C}_{\text{CA-CO}}$	Mean Rank	U	P
All individuals	Pre-Ceramic	35	3.26	40.09	662.00	.563
	Ceramic	41	3.13	37.15		
Excluding Adolescents	Pre-Ceramic	34	3.25	39.35	651.00	.624
	Ceramic	41	3.13	36.88		
Females	Pre-Ceramic	8	3.83	11.88	37.00	.427
	Ceramic	12	3.06	9.58		
Males	Pre-Ceramic	8	3.60	9.25	42.00	.897
	Ceramic	10	3.59	9.70		
Males and Females	Pre-Ceramic	16	3.71	21.16	149.5	.438
	Ceramic	22	3.30	18.30		

Table 6.8 compares the $\delta^{13}\text{C}$ from bone collagen between males and females of both time periods, using sex as a grouping variable. Males from the Pre-Ceramic and Ceramic occupations are more enriched in $\delta^{13}\text{C}_{\text{COL}}$ than females from both time periods ($U=98.00$, $p=.016$). Males from the Pre-Ceramic period are also more enriched in $\delta^{13}\text{C}$ from collagen than their Pre-Ceramic female counterparts ($U=9.00$, $p=.015$). However, males and females from the Ceramic period showed no statistically significant difference in the measurement of this stable carbon isotope ($U=42.00$, $p=.254$).

Table 6.8: Comparison of $\delta^{13}\text{C}$ from Collagen between Males and Females

Occupation	Sex	n	Mean $\delta^{13}\text{C}_{\text{COL}}$	Mean Rank	U	p
Pre-Ceramic and Ceramic	Male	18	-12.06	24.06	98.00	.016
	Female	20	-13.73	15.40		
Pre-Ceramic	Male	8	-11.91	11.38	9.00	.015
	Female	8	-14.81	5.62		
Ceramic	Male	10	-12.17	13.30	42.00	.254
	Female	12	-13.01	10.00		

Table 6.9 also examines differences between males and females. $\delta^{13}\text{C}$ of bone apatite shows that males from the Pre-Ceramic and Ceramic occupations have more enriched carbon apatite ratios than females from both time periods (U=244.5, p=.021). Males from the Pre-Ceramic period are also more enriched in apatite $\delta^{13}\text{C}$ than Pre-Ceramic females (U=65.00, p=.048). As for $\delta^{13}\text{C}$ of collagen, there is also no statistically significant difference in the bone apatite ratios between males and females of the Ceramic period (U=48.5, p=.110).

Table 6.9: Comparison of $\delta^{13}\text{C}$ from Apatite between Males and Females

Occupation	Sex	n	Mean $\delta^{13}\text{C}_{\text{AP}}$	Mean Rank	U	p
Pre-Ceramic and Ceramic	Male	32	-8.87	32.86	244.5	.021
	Female	24	-10.32	22.69		
Pre-Ceramic	Male	19	-9.24	18.58	65.00	.048
	Female	12	-10.71	11.92		
Ceramic	Male	13	-8.34	15.27	48.5	.110
	Female	12	-9.94	10.54		

I also examined stable nitrogen isotope ratios, and compared differences between males and females between time periods. Table 6.10 reveals that there are no statistically significant differences in $\delta^{15}\text{N}$ from bone collagen between males and females of the Pre-Ceramic and Ceramic time periods. However, males from the Pre-Ceramic period have higher $\delta^{15}\text{N}$ than females of the Pre-Ceramic period, and this difference is nearly significant at $U=15.00$, $p=.083$.

Table 6.10: Comparison of $\delta^{15}\text{N}$ from Collagen between Males and Females

Occupation	Sex	n	Mean $\delta^{15}\text{N}$	Mean Rank	U	P
Pre-Ceramic and Ceramic	Male	18	16.52	22.03	134.5	.186
	Female	20	15.32	17.22		
Pre-Ceramic	Male	8	16.96	10.62	15.00	.083
	Female	8	14.17	6.38		
Ceramic	Male	10	16.17	11.40	61.00	1.00
	Female	12	16.08	11.58		

Finally, I analyzed the difference in $\delta^{13}\text{C}$ between bone fractions of collagen and apatite between males and females of both time periods. Table 6.11 illustrates that no statistically significant differences in $\delta^{13}\text{C}_{\text{CA-CO}}$ are observed for these groups.

Table 6.11: Comparison of $\Delta^{13}\text{C}_{\text{CA-CO}}$ from Collagen between Males and Females

Occupation	Sex	n	Mean $\Delta^{13}\text{C}_{\text{CA-CO}}$	Mean Rank	U	p
Pre-Ceramic and Ceramic	Male	18	3.59	21.25	148.5	.361
	Female	20	3.37	17.92		
Pre-Ceramic	Male	8	3.60	8.62	31.00	.959
	Female	8	3.83	8.38		
Ceramic	Male	10	3.59	12.70	48.00	.456
	Female	12	3.06	10.50		

Paleodietary Analysis

Based on the isotopic values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, it is clear that *sambaqui* populations relied heavily on marine resources for their subsistence both before and after the introduction of ceramic technology. It is also worth noting the variation in diet that was present at each archaeological site. For instance, the Pre-Ceramic period site of Cabeçuda showed very high average nitrogen isotope values at 18.33‰, while its carbon isotope ratio average of collagen was heavily enriched at -11.23‰. Meanwhile, the Ceramic period site of Tapera also showed a heavy reliance on marine resources with $\delta^{15}\text{N}$ and $\delta^{13}\text{C}_{\text{COL}}$ at 16.15‰ and -11.36‰, respectively. The results presented here are also in keeping with the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values reported by De Masi (1999) for other *sambaqui* populations of southeastern Brazil.

A model developed by researchers Kellner and Schoeninger (2007) offers a way to analyze prehistoric diet by plotting $\delta^{13}\text{C}_{\text{AP}}$ and $\delta^{13}\text{C}_{\text{COL}}$ together to form regression lines that elucidate sources of C_3 , C_4 , and marine sources of dietary protein for a given

population; C₃ or C₄ sources of energy are also plotted along the regression lines of dietary protein source. The study uses data that has been published from experimental feeding research designs and from free-ranging terrestrial animals, so archaeological data is corrected by 1.5‰ to match modern standards caused by the Suess Effect, and is then plotted against the dietary model.

Figure 6.3 shows a plot of stable carbon isotope values of collagen and apatite from *sambaqui* populations, and compares those values with Kellner and Schoeninger's (2007) model lines of regression for dietary protein source. As expected from the archaeological findings of previous research and the known natural resources available to those on the Atlantic coast of Brazil during this time period, *sambaqui* populations relied heavily on marine protein and C₃ energy plant resources for their subsistence. An examination of this plot, though, does reveal that some individuals from Pre-Ceramic and Ceramic occupations depended on C₃ energy foods to a greater degree than the majority of other coastal inhabitants. The carbon isotope ratios for these skeletal remains plot on or near the C₃ energy line of Figure 6.3, and include burial 140 from Laranjeiras I (Pre-Ceramic period, sex indeterminate), and burial 22 from Laranjeiras II (Ceramic period, sex indeterminate). Other skeletal remains from Laranjeiras II, a Ceramic occupation, also show moderately higher evidence for the consumption of C₃ food sources. These include burials 30 (female), burial 36 (indeterminate), burial 37 (female), burial 45 (male), and burial 94 (indeterminate). The archaeological site of Laranjeiras lies directly on a small bay of the Atlantic Ocean on mainland Santa Catarina, and was also covered by the abundant resources of the Atlantic Forest, which include a wide

variety of C₃ plants and animals for the inhabitants to consume. The inhabitants of Laranjeiras I and II may have had greater access to Atlantic Forest food resources than populations that lived on the islands, and therefore consumed fewer marine foods. Pre-Ceramic occupation burials 33 and 59 from Morro de Ouro, both female, also display a high reliance on C₃ energy sources. Morro de Ouro is also a mainland site, and rests near the city of present day Joinville.

According to the model provided by Kellner and Schoeninger (2007), there is no evidence that these inhabitants consumed C₄ plant resources, such as maize. None of the tests examining $\Delta^{13}\text{C}_{\text{CA-CO}}$ show any statistical significance between time periods, age, or sex. Twelve individuals out of 86 (13.9%) in the study sample have a $\Delta^{13}\text{C}_{\text{CA-CO}}$ greater than 4.4‰, which means that the ¹³C of their whole diet (as indicated by measurements of bone apatite) is more enriched than the protein portion of their diet. Individuals from both Pre-Ceramic and Ceramic sites have collagen-apatite spacing over 4.4‰, and include two Ceramic occupation skeletons from Enseada I, two from Laranjeiras I (PC), two from Laranjeiras II (C), two from Morro de Ouro (PC), and four from Tapera (C). It is likely that these individuals consumed a larger quantity of C₃ plant resources and lower trophic level freshwater or marine resources than those individuals with collagen-apatite spacing less than 4.4‰. The majority of coastal inhabitants display collagen-apatite spacing measuring less than 4.4‰, so that the protein portion of diet is more enriched in ¹³C than the whole diet. These individuals relied heavily on carbon-enriched marine protein resources for a significant part of their subsistence.

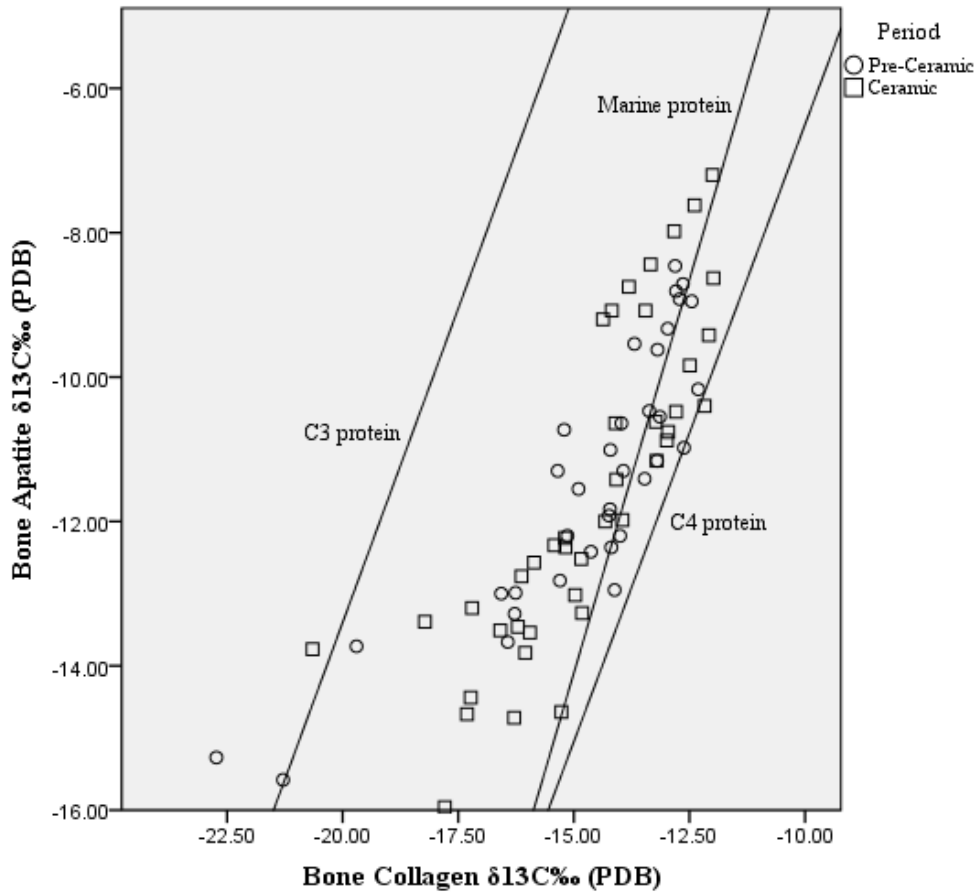


Figure 6.3: Relationship between $\delta^{13}\text{C}_{\text{AP}}$ and $\delta^{13}\text{C}_{\text{COL}}$ Following the Model by Kellner and Schoeninger (2007)

Discussion

To test whether a change in diet occurred with the adoption of ceramic technology among *sambaqui* coastal hunter gatherers, I examined the stable carbon and nitrogen isotope ratios for Pre-Ceramic and Ceramic occupations at these sites. I hypothesized that if a change in diet is observed between time periods, that the *subsistence model* for the adoption of ceramic technology would be supported;

conversely, if there is no change in diet associated with pottery, the *prestige model* would require further consideration.

Results from the examination of stable carbon and nitrogen isotope ratios among *sambaqui* populations indicate that, when all individuals are considered in the analysis, there is no significant difference in $\delta^{13}\text{C}$ of collagen or apatite between Pre-Ceramic and Ceramic groups. However, when only sexed individuals are considered, males show a significant enrichment of $\delta^{13}\text{C}_{\text{COL}}$ and $\delta^{13}\text{C}_{\text{AP}}$ over their female counterparts for the Pre-Ceramic period. It is interesting that the same differences in $\delta^{13}\text{C}_{\text{COL}}$ and $\delta^{13}\text{C}_{\text{AP}}$ are not observed between males and females of the Ceramic period.

When all individuals are considered, stable nitrogen isotope ratios are significantly higher for the Ceramic occupation than the Pre-Ceramic occupation. The same is true when only adults are considered. When $\delta^{15}\text{N}$ are examined by sex, there is no significant difference between males and females, although males from the Pre-Ceramic period do show a trend toward higher values than Pre-Ceramic females ($U=15.00$, $p=.083$). This trend parallels the differences in Pre-Ceramic male and female $\delta^{13}\text{C}$ values from collagen and apatite.

These results indicate that the appearance of ceramic technology among coastal *sambaqui* inhabitants does not coincide with an apparent intensification of terrestrial C_3 or C_4 plant resources, nor is there an indication that the coastal inhabitants shifted their subsistence away from marine resources. In fact, $\delta^{15}\text{N}$ values suggest that high trophic marine foods became increasingly more important during the Ceramic period. If this is the case, one must consider whether this importance lies in a change in subsistence

strategy (i.e., people consuming more marine resources at the expense of other foods, such as C₃ animal protein), or a change in technology. Perhaps individuals during the ceramic period used the pottery for short term food storage or curing, thereby increasing the availability of these foods over a longer period of time. It is also possible that a significant social change occurred with the adoption pottery among these groups.

There is no indication based on stable carbon isotopes of energy that coastal foragers of the Atlantic coast began cultivating C₄ maize with the adoption of pottery.

The difference in diet between males and females of the Pre-Ceramic period is striking, especially as this difference dissipates for the Ceramic period. Males of the Pre-Ceramic period had significantly more enriched carbon isotope ratios than females of the same period, as well as higher (approaching significant) nitrogen isotope ratios. This indicates that males of the Pre-Ceramic period enjoyed a diet richer in marine resources than females.

After examining this data, I find some support for the *subsistence model* for the adoption of ceramic technology. While differences in stable carbon isotope ratios between Pre-Ceramic and Ceramic populations are not significant when all individuals are considered, nitrogen isotope ratios do show a significant change. Moreover, when the data is analyzed according to sex, significant differences between the Pre-Ceramic and Ceramic occupations are observed.

CHAPTER VII

DENTAL MICROWEAR ANALYSIS: LITERATURE REVIEW AND RESEARCH METHODS

Anthropological research on dental microwear entails the microscopic study of tooth enamel surfaces to characterize diet. The underlying principle behind dental microwear research is that, due to their inherent degree of hardness or abrasiveness, certain foods will leave microscopic features on tooth surfaces. These features, described as scratches and pits, allow the researcher to describe and interpret broad dietary practices of a population. Anthropologists began using scanning electron microscopy (SEM) to conduct dental microwear research during the 1980s, and their work was applied to a wide range of biomechanical, primatological, paleoanthropological, and paleoenvironmental problems (Covert and Kay 1981; Gordon 1982; Gordon 1984a; Grine 1986; Grine and Kay 1988; Puech and Albertini 1984; Teaford 1985; Teaford 1988a, 1988b; Teaford and Oyen 1989; Teaford and Walker 1984; Walker and Teaford 1989). Anthropologists have since used dental microwear methods to investigate bioarchaeological questions (Bullington 1991; Eshed et al. 2006; Harmon and Rose 1988; Littleton and Frohlich 1993; Mahoney 2006a, 2006b, 2007; Molleson et al. 1993; Organ et al. 2005; Schmidt 2001; Teaford and Lytle 1996; Ungar and Spencer 1999). However, some researchers voiced concerns regarding the comparability and consistency of SEM microwear measurements (Gordon 1988). The development of semi-automation software to digitally measure microwear features helped to standardize

methods for greater comparability between sample sets (Ungar 2001), but criticisms persist (Grine et al. 2002; Scott et al. 2005; Ungar et al. 2003). This chapter reviews relevant dental microwear methods and their applications in anthropological research, and explains a new technique for gathering microwear data.

Biomechanics: Mastication and Dental Anatomy

Microscopic features of tooth enamel inform not only on the texture and hardness of a diet, but on the biomechanical processes of mastication. As dental microwear analysis began to develop as a method for characterizing diet, researchers recognized the need to tease apart the intertwined processes of form, function, and food. In an early and influential study, Kay and Hiiemae (1974) described the process of mastication and formation of dental wear in species of tree shrew (*Tupaia*), bushbaby (*Galago*), squirrel monkey (*Saimiri*), and spider monkey (*Ateles*) through an analysis of occlusal molar surfaces and cinefluorography, a method whereby x-ray images of biological tissues are filmed and projected onto a screen. The authors examined and compared these same processes in fossil primates *Palenochtha*, *Pelycodus*, and *Aegyptopithecus*, and found a high degree of similarity in mastication among extant primates. They concluded that cheek tooth morphology is ultimately dependent upon the consistency of the food, or diet, of the animal, such that “two different animals given the same food will handle it in the same way, irrespective of differences in tooth form...this emphasizes the importance of aggregate changes in diet as the selection pressure for dietetic adaptations” (Kay and Hiiemae 1974: 255). Stated another way, diet plays a critical evolutionary role in the development of tooth morphology.

Kay and Hiiemae (1974) also made significant contributions to dental microwear methodology by defining terminology related to the mechanics of chewing. They explicitly described the mechanical processes of chewing food through the terms ‘shear’, ‘crushing’, and ‘grinding’. The term ‘shear’ refers to a cutting and sliding (or dragging) action, whereby the cuspal tips of molars make contact with one another in a motion that is parallel to the occlusal plane. In ‘crushing’, the food is crushed in the flat surfaces of the tooth, and the motion is perpendicular to the occlusal plane. The ‘grinding’ stage of mastication uses both shear and crushing to process food. According to Kay and Hiiemae (1974), Phase I mastication involves tooth-food-tooth (*abrasion*) or tooth-tooth (*attrition*) contact, where food is cut and then crushed. However, in a later publication, Gordon (1982) counseled against using the terms *abrasion* and *attrition* because at high levels of magnification one cannot detect differences between the two surface types. Phase II mastication involves grinding the food using an antero-lateral movement of the lower molars, and the transition from Phase I to Phase II mastication is a single, fluid movement (Kay and Hiiemae 1974).

Molar wear facets are created by the mechanical loading forces of the cranium and jaw during Phase I and Phase II mastication, and contain microscopic features that reflect the physical properties of a species’ dietary regimen. Researchers conducting dental microwear analysis analyze different tooth facets to understand the range of mechanical interplay that exists between the food bolus and the occlusal surface during the chewing process. Kay and Hiiemae’s (1974) important contribution includes a description of extant and fossil primate molar function and facet type, which the authors

describe in detail. Each specialized facet, numbered 1-10, represents part of Phase I and Phase II mastication. Interestingly, the researchers note that “[f]acets 1-6, 9-10 had evolved in many placental mammals by the Upper Cretaceous and are still found in modified form, in all primate lineages” (Kay and Hiiemae 1974: 233). Therefore, though this study examined the mechanics of chewing and molar morphology of non-human primates, the system of facet numbering and the examination of shear, crushing, and grinding can be applied to human and non-human primates alike. In general, facets 1-4 represent the cutting edges of Phase I mastication, and facets 3-8 represent the crushing component of Phase I. Note that there is an overlap in cutting and crushing action for facets 3 and 4. Facets 9 and 10 are formed during the grinding action of Phase II mastication. In a related study, significant changes in Phase I and Phase II wear facets among Oligocene catarrhines and extant Old World monkeys help clarify evolutionary affiliations and cladistic relationships (Kay 1977). Figure 7.1 shows the occlusal surface of a mandibular molar, with demarcated facets. Though this study employs the use of maxillary molars, the locations of these facets may be generalized to the same points on the occlusal surface of the maxillary molar.

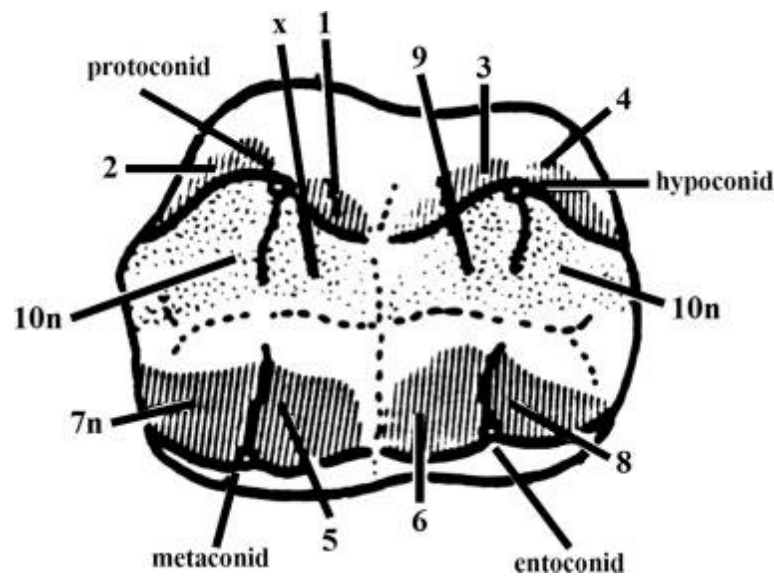


Figure 7.1 Drawing of a Mandibular Molar Showing Relevant Facets x, 9, and 10n (from Kreuger et al. 2008)

In an effort to understand the manner in which microscopic features on tooth enamel form, researchers began using scanning electron microscopy (SEM) to study the mechanics of mastication and tooth function. For example, an early study by Grine (1977) used SEM to analyze occlusal wear in the posterior dentition of *Diademodon*, a mammal-like reptile of the early Triassic. The author concluded that it lacked the ability to move its jaw side-to-side (ectantal movement) or forward to back (propalinal movement); instead, it chewed using an up and down movement (Grine 1977). Through an understanding of the biomechanics of chewing and dental function, as well as the development of SEM methods, researchers began to explore evolutionary and paleoecological questions with increasing enthusiasm. Using this methodology,

scientists gained the power to examine tooth surfaces at much greater resolutions, and dental microwear research began to flourish.

Following the facet numbering system described by Kay (1977), Gordon (1982) examined the degree of shear and crushing involved in chimpanzee mastication by analyzing facets 1, 2, x, and 10n surrounding the protoconid of mandibular first, second, and third molars. Facets 1 and 2 are produced by a shearing/cutting action of Phase I. Facet x is an anterior extension of facet 9, and represents the grinding component of Phase II mastication. Facet 10n is also a product of Phase II, and is located on portions of the hypoconulid and protoconid. Gordon (1982) measured the dimensions of microscopic features, including striations (currently termed 'scratches', which are linear marks where length is greater than breadth), gouges (broader, often s-shaped striations), and pits (features where length and breadth are roughly equal) from SEM micrographs, and recorded the direction of the marks. Feature density and feature type, as well as absolute measurements of striations and pits, corresponded with facet number and molar position. Gordon (1982) noted a decrease in striation length from anterior molars to posterior molars, which she attributes to a shortening of shearing action by the jaw during mastication. Compressive forces tend to be greater on posterior molars, and shearing forces greater on anterior molars. Striations on posterior molars are shorter due to a shortening of shear arc, and may be mistaken for pits. In addition, while first and second molars displayed similar wear patterning associated with shear and compression forces, third molar wear was more variable. Therefore, the author advised that researchers use only first and second molars for their studies, and that they analyze

homologous facets to ensure the accuracy of dietary interpretations and comparability with other microwear datasets. Gordon (1982) underscores the importance of understanding the normal range of microwear variability caused by biomechanics; patterns of microwear that fall outside of this range may be used to infer subsistence practices between different populations. A related report reinforces the importance of controlling for age, as juvenile chimpanzee molar enamel had significantly higher feature densities than adult samples; this is likely due to the cumulative effect of attrition, as microwear features in adults become reworked at a faster rate than in juveniles (Gordon 1984b).

Focusing on the dentition of modern humans, Maier and Schneck (1982) devise a facet numbering system that differs from those of previous studies. Their study argues that the systems developed by Kay and Hiiemae (1974) and Kay (1977) are not adequate to characterize existing hominoid dentition, because they are largely based on the molar morphology of Oligocene primates. Hominoid molar morphology also shows greater differentiation than Ceboidea and Cercopithecoidea (specimens whose molar wear is also described in numbering systems); therefore, Maier and Schneck (1982) argue that hominoid Phase I occlusal facets 1-8 be modified to include 4', and that Phase II be modified to include facets 11-13. This numbering system primarily acknowledges the role of the hypoconulid, whose action creates facet 4' of Phase I mastication, and facets 12 and 13 of Phase II mastication. Maier and Schneck's (1982) analysis of hominoid wear facets allows for greater precision in dental microwear research, particularly in studies that focus on the diet of human populations. The facet numbering system

described by Kay and Hiimae (1974) and Kay (1977) are still widely used in dental microwear studies, but researchers who focus on human populations sometimes prefer to use Maier and Schneck's (1982) system.

Experimental work by Maas (1991) investigated the response of prismatic and non-prismatic enamel to masticatory shear force, and the degree to which the underlying properties of tooth enamel and biomechanics are related to the formation of dental microwear. Using three types of silica grit, the author abraded the non-prismatic tooth enamel of crocodiles, and the prismatic enamel of sheep, lemurs, and humans, to understand inter-specific structural differences to shearing force. Mammalian teeth contain both prismatic and non-prismatic enamel, while reptiles have non-prismatic tooth enamel. The study confirmed that food particle size (mimicked by the silica grit size) did not correspond with scratch width, at least for prismatic enamel, but that particle shape and hardness may play a role in the striation morphology. Results from this study also suggested that the organization of crystallites in enamel prisms and the direction of shear force correlate with striation width. An oblique position of crystallites relative to the wear surface makes striations wider, as does shearing force in a cuspal-cervical direction. Individual and species-level variation in microstructural enamel, as well as the magnitude of masticatory force, may be impossible to eliminate as a contributing factors in the creation of dental microwear. Dietary interpretations based on dental microwear must consider that biomechanics and enamel structure may play a role in creating microscopic features within individuals, as well as within a population. Even so, Maas (1991) stresses that microscopic wear feature morphology and density are still

causally linked with diet, and remain viable candidates of study for those interested in dietary reconstruction.

Organ et al.(2006) introduced an innovative technique to investigate diet and its role in shaping structural properties of mandibular bone and tooth wear. These authors used SEM and computed tomography to investigate whether juvenile pigs fed hard animal chow versus softened, gruel-like chow displayed differences in dental microwear and mandibular structural properties. Results from the dental microwear analysis were not robust, as molars from each dietary group displayed no significant differences in wear features, including pit size and number. The authors noted several potential problems with the experimental design that may have interfered with the microwear data, including possible genetic malocclusion of the study animals, modified chewing strategy by the soft diet group fed an unusual diet, and chewing behaviors independent of the diet. However, pigs fed the hard diet demonstrated significantly greater mandibular corpus strength than those fed the soft diet; therefore, the authors argued that analysis of mandibular bone using computed tomography provides a viable way to identify dietary differences in animals with distinct feeding strategies.

To understand the relationship between the dental microwear patterning and mandibular morphology, Mahoney (2006c) examined SEM micrographs of M₁, M₂, and M₃, and measured mandibular corpus length, width, and depth in a human archaeological skeletal sample from Sudan. The author discovered that adult males with wide mandible corpi had significantly longer scratch marks on their M₁ than those who had narrow corpi, and that narrow mandibular corpi were associated with fewer and smaller pits and

narrower scratches on the same tooth. While these correlations are significant, Mahoney (2006c) admitted that it remains difficult to separate mandible morphology from masticatory load as a causal factor in the creation of dental microwear patterns, as these two processes are so interrelated. However, the author did not consider that masticatory load has been shown to be a significant factor in the formation of microscopic pit and scratch marks in previous studies (Gordon 1982, 1984b), while differences in mandibular corpus size alone have not been explicitly linked with microwear formation. Future microwear investigations that consider mandible measurements may also want to investigate sex differences, as well as diet, in their research design.

Methodological Considerations of Dental Microwear and Diet: Experimental Designs

Due to the complexities involved in parsing out the causal agents of dental microwear patterning, experimental research designs have played a crucial role in the development of the method. For all practical purposes, the interpretation of dietary patterns using microwear analysis would be impossible without experimental research aimed at understanding the intersection of jaw mechanics, tooth form and structure, and interspecific comparisons. Though difficult to conduct, controlled feeding experiments and innovations in technology have allowed anthropologists to use dental microwear as another line of evidence in understanding past dietary behaviors.

An influential, as well as controversial, study involved a controlled feeding experiment whereby opossums were fed diets that varied in grit content (Covert and Kay 1981). The baseline (and control) diet given to the opossums was a soft cat food, to which soybean husks and chitin were added to mimic herbivorous and insectivorous

diets, respectively. As a proxy for soil, the researchers added fine-ground pumice to the diet of one opossum for the last third of the experiment time. Through SEM, the authors examined M₃ and M₄ of each study group and found no significant differences in wear patterning between the first three groups; however, the opossum that was fed pumice displayed a pattern that was similar to a species of hyrax that consumes grasses (Walker et al. 1978). Comparing these results with dental casts of *Sivapithecus*, Covert and Kay (1981) concluded that the hominoid's diet did not include opal phytoliths, or grasses, because these would have left distinguishing marks on its enamel. The researchers also cast doubt on the ability to distinguish between herbivorous and insectivorous diets in the fossil record using dental microwear analysis.

Responding to criticisms from Gordon and Walker (1983) that Covert and Kay's (1981) experimental design was flawed, Kay and Covert (1983) defended their opossum study vigorously, refuting claims that the feeding period was too short and the dietary regimes were unrealistic. However, the authors noted that the resolution of wear would have been greater had the protective enamel pedicle from the opossums' teeth been removed before making the dental impressions. Kay and Covert (1983) presented a simple method that removes this coating, and demonstrated that the baseline soft cat food was adequate for the study.

Another *in vivo* study involving 15 vervet monkeys demonstrated that the turnover rate of dental microwear features in crushing molar facets is high for some diets (Teaford and Oyen 1989). In this research design, the authors supplied one group of monkeys with a hard diet (Monkey Chow) supplemented with apples, and another group

a soft diet (softened Monkey Chow) supplemented with fruit puree. Due the findings of Walker et al. (1978), which described a seasonal turnover rate for microwear features in hyraxes, Teaford and Oyen (1989) expected to see rapid turnover, and took three dental impressions of M₁ over a 72 hour period. They also conducted an *in vitro* experiment using isolated baboon teeth, and manually rubbed the occlusal surfaces at regular intervals with Monkey Chow. In the three day time frame, Teaford and Oyen (1989) found a high rate of turnover in both dietary groups, with the hard diet group showing a significantly higher number of new features. After analyzing shearing facets 1 and 3, and crushing facets x and 9, the authors also found that crushing facets displayed a higher turnover rate than shearing facets. Based on these results, they suggested using large sample sizes when comparing species with different dietary practices (Teaford and Oyen 1989). This study has profound implications for the interpretation of dental microwear patterning, as dietary regime for some species, such as *Homo sapiens*, can change from one season to the next. And, depending upon the abrasive quality of the diet, changes are likely to occur much more frequently, perhaps at a rate of every 1-2 weeks, or faster (Teaford and Oyen 1989; Walker and Teaford 1989). This phenomenon, termed the “Last Supper” effect, is a recognized complication in the broad-scale understanding of diet in a human archaeological population, particularly when one considers the issue of selective mortality in a mortuary population (Wood et al. 1992).

To investigate whether cereal phytoliths create distinctive wear patterns on human tooth enamel, Gügel et al. (2001) designed an experiment whereby 10 unworn, permanent, and impacted molars from recent surgical patients were compared to upper

and lower second molars from a medieval population (5-8th century) from Southern Bavaria. The authors examined spelt, wheat, barley, rye, oats, and millet, grains that were present in the region at this time and vary in levels of abrasiveness. The surgical specimens were placed in a device built for the purposes of simulating mastication, and abraded with cereal-specific slurry. The archaeological samples were analyzed using SEM, and pit size and shape were documented. The results from the simulation indicate that, due to their unique morphological characteristics, cereal grain phytoliths leave distinct wear on tooth enamel. Comparisons with the archaeological teeth seem to rule out the use of some cereal grains in medieval Southern Bavaria, but Gügel and colleagues (2001) recognize the need to examine larger sample sizes before any dietary conclusions are drawn from the study. The authors also expressed pleasant surprise at the discovery of intact phytoliths on medieval period molars, and hope to pursue this line of evidence in future work. In an earlier study conducted by Lalueza Fox et al. (1996), researchers uncovered silica phytoliths embedded at the terminus of microscopic scratch marks recovered from buccal tooth surfaces of ancient Roman skeletons.

Dental Microwear: Analytical Techniques

Though researchers had begun to examine tooth enamel surfaces with light microscopes in the 1960s, it was not until the development of scanning electron microscopy and high precision casting materials that the field of dental microwear research burgeoned (Rose and Ungar 1998; Teaford 1988a). Beginning in the 1970s, anthropologists began using SEM to research the diet and ecology of human ancestors and fossil primates, and sought to characterize the dietary strategies, dental anatomy, and

mastication processes of extant primates. As discussed above, research designs involving *in vitro* and *in vivo* experiments using a variety of species led to a great deal of practical and theoretical advancements. As far as experimental research is concerned, however, Walker and Teaford (1989) insist that, though studies of jaw mechanics, tooth enamel structure, and tooth morphology are helpful to the field, they are ultimately not necessary for interpreting diet from dental microwear. Instead, the authors expressed optimism for using a variety of analytical techniques in the reconstruction of paleodiet; for example, dental microwear analysis is able to track recent dietary practices, such as seasonality, while stable isotope research represents a cumulative indicator of diet. Used together, a combination of research methods retains greater interpretive power.

Early SEM analysis of dental microwear features were qualitative, as researchers documented various types of marks on different teeth (and different aspects of teeth) in an attempt to understand the manner in which striations and pits formed. Once researchers gained a common language for discussing the chewing process and tooth facet formation, quantitative analyses of microwear patterns began to develop. Using a digitizer controlled by a minicomputer, Teaford and Walker (1984) conducted a dental microwear analysis of seven species of extant primates whose diet ranged from frugivorous to folivorous. The authors' study found that the microwear patterns of *Sivapithecus indicus* most closely approximated that of *Pan troglodytes*, a species that is known to be intermediate in range between frugivores and folivores.

As the first application of quantified methods, Teaford and Walker (1984) defined a scratch mark as anything above a 10:1 ratio in length, and anything below, a

pit, and chose to analyze a field of 0.03mm^2 , which the authors estimate was the equivalent of using 500 X magnification. The ability to quantify data enabled researchers to discuss microwear features in terms of means, densities, and ratios, and offered the hope of greater comparability and pattern recognition among different sets of data. However, researchers did not necessarily define or measure microwear features in the same way. For example, Gordon (1988) noted that methodological differences emerge when defining the shape and size thresholds of ‘pits’ and ‘scratches’. Some researchers use a length:breadth ratio range of 1:1 to 2:1 to define a pit (Gordon 1988), some use a 1:1 to 4:1 ratio (Grine 1988), while others define a pit as anything less than a 1:10 ratio (Teaford and Walker 1984). Gordon (1988) adds that pit and scratch marks are sometimes simply ambiguous. Statistically, however, it is important to analyze the wear features for each individual, and then calculate a population mean; doing this allows the researcher to evaluate individual variation from the mean. Gordon (1988) criticized Teaford and Walker’s (1984) pooling of scratch wear data from 10 individuals as biologically and statistically meaningless.

In addition to the difficulties inherent in defining wear features, Gordon (1988) also discussed magnification level choices using SEM. For example, at high magnification, such as 500 X, one can lose valuable data because the surface area under study is small. Feature dimensions may also be affected at high magnification. At low magnification, such as 200 X, precision may be lost, as some microwear features are too small to see. A compromise to this problem, stated Gordon (1988), was employed by Grine (1987a) in his study of dietary differences between *Australopithecus* and

Paranthropus. The author's solution involved using a magnification of 200 X, and enlarging the photomicrograph to 500 X for digitized measurements (Grine 1987a). A final problem Gordon (1988) considered involves instrumentation and feature visibility. Proper orientation of the field is crucial when taking photomicrographs of the tooth, because distortion of the image can occur if the tooth is angled, and not level in relation to the microscope. If this occurs, measurements taken from the micrograph will be inaccurate and will affect interpretation.

In a later publication, Teaford (1994) noted that, though quantification provides interesting results, measuring wear features from just one micrograph can take hours (Teaford 1994). To combat this, some researchers employed different sampling strategies, i.e., examining a smaller area of the tooth surface, to minimize time costs. This practice, however, limits the comparability between dental microwear studies, and calls into question the interpretive power of the dataset. In addition to this, micrographs contain overlapping features that prove difficult to distinguish from one another; this leads to a great deal of subjectivity during the counting and measuring process of scratch and pit marks (Teaford 1994). Teaford wondered whether “replacing the SEM with other measures of microtopography” might be more beneficial for future research in dental microwear analysis.

Grine et al. (2002) reported intra- and inter-observer error rates among researchers using Microware 4.0, a semi-automated software program used to measure wear features on occlusal tooth surfaces from SEM micrographs. This digitized and mouse-guided software program has become standard in dental microwear research, but

quantification methods used to interpret the data vary widely. In this study, Grine and colleagues (2002) assessed three of the most common quantification techniques using mean absolute percentage difference, or MAPD, where observed values from one micrograph and sample means are evaluated. Researchers examined individual micrographs and collected standard descriptive data, such as feature frequencies and scratch:pit ratios, to obtain the observed value. The authors obtained intra- and inter-observer error rates by analyzing observed value averages and sample means (the average value of observed value averages) using ANOVA, and significant results were analyzed using least significant difference (LSD) and Games and Howell tests. After analyzing the methodological approaches adopted by Teaford (1985), Grine (1986) and Ungar (1995), Grine et al. (2002) found the intra-observer error rate to be 7%, and the inter-observer error rate to be 9%. Methodological differences included level of SEM magnification, size enlargement of the micrograph, and the strength of kV employed during the SEM image collection. The manner in which data were scored from SEM images accounted for both intra-observer and inter-observer error rate. Between researchers, the most common error made was the measurement of pit dimensions; in contrast, feature densities and scratch breadths made up the majority of intra-observer errors. Though hopeful that fully automated analysis of dental microwear, such as pattern recognition systems, may be available in the future, the technology at present is not advanced enough to distinguish antemortem wear patterns from postmortem artifacts on teeth. Still, Microware 4.0 remains a valuable and accurate technique for determining broad-scale dietary differences between species or populations (Grine et al. 2002).

3D Imaging Technology and Dental Microwear Analysis

Due to some of the constraints of traditional SEM methods to characterize diet, researchers began employing analytical techniques that generate a 3D image of the occlusal tooth surface (Boyde and Fortelius 1991; Dennis et al. 2004; Jernvall and Selanne 1999; M'Kirera and Ungar 2003; Scott et al. 2005; Scott et al. 2006; Ungar 2004; Ungar and Williamson 2000; Ungar et al. 2003; Walker and Hagen 1994; Zuccotti et al. 1998). In one of the earliest of these studies, Walker and Hagen (1994) evaluated teeth with significantly different scratch to pit ratios by analyzing a 2mm² section of enamel using a profilometer and calculating anisotropy. The authors created a topographic image of tooth surfaces, and obtained wear feature data ranging in size from 0.1µm to 0.1mm (Walker and Hagen 1994). Using a confocal microscope, Boyde and Fortelius (1991) created a 3D topographic map of Miocene suid molars (*Listriodon splendens*) at a resolution of 0.1 µm. These methods generated a great deal of interest among researchers studying dental microwear, and different approaches to 3D imaging began to emerge.

One method, *dental topographic analysis*, uses Geographic Information Systems (GIS) software to generate digital elevation models (DEM) of occlusal molar surfaces by taking measurements of x, y, and z coordinates (Dennis et al. 2004; Klukkert et al. 2012; M'Kirera and Ungar 2003; Ungar 2004; Ungar and Williamson 2000; Zuccotti et al. 1998). By treating occlusal surfaces like geographical terrain, digital elevation models obtained through GIS confer a variety of benefits to the study of dental microwear, including the ability to examine cuspal slope, angularity, surface area, and relief, as well

as to measure occlusal basin volumes (Jernvall and Selanne 1999; Ungar and Williamson 2000; Zuccotti et al. 1998). These models also create permanent 3D images of the tooth that are easily stored and shared (Jernvall and Selanne 1999).

Using a laser to scan the enamel wear surface of M₂ in chimpanzees and gorillas, M'Kirera and Ungar (2003) created a GIS map of worn and unworn teeth from these species to examine shearing quotient, a measure of the shearing cusp length relative to the length of the molar. Degree of shear, or shearing quotient, is a measurement that has been correlated with non-human primate diets, specifically fruit eaters and leaf eaters (Kay and Covert 1984). In general, frugivores have a lower shearing quotient (and shorter shearing crest) than insectivores and folivores, who have a high shearing quotient. The authors noted that fruit specialists that eat harder fruits, rather than softer fruits, have a lower shearing quotient by comparison, as their flatter molar cusps are used to crush food. After analyzing shearing quotient in 3D space, M'Kirera and Ungar (2003) found significant differences in the dental topography of gorillas and chimpanzees, and discovered that these differences remain consistent throughout each stage of wear for each species. Gorilla diet, which consists largely of leaves and stems, is comparatively tougher than chimpanzee diet; consequently, gorilla dental topography is more pronounced (of higher shear) than that of the chimpanzee. Though this study did not address microscopic wear features, it demonstrated that 3D laser technology and GIS can be used to topographically characterize occlusal tooth surfaces and distinguish dietary regimes (M'Kirera and Ungar 2003).

In a longitudinal study of *Alouatta palliata*, Dennis et al. (2004) used dental topographic analysis to determine whether worn molar teeth display wear in a predictable manner through time, or whether the pattern or shape of tooth wear varies by individual. The authors made dental molds of fourteen howler monkeys over a period of seven years, and created digital elevation models of the occlusal surfaces. The study found that cusp slope and occlusal relief decreased over time, but that crown angularity stayed constant. Ungar and Williamson (2000) obtained similar results in their GIS study of tooth wear and functional efficiency in M₂ in *Gorilla gorilla*; cusp angularity showed no significant change through time, and confirmed that worn teeth could be used in functional anatomy studies.

Ungar (2004) applied dental topographic analysis of occlusal M₂ surfaces in a comparative study of dental morphology and tooth wear among *Pan troglodytes*, *Gorilla gorilla*, *Australopithecus afarensis*, and early *Homo sapiens*. The purpose of the study was to examine occlusal molar surfaces in different stages of wear, so that tooth form and function throughout the life of a specimen, as well as dietary adaptations, may be better understood. Occlusal slope and relief at each stage of wear was most pronounced in *G. gorilla* molars, and is less rough in *P. troglodytes*, early *Homo*, and *A. afarensis* molars (in descending order, where *A. afarensis* is the flattest). A high degree of occlusal slope and relief is associated with diets that include tough foods such as leaves and stems, as a great deal of shear is required for proper mastication; conversely, flatter molar relief is associated with hard or brittle foods. Ungar (2004) hypothesizes that the occlusal slope and relief differences between sympatric gorilla and chimpanzee molars is

due to the consumption of different fallback foods, and that early *Homo sapiens* likely relied on a variety of alimentary reserves, particularly tougher foods like meat, than *A. afarensis*.

Klukkert et al. (2012) test whether dental topographic analysis can distinguish different dietary practices among three subspecies of chimpanzee, specifically *Pan troglodytes troglodytes* (n=52), *Pan troglodytes verus* (n=28), and *Pan troglodytes schweinfurthii* (n=20). The authors did not expect to find evidence for dietary differences, specifically for preference in fallback foods, among the specimens, even though molar morphological traits among the groups do vary. The authors selected intact molar samples from museum collections; all chimpanzees in the study had lived in the wild, with the exception of one. An XSM multi-sensor scanner was used to collect x, y, and z coordinates, and the data was converted into a GIS scan using ArcView software. As expected, the authors discovered no significant difference in the occlusal molar surfaces of the chimpanzees, which confirms earlier studies that show little dietary differences among these groups. However, dental topographic analysis may be able to show more fine-grained changes related to the “smoothing” of molar wear over time that other methods have not detected. More work is needed to evaluate the potential of this finding.

Jernvall and Selanne (1999) discussed the methodology of laser confocal microscopy and GIS, and the applications of these analytical techniques to the study of dental morphology. Though not a study of dental microwear, these researchers were the first to use the confocal microscope to study tooth surfaces, and some of their techniques

were later adopted by those interested in dental microwear analysis. The confocal microscope, widely used in the biomedical sciences, uses a laser to penetrate the surface of the tooth and detect reflective or excited fluorescent light. While original teeth may be used to collect data, one may also make dental epoxy casts and place a fluorescent dye into the material; in this study, the researchers placed a mixture of eosin dye and ethanol into the epoxy material, and poured the casts the following day. Other researchers using confocal microscopy or other laser technology coated hardened epoxy casts with Magniflux SKD-S2 Developer (Illinois Tool Works, Inc, Glenview, IL) (M'Kirera and Ungar 2003; Ungar 2004; Ungar and Williamson 2000), or did not coat them at all (Scott et al. 2006; Ungar et al. 2003). Jernvall and Selanne (1999) used 2.5x and 10x magnification on the confocal microscope, which gave them a maximum working window of 12.8 x 10.2 mm; specimens larger than 10mm have to be scanned in sections, which holds true for all studies using a confocal microscope. The authors created digital elevation models using the National Institute of Health's 3Dview Version, and optically sliced the image of the epoxy cast at intervals of 25 to 100 microns. Image measurements may be taken with any GIS software package, including lengths, widths, longitudinal and transverse slopes, and occlusal volumes (Jernvall and Selanne 1999).

Using laser confocal microscopy and scale-sensitive fractal analysis, Ungar and colleagues (2003) and Scott and colleagues (2005, 2006) have developed *texture analysis*, a method whereby researchers analyze and compare the texture of the tooth facet surface using complexity and anisotropy as defining characteristics. Complexity considers the degree of surface roughness, while anisotropy reflects the directionality of

surface roughness. Hard and brittle foods, typically associated with pits, will cause greater surface complexity, while tough foods will leave anisotropic features, or “striae”, on the tooth surface. The software Toothfrax, based on fractal analysis, was developed specifically for the purpose of analyzing tooth wear. Visual observation of SEM images has a lower rate of error than SEM image analysis (Boyde and Fortelius 1991; Scott et al. 2005; Ungar et al. 2003) and, like SEM, is a repeatable process. With texture analysis, pits and scratch marks do not have to be individually counted, estimated, or defined. Instead, a 3D relief of the tooth surface is generated, and the contours are analyzed based on surface texture.

Ungar et al. (2003) applied texture analysis in a study of the occlusal lingual portion of M²s from a browser (a bushbuck), a grazer (a brindled gnu), and a frugivore (a capuchin monkey). Using a NanoProbe II Pro tandem scanning confocal microscope, the researchers made images of the epoxy casts at a resolution of 0.06 microns, which is comparable to the resolution of a scanning electron microscopy. The images were sampled at 0.3 micron intervals, and were analyzed using Kfrax, a software program that applies scale-sensitive fractal analysis to characterize and measure surface texture. The authors compared peak to valley ratios of the three taxa, and found significant differences that correspond with the results from traditional SEM studies. Capuchin molars were heavily pitted and had fewer scratches than bushbuck or gnu molars, and the molar surfaces of the grazing gnu were far more complex than the surfaces of the browsing bushbuck. Gnu molars showed greater anisotropy than capuchin molars at a scale below 30 microns, as frugivores tend to have higher pit to scratch ratios. Ungar and

colleagues (2003) stressed the limitations inherent in scanning electron microscopy, specifically noting that microscope settings, such as collector-specimen geometry, electron type, voltage, working distance, coating, and other data collection choices significantly affect microwear images. Image analysis, which has high intra- and inter-observer error rates and consumes a great deal of time, presents additional problems for researchers. One can attain the same level of resolution with a confocal microscope as with SEM without the high rates of error or lengthy analysis, and the authors suggested that this approach will eventually supplant traditional SEM analytical methods (Ungar et al. 2003).

Scott et al. (2005) used texture analysis to characterize the diets of *A. africanus* and *P. robustus*. In addition, the authors examined *Cebus apella* and *Alouatta palliata* for comparative purposes, since the diets of these primate species are known and have been characterized using traditional microwear SEM methods. The researchers studied the M₂S of each taxa (four areas surrounding facet 9) and measured a total area of 276 x 204 microns using a white-light scanning confocal microscope. The authors found that the molar surface characteristics of *C. apella*, a fruit and seed specialist, were more complex than *A. palliata*, which consumes tougher foods, such as leaves. Conversely, *A. palliata* displayed a greater degree of anisotropy than *C. apella*. Interestingly, the molar surface texture of *P. robustus* was more complex than *A. africanus*, and *A. africanus* had more anisotropic texture than *P. robustus*. The authors concluded that the robust hominin consumed harder and more brittle foods than *A. africanus*, which consumed tougher foods. Through fractal analysis, the authors determined that, though both

hominins enjoyed many of the same foods, they differed significantly in other aspects of diet. As in Ungar's (2004) hypothesis regarding fallback food exploitation differences, Scott et al. (2005) suggested that *P. robustus* and *A. africanus* may have consumed different food reserves during periods of primary resource scarcity.

In another study, Scott and colleagues (2006) applied scale-sensitive fractal analysis, using Toothfrax, to the molar surfaces of *Lophocebus albigena* (black mangabey), *Trachypithecus cristatus* (silvered leaf monkey), *Alouatta palliata* (howler monkey), and *Cebus apella* (capuchin). As in their previous study, the authors examined complexity and anisotropy to infer dietary patterning. However, they also introduced new analytical parameters, which they described as heterogeneity, scale of maximal complexity, and textural fill volume. Heterogeneity refers to the variation in complexity across the facet surface, and scale of maximal complexity is defined as the "scale of wear-causing particles" that produces complexity. Textural fill volume is a measurement of the basins and troughs along the facet surface, and will be highest in those surfaces with the greatest amount of pitting, or gouging. Each of these analytical parameters is calculated by three algorithms: the length-scale rotational algorithm (heterogeneity), the area-scale tiling algorithm (scale of maximal complexity), and the volume filling v. scale square cuboid filling algorithm (textural fill volume). After completing the fractal analyses on the four taxa listed above, the researchers concluded that *L. albigena* and *C. apella* consumed harder foods than *A. palliata* or *T. cristatus*, and that texture analysis was able to provide greater subtlety in distinguishing species that have similar, but not the same, dietary patterns.

Scott et al. (2009) continue to investigate the manner in which microwear texture analysis can shed new light on the interpretation of dietary strategies through their examination of two families of subfossil lemurs, the Archaeolemurids and the Megaladapids. Previous studies of these primates that used conventional SEM methods and low magnification light microscopy arrived at different conclusions regarding their diet; therefore, this study seeks to offer some resolution to the conflicting data. In the Archaeolemurid family, *A. edwardsi*, *A. majori*, and *H. stenognathus* were examined; in the Megaladapid family, *M. edwardsi*, *M. grandidieri*, and *M. madagascariensis* were studied. The authors used the maxillary second molar whenever possible, and examined Phase II facets (9, 10, n, and x). Results from scale-sensitive fractal analysis indicate some dietary overlap between the two families of subfossil lemurs; Archaeolemurids were found to show some evidence of hard-object feeding, but cannot be categorized as “hard-object feeders”. Support for a more generalized diet in this primate family is found in the microwear data and from stable isotope analysis, as well. *A. edwardsi* shows the least amount of evidence for a hard-object diet. This study supports previous research in categorizing the Megaladapid family as folivores. Scott et al. (2009) point out that Liem’s paradox applies to this study of Archaeolemurids, as the dental anatomy in these primates indicates a specialization for hard-object foods.

In a 2012 study using dental microwear texture analysis of 21 anthropoid primate species, Scott and colleagues seek to understand the extent to which dental microwear correlates with diet. Though the study uses a large sample size, the authors express concern over the lack of consistent primatological field data, which they concede is

difficult and time consuming to obtain. The researchers used 5 species of African cercopithecids, 3 species of African open terrestrial Papionini, 3 species of African ape, 6 taxa of New World monkeys, and 5 species of Asian catarhine. These primates were selected because of their divergent feeding strategies and diet. After conducting scale-sensitive fractal analysis, Scott et al. (2012) found that about 70% of the variation seen in microwear texture can be attributed to species differences, and that primate diet is, on a whole, “complicated and variable”. In addition, out of all of the SSFA variables used in the study, measurements of complexity (*Asfc*) and anisotropy (*epLsar*) remain the most useful for characterizing diet.

To test the efficacy of using Phase II facets for dental microwear studies, Krueger and colleagues (2008) examined Phase I and Phase II facets from *Alouatta palliata*, *Cebus apella*, and *Lophocebus albigena* using texture analysis.

Crushing/grinding Phase II facets have traditionally been analyzed in microwear studies to characterize and infer diet, and are widely chosen for analysis over Phase I shearing facets. Krueger et al. (2008) tested whether this methodological practice was sound, and concluded that Phase II facets are indeed the most reliable for recording dietary information. However, the authors discovered that between-taxa differences in Phase I and Phase II facets (caused in part by biomechanical forces and food fracture properties) are able to offer even more fine-grained dietary information than simply analyzing Phase II facets.

In addition to primatological and methodological questions, researchers have also recently used texture analysis to investigate palaeoanthropological problems (Ungar et

al., 2008; Ungar et al. 2010; Ungar et al. 2012). In a study of *Paranthropus boisei*, Ungar and colleagues (2008) discovered a significant disconnect between functional morphology and actual use in a study of seven individuals from this species. *P. boisei*, due to its thick molar enamel, large and flat cheek teeth, and wide mandibular corpus, has long thought to have been adapted to a diet largely consisting of hard and brittle foods. An examination of facet 9 from all permanent molars, however, reveals that *P. boisei* had low values of both complexity and anisotropy, meaning that its diet did not reflect food choices that were particularly hard or tough. The results were compared to extant primates *C. apella*, *L. albigena*, *T. cristata*, and *A. palliata*, for which data already exists, as well as South African hominins *A. africanus* and *P. robustus*. Texture analysis of *P. boisei* shows complexity values that are quite low compared to living primates, and suggest a diet that most closely resembles that of a frugivore. The study also shows significant differences between the diets of *P. boisei* and *P. robustus*, wherein *P. robustus* appears to have eaten a diet that was considerably harder and less tough than *P. boisei*. The authors conclude that that *P. boisei* may have relied on hard and brittle foods as “fallback” items, but preferentially consumed foods that were far softer than it was capable of eating. Even so, the present research offers no concrete evidence of support for such a fallback model in *P. boisei*, as none of the specimens showed microwear features that were consistent with the consumption of hard or brittle foods (Ungar et al. 2008).

Ungar and colleagues (2010) discovered a similar research outcome when they conducted a microwear study using texture analysis on *Australopithecus anamensis* and

Australopithecus afarensis. Though the hominins display morphological characteristics that have led researchers to infer a diet based on hard and brittle foods, microwear analysis of permanent molars shows low values of complexity and anisotropy. *A. anamensis* and *A. afarensis* have low complexity values that compare most closely with extant primates that consume grasses and leaves. Anisotropy values are also low in comparison to living primates. Similar to the results reported by Ungar et al. (2008) regarding *P. boisei*, *A. anamensis* and *A. afarensis* have complexity values that are lower than that of the South African hominins *A. africanus* and *P. robustus*. Ungar et al. (2010) posit that low anisotropy values of East African hominins, compared to primate species, may be due to biomechanical differences; the flat teeth of hominins may afford them greater range of movement to grind food, as opposed to the dental morphology of primates, which has greater occlusal relief with more restricted movement.

Another recent study by Ungar and colleagues (2012) contributes texture analysis data for an additional 7 hominin samples, two from *Homo habilis* and 5 from *Paranthropus boisei*. These are compared to existing microwear data from extant primates and other hominin samples from East Africa and South Africa. In addition to measures of complexity (*Asfc*) and anisotropy (*epLsar*), the authors (2012) also report values of scales of maximum complexity (*Smc*), textural fill volume (*Htv*), and heterogeneity of complexity (*HAsfc*). The results further confirm the Ungar et al. (2008) study that showed low complexity values for *P. boisei*, which indicates that none of these individuals consumed a hard or brittle diet in the days or weeks prior to death. The authors also report that the values for complexity in *P. boisei* are very similar to those

seen in *A. afarensis*. When measures of complexity for *P. robustus* and *P. boisei* are compared, the former fall into the range of a hard object “fallback” feeder, while the latter do not. Meanwhile, the authors (2012) note a difference in microwear texture between *H. habilis* and *H. erectus*. Early *Homo* samples show moderate values in terms of complexity, and low values of anisotropy; the authors posit that these hominins ate hard foods only in times of resource stress. This pattern of microwear suggests a broad, varied diet. However, the presence of more small pitting, or pits, on the molars of *Homo erectus* indicate that this hominin may have eaten a wider range of harder foods than *H. habilis*, *A. afarensis*, and *A. africanu*, or *P. boisei*.

In a study of the earliest fossil hominin to date found outside of Africa (1.8 million years), Pontzer et al. (2011) describe the dental microwear texture of 2 mandibular molars from Dmanisi, Georgia. Hypotheses surrounding the cognitive and behavioral development of *H. erectus* have sometimes attributed diet (some based on meat, others on USOs) and/or cooking methods as the driving forces of hominin evolution. Though the sample size is too small to conduct any meaningful measure of statistical analysis, dental microwear texture analysis showed that the hominin remains from Georgia were similar to *H. erectus* samples from Africa. Molars displayed moderate complexity, low textural fill volume (*Tfv*), and relatively low scale of maximum complexity (*Smc*). These results indicate a varied diet, with food that was not particularly hard or tough. No evidence was found to support the hypothesis that this early hominin focused solely on meat or USOs to meet its dietary needs.

El Zaatari et al. (2011) explore whether climate change affected Neandertal dietary patterns in their microwear texture analysis of 25 individuals from European and Levantine sites. The authors divided the subjects of their study into ecological categories that include open (little to no tree cover), mixed (a mixture of open land and tree cover), and wooded environments. Permanent molars, either M1 or M2, were characterized using five variables of scale-sensitive fractal analysis (*Asfc*, *epLsar*, *Smc*, *Tfv*, and *HAsfc*). In addition to the ecological classification, the researchers divided up the sample by time period and geography. Drawing on a comparative study of hunter-gatherers (El Zaatari et al. 2010), the authors assess the degree to which meat played a role in Neandertal diet. Cluster analysis of each Neandertal subcategory with each hunter-gatherer group (Chumash, Fuegians, Tigara, Andamanese) revealed that Neandertal groups most closely correlated to the hunter gatherer group with the most similar ecological background. Interestingly, as the level of tree cover in an environment increased, so did the level of tooth enamel complexity (*Asfc*) and heterogeneity (*HAsfc*). This indicates an increase in the ingestion of hard foods and more variability in the diet.

Using texture analysis, Schubert et al. (2010) tackle the uncommon subject of carnivores, and examine three predatory animals with known differences in dietary practices. The researchers used wild-caught specimens to conduct their study of *Acinonyx jubanus* (cheetah, n=7), *Panthera leo* (African lion, n=11) and *Crocuta crocuta* (spotted hyena, n=12). The cheetah is known to avoid consuming bone while eating, while the spotted hyena is known to devour the entire animal carcass, including bone. The African lion lies somewhere between the cheetah and the hyena in feeding

habits; it does not go out of its way to avoid eating bones, but the lion does not typically consume the entire carcass. Measurements of *Asfc* and *epLsar* show that the cheetah has the lowest level of complexity on its molars, and the highest measurements for anisotropy, respectively. Meanwhile, the lion and the hyena have lower anisotropy and higher levels of complexity than the cheetah. Moreover, the hyena displays the greatest amount of variability in the complexity of its molars (as measured by *HAsfc*), and the highest average complexity values. High *Asfc* and *HAsfc* in the hyena reflect the animal's practice of consuming hard, brittle bones. The results from this dental microwear texture analysis are in line with earlier dental microwear studies that use SEM; in those studies, cheetah teeth showed few pits and a large number of scratches (Schubert et al. 2010).

Schulz and colleagues (2010) introduce a novel approach to 3D dental microwear analysis in their comparative study of *Connochaetes taurinus* (Blue wildebeest) and *Equus grevyi* (zebra). The method employs the use of ISO/DIS 25178 (International Organization of Standardization), which specifies standards related to the collection and analysis of surface area textures, and SSFA (scale-sensitive fractal analysis), which has been used by Ungar and colleagues (2003) to examine tooth enamel textures for dental microwear analysis. Schulz et al. (2010) wish to determine if more fine-grained detail of tooth enamel can be gleaned by combining these methodologies, and endeavor to examine 16 wear facets on ungulate teeth. The authors tested for differences in tooth enamel by collecting and analyzing data on tooth position (between upper and lower teeth), cusp sides (mesial and distal), enamel ridges, and species (both within and

between zebras and wildebeests). Thirty surface texture parameters outlined by ISO were collected when the samples allowed it, and SSFA data (*Asfc*, *epLsar*, *Smc*, *Tfv*, *Ftfv*, and *HAsfc*) was collected through confocal microscopy and processed using SFrax and Toothfrax software. The authors discovered lower *Tfv* (measurement of textural fill volume) in the distal teeth of zebras, which is likely related to the smaller food particles that these teeth encounter as food is chewed and pulled to the back of the mouth. Comparisons of mesial and distal cusps for both animals did not yield any differences for either animal. The authors found support for their hypothesis that central enamel ridges should show less attrition and more abrasion than peripheral ridges, as food will be guided by the peripheral ridges to the center enamel. Finally, in their analysis of the dietary differences of these species, the researchers found that the greater number of anisotropic features found on the teeth of zebra are due to their reliance on long, dry and brittle grasses, which leave these distinctive marks. In contrast, the Blue wildebeest prefers to eat short, fresh grass. The zebra also has fewer complex features on its teeth than the wildebeest. This is likely due to the wildebeest's preference for shorter grasses, which cause it to encounter more sand and grit from the ground as it grazes; in addition, the wildebeest is not a "pure" grazer, as 12% of its diet comes from browsing (Schulz et al. 2010).

Building on the parameters outlined by ISO/DIS and the methods employed through SSFA, Calandra et al. (2012) describe a methodology called dental area surface texture analysis, or DASTA. In their study, the authors examine the phase II grinding surface of facet 9 from eight primate species (*A. seniculus*, *G. gorilla gorilla*, *L.*

albigena, *M. fascicularis*, *P. troglodytes*, *P. cynocephalus*, *P. abelii*, and *T. gelada*) to determine if these techniques, used together, can estimate the proportion of fruit and other hard items that are consumed in a diet. The authors also examine enamel fracture and deformation properties as they relate to food properties, and whether microtexture analysis can be used to infer diet of extant primates, especially when sample sizes are small (greater than 2, but less than 10). Calandra and colleagues (2012) selected these primates based on their varied diets of fruit and grasses, and took into consideration the manner in which the fruit-eaters “treated” the seeds of the fruit, dividing them into ‘swallowers’, ‘spitters’, ‘destroyers’, and ‘cleaners’. The authors discovered a positive correlation between measurements of *Asfc* and the proportion of fruit in a primate’s diet, and a negative correlation between *HAsfc* and the proportion of fruit in the diet. The researchers also noted no correlation between *Tfv* and the proportion of fruit in the diet. In addition, an analysis of *epLsar*, the measurement for anisotropic features, separates primates based on their consumption of abrasive plant material. In this study, *A. seniculus*, *P. troglodytes*, *M. fascicularis*, and *L. albigena* displayed low values of *epLsar*, while *G. gorilla*, *P. cynocephalus*, and *P. abelii* had high anisotropy. The research by Calandra et al. (2012) supports Scott et al.’s 2006 study that shows a relationship between high *Asfc* and the consumption of hard items, such as fruit. Calandra et al.(2012) hope that, taken together, DASTA and SSFA can be used as powerful tools in dietary analysis and interpretation.

Dental Microwear: Bioarchaeological Applications in Anthropology

A great deal of dental microwear research has been devoted to questions related to primatology (El-Zaatari et al. 2005; Kay 1987; Kay and Covert 1984; Lucas and Teaford 1995; Merceron et al. 2005; Teaford 1985; Teaford and Glander 1991; Ungar 1996; Ungar et al. 1995; Walker 1976) and paleoanthropology (Grine and Kay 1988; Kay and Grine 1988; King et al. 1999; Rafferty et al. 2002; Teaford and Ungar 2000; Ungar 2004). In bioarchaeological research, macroscopic analysis of dental microwear had shown that the occlusal tooth surface of hunters and gatherers tends to be plane, while the occlusal wear angle of agriculturalists tends to be oblique (Smith 1984). Food processing techniques, such as grinding grains using stone implements, and boiling food in water, lead to an angled pattern of molar enamel attrition among agriculturalists, as softened food promotes greater tooth-on-tooth contact than tougher, unprocessed food, which requires different forces of mastication (Smith 1984). Eshed et al. (2006) found similar patterns of wear for Natufian hunter-gatherers and agricultural Neolithic populations, with the latter displaying cupped, as well as angled, molar wear patterns. Kieser and colleagues (2001) also found cupping, also known as Monson's curves, of occlusal surfaces among a recent archaeological Maori population that consumed gritty foods, such as fern root and shellfish. Though studies of dental attrition, or macrowear, provide a good basis for understanding broad-scale dietary patterns, particularly between hunter-gatherer groups and agriculturalists (Smith 1984), the utility of microwear analysis for reconstructing the diet of archaeological populations is evident.

Some researchers, rather than focus on one line of evidence, use several dental and skeletal measures to understand prehistoric dietary adaptations. Blaeuer and Rose (1982) examined the Powell Canal skeletal series from the Baytown phase of the Late Woodland period (700-1000 A.D., southeastern Arkansas). Comparing the sample with skeletal populations of similar cultural affiliation, the authors scored for porotic hyperostosis, periostitis, abscessing, calculus, and antemortem tooth loss (AMTL), calculated rates of caries and dental attrition (macrowear), and examined dental microwear on two infants and three adults. The researchers found a low caries rate, a high rate of dental attrition, and occlusal molar surfaces that, in one adult, were highly pitted. The dental microwear of the remaining two adults was not as heavily pitted, but contained significant scratching. Blaeuer and Rose (1982) suggest that the individual with heavy pitting may have died during the time of year when hard nuts were abundant. Overall, the dental evidence resembled a dietary pattern that more closely fits with hunter-gatherer groups from this region, rather than agricultural groups. Evidence for iron deficiency anemia was low, and skeletal lesions, though present, were not severe, and were restricted to the tibiae and fibulae. Though the adult skeletal sample was small, Blaeuer and Rose (1982) conducted an integrated bioarchaeological analysis of the skeletal remains, and actively addressed the interacting processes of disease and diet.

Littleton and Frohlich (1991), in a study of prehistoric skeletal populations from the Arabian Gulf, compared patterns of dental pathology, macroscopic tooth wear, and tooth loss in culture groups with diverse modes of subsistence. The authors scored for rates of dental attrition, AMTL, caries, calculus, and abscesses in populations of

maritime specialists, pastoralists, horticulturalists, and mixed economies (agriculture with either fishing or pastoralism). The study found that each group displayed a particular set of characteristics. The Ras el-Hamra maritime population had high rates of tooth wear and abscessing, and an absence of dental caries, calculus, and low rates of antemortem tooth loss. The dental attrition in Ras el-Hamra skeletons is mainly limited to occlusal molars, but is also present on the lingual side of the lower incisors. Littleton and Frohlich (1991) suggested that the extensive dental wear among the maritime people was likely due to the consumption of gritty foods, such as dried fish and shellfish, and not the incidental ingestion of sand, to which all groups in this region were subjected. This study has particular relevance for the study of coastal foragers from Brazil, who also relied heavily on fish and shellfish for subsistence. *Sambaqui* populations also show high rates of dental attrition, low caries, and low AMTL; however, moderate dental calculus is seen in some *sambaqui* populations, and rates of abscessing are low (Okumura and Eggers 2005).

Early bioarchaeological applications of dental microwear research involved the characterization and comparison of microscopic wear patterns in populations with known and distinct diets. For example, a bioarchaeological study by Gordon (1986) found differences in microwear features between the Zuni, agriculturalists of the American Southwest who rely on ground corn, and the Inuit, Pacific coastal foragers who primarily consume sea mammals and fish, usually raw. Zuni tooth enamel was marked with broader scratches and larger pits than Inuit enamel (Gordon 1986). In another study, Harmon and Rose (1988) correlated microscopic pitting on tooth enamel

with the consumption of hard hickory nut hulls at archaeological sites in the Southeastern United States. The hulls were known to have been ingested, because they were recovered in large quantities from coprolite specimens.

Continuing work in the Southeast region, Rose et al. (1991) synthesized and compared bioarchaeological data to find the earliest evidence for maize agriculture at archaeological sites in the central and lower portions of the Mississippi valley. Archaeological evidence, such as artifact assemblages and settlement patterns, encouraged several hypotheses regarding the timing of the introduction of maize cultivation, but none of these data was able to provide unequivocal support on its own. For a fuller, more integrated approach to the prehistoric record, the authors compiled adult skeletal and dental information from previous studies, including analyses of stable carbon isotope ratios, dental microwear, dental attrition, dental caries, porotic hyperostosis, and bony infectious lesions. Based on previous bioarchaeological interpretations of subsistence and the transition to agriculture, Rose and colleagues (1991) attributed low rates of caries (less than 2 per dentition), high enamel attrition, and rough microscopic molar surfaces (caused by coarse and abrasive foods) as indicative of low carbohydrate diets associated with pre-agricultural societies. High carbohydrate diets, on the other hand, are often associated with the consumption of grains, such as maize. However, other starchy plants, such as seeds, can produce similar dental conditions, particularly if the food is processed with stone implements, which add grit to the diet. In conjunction with stable carbon isotope ratios, which were used to distinguish C₃ and C₄ plant sources, dental evidence from Southeastern archaeological sites helped

clarify a complex problem in Southeastern archaeology, and lay the foundation for future studies exploring subsistence change and the transition to agriculture.

In a study of prehistoric juveniles of the Illinois River Valley, Bullington (1991) compared dental microwear patterns of individuals from Middle Woodland and Mississippian archaeological sites. Middle Woodland groups practiced horticulture, and consumed a diet that contained hard nuts and seeds. Though Middle Woodland horticulturalists had pottery, it was not structurally suitable for softening foods by boiling. In contrast, Mississippian groups consumed maize, which was boiled using pots. Using SEM to examine the surfaces of deciduous lateral incisors and first mandibular molars, the author calculated total feature frequency, pit frequency, and scratch frequency. The purpose of the study was to characterize early juvenile diet in individuals 6 to 27 months of age (divided into two age groups of less than and greater than 16 months); therefore, Bullington (1991) examined cusp tip surfaces, the part of the tooth enamel that first begins to show wear (rather than choose the standard Phase I or Phase II facets). Only one tooth, incisor or molar, was used per individual, even though the biomechanical properties and function of these teeth differ dramatically. Bullington (1991) found that feature frequency increased with age and duration of tooth eruption, and that pit frequency was greater in the older juvenile age group for both Middle Woodland and Mississippian populations. This last finding indicates that older juveniles in both culture groups were fed different diets than their younger counterparts. Due to consistently higher feature frequencies of Middle Woodland teeth compared to Mississippian teeth, Bullington (1991) concluded that the former maintained a diet that

was harder and more variable than the latter. This finding was expected, as Mississippian groups were able to soften their dietary staple, maize, using ceramic technology.

To test the hypothesis that cooked foods leave different dental microwear patterns on occlusal molar surfaces than uncooked foods, Molleson et al. (1993) used scanning electron microscopy to examine teeth from pottery-bearing and non-pottery-bearing populations. Additionally, the authors investigated the manner in which the Neolithic 2C population of Abu Hureyra, Syria, processed their food. At 7300 BP, Neolithic 2C represents the first appearance of pottery in this area; therefore, Molleson et al. (1993) compared the dental microwear patterns from this group with known consumers of cooked and uncooked foods to see whether Neolithic 2C peoples used pottery to process food by soaking and/or boiling, as well as to attempt to identify the types of food they consumed. The comparison pottery-bearing groups included Spitalfields, an 18th-century cemetery population from London, and skeletons recovered from Modern occupations from Abu Hureyra, Syria. These populations consumed cooked cereal grains and meat. Teeth from Mesolithic and Neolithic 2A and 2B occupations from Abu Hureyra represented groups that relied on uncooked foods, with the former subsisting on dry seeds and meat, and the latter on coarse dry grains and meat. Permanent and deciduous teeth were used in this study, for a total sample size of 21. Molleson et al. (1993) found that all populations who consumed cooked foods displayed similar microwear characteristics as one another, and were distinct from groups that did not cook their foods. Interestingly, Spitalfields individuals, who relied on a greater quantity of meat than Modern Abu Hureyra individuals (who eat little meat)

left similar microwear patterning, indicating that the quantity of meat consumption is not easily traced as a dietary factor in groups that rely on cooked cereal grains. Groups that consumed uncooked foods showed a greater amount of pitting over a larger area on occlusal surfaces and had high rates of dental attrition; this is due to eating a harder diet, as non-pottery-bearing groups did not have access to vessels in which to soak and/or boil food. Molleson et al. (1993) also found that the Neolithic 2C population most closely resembled groups that ate cooked food, indicating the use of pottery to process, and soften, food. They suggested that the agricultural revolution, marked by the ability to cook cereal grains, led to greater adult fecundity, an increase in birth rates, and a shortening of the birth interval.

Teaford and Lytle (1996), in an experimental study investigating the impact of food processing techniques on rates of dental attrition, demonstrated that stone ground maize significantly altered occlusal enamel surfaces within a short amount of time, and that the physical treatment of cereal grains, prior to consumption, greatly affects the tooth at the microscopic level. In this experiment, the authors took a baseline dental mold of an American eating a “normal”, everyday diet. The subject then ate one corn muffin made with sandstone ground maize (following Anasazi grinding methods) at every meal for one week. A mold was made, and the subject followed the same procedure for corn muffins made with igneous ground maize. He then returned to his American diet, and another mold was made after the passing of several weeks. Using SEM, Teaford and Lytle (1996) calculated the number of wear features on molar facet 9 for each set of dental impressions, and found that the sandstone ground corn muffin diet

yielded a rate of wear that was 30 times higher than the subject's American diet; the rate of wear was less extreme on the igneous ground corn muffin diet (though greater than the American baseline diet), as igneous is less abrasive than sandstone. The authors concluded that, given the observed rates of attrition in this experiment, an individual could expect to lose most of his dental enamel after a period of 10-15 years if consuming a sandstone ground diet. While the Molleson et al. (1993) study underlined the difference between cooked, soft cereals and uncooked, hard cereals and the formation of dental microwear, it is crucial to remember that the processing of food is equally pertinent to rates of dental attrition.

Schmidt (2001) considers shifts in subsistence and food processing methods of Late Archaic (and Early/Middle Woodland populations of Indiana, non cereal-reliant groups, and stresses that dental microwear analysis is able to detect subtle changes in dietary practices. Using SEM to analyze occlusal M₂ surfaces, Schmidt examined Late Archaic groups, semi-sedentary foragers whose plant food diet consisted largely of tubers, seeds, and nuts. He also analyzed the tooth enamel from Early/Middle Woodland people who practiced a mixed economy of horticulture and foraging. Early/Middle Woodland groups relied more heavily on nuts and seeds, and less on tubers, than Late Archaic groups. Significantly, while neither group had access to maize, Early/Middle Woodland populations in this region may have boiled their food in ceramic vessels. Schmidt (2001) found a significant increase in the number of pits from the Late Archaic to the Early/Middle Woodland period, as well as a decrease in scratch length and width. The increase in pit number and decrease in scratch dimensions among Early/Middle

Woodland groups are explained by a greater reliance on hard nuts and a lesser reliance on abrasive wetland tubers, respectively. Schmidt (2001) noted that the presence and size of exogenous grit in the Late Archaic foraging diet, such as sand from wetland food resources, may have contributed to enamel surfaces that were more highly abraded. The author cast doubt on the importance of differing food processing techniques between these groups, as boiled food is softer (and would leave less pitting) than food which has not been boiled. Instead, the diet became harder for Early/Middle Woodland groups. While cooking methods may not have played a significant role in the formation of dental microwear in this study, softening food by soaking and boiling may explain microwear variability for other groups.

Using scanning electron microscopy, Organ and colleagues (2005) investigated differences in dietary regimes among early Spanish mission and late Spanish mission sites in modern-day Georgia and Florida. At mission sites throughout the region, written records failed to address variability in diet among native inhabitants. The authors hypothesized that, due to the circumstances of habitat, the diet from the inland Mission San Luis de Apalachee site would differ from that of other inland and coastal mission sites, specifically in relation to the consumption of meat. Occlusal molar surfaces of individuals from Mission San Luis Apalachee displayed the highest number of microwear features, including medium-to-large pit marks and a high number of scratch marks. Interestingly, dietary patterns among all mission sites became clearer when each locale was divided into “early” and “late” periods, as the consumption of marine resources at coastal sites decreased as the missionization process increased. Organ et al.

(2005) suggested that the inland Mission San Luis de Apalachee population may have consumed greater quantities of meat than other mission populations, and that food processing associated with the consumption of non-maize plant foods may have also contributed to microwear patterning observed on teeth. Though results from the Mission San Luis de Apalachee study are not conclusive, by reorganizing the skeletal data set into early mission and late mission, as well as comparing the sites by habitat, Organ et al. (2005) clarified the dietary response to Spanish missionization among native groups of Georgia and Florida.

In light of the previous studies, the effects of introduced food processing methods on microwear patterning depend upon whether foods are made softer (by soaking or boiling) or harder (by grinding and the inclusion of abrasive particles) as a result of new technology. A hard diet typically results in pitting of the enamel surface (the harder the diet, the larger the pitting), and an abrasive diet in scratching of the surface. In one study, Mahoney (2006a) used SEM to compare Natufian (12,500-10,250 BP) and pre-pottery Neolithic (10,250-7500 BP) populations from Israel in an effort to see whether microwear feature number and morphology correlated with a change in food preparation methods. As foragers, the Natufian diet was highly varied, and included an array of animal proteins, such as goat, deer, cattle, and fish, and plant foods, like lentils, nuts, and barley. Neolithic groups consumed similar animal proteins, but concentrated more effort on cultivated grains, such as wheat and beans, which were processed with large grinding slabs. Natufian groups, in contrast, used smaller grinding stones and mortars and pestles to process plant foods. The changes in tool technology from the Natufian to the Neolithic

period strongly suggest that farming and larger-scale cereal processing became more important during the Neolithic (Mahoney 2006a). Using upper and lower sections of grinding facet 9 of M₂ to examine within group and between group variability, Mahoney (2006a) found significant correlations between changes in food processing methods and dental microwear patterning. Within-group comparisons that tested for microwear variability across facet 9 showed an increase in the number of pits from the top of the facet to the bottom within the Neolithic sample. This result suggests that farmers used greater compressive forces at the bottom of facet 9 than the hunter-gatherer population, for whom the microwear features along facet 9 were consistent. When the bottom portion of facet 9 was analyzed, between-group results showed that farmers had statistically larger pit marks and wider scratch marks than Natufian hunter-gatherers. Interestingly, both groups displayed a negative correlation between pit size and pit percentage; this finding was unexpected, as pit marks generally increase with hard diets. Mahoney (2006a) suggested that, as greater compressive forces are required to masticate harder foods, pits become wider, and merge. The researcher concluded that the diet of Neolithic farmers contained greater amounts of hard and abrasive grit from stone-ground foods than that of their foraging Natufian predecessors (Mahoney 2006a).

An examination of dental microwear patterning from two individuals of the Upper Paleolithic Levant (22,500 to 23,500 BP) revealed a diet that most closely resembled that of pre-pottery Neolithic A (PPNA) groups (10,300 to 9300 BP), as well as Chalcolithic groups (6300 to 5300 BP) of the same region (Mahoney 2007). According to the author, the diet at the Upper Paleolithic Ohalo II site produced wear

that is consistent with a tough diet that required more shear than compression, as the scratches were long and narrow, and the pits were small (Mahoney 2007). In contrast, Natufian and pre-pottery Neolithic B (PPNB) groups had wide scratch marks and large pit marks consistent with a hard diet. Differences in settlement patterns, diet, and technology existed among the groups: Natufians were semi-sedentary hunter-gatherers who ate fish, wild and domesticated animals, and uncultivated cereals; PPNA groups lived in more permanent villages, relied largely on aquatic foods, such as fish and mollusks, and may have cultivated cereal grains, such as wheat and barley; PPNB groups had a similar settlement strategy and diet, but ate fewer aquatic resources and more gazelle. Chalcolithic groups, in contrast, lived in permanent farming villages, consumed domesticated livestock (pigs and sheep), cultivated cereals, and used ceramic tools with which to cook food. Though Mahoney (2007) expected to find similarities between Upper Paleolithic and Natufian groups, he found no smooth chronological trajectory in the hardness of the diet. The PPNA reliance on aquatic foods and the fine clay particles adhering to them produced microwear inconsistent with a hard diet, just as the use of ceramic vessels that softened foods led to a similar pattern among Chalcolithic people. Natufian and PPNB groups consumed more land proteins, like gazelle, which may have introduced a larger-sized quartz grain into the diet that, in turn, produced wider scratches and larger pits.

Using dental microwear texture analysis, El Zaatari (2010) characterize the tooth enamel of 5 ecologically divergent hunter gatherer groups with recent ethnohistorical backgrounds. The researcher used a total of 117 permanent molars, M1 or M2 (upper or

lower), depending on which showed the best preservation. The hunter-gatherer groups included: Andamanese Islanders from Southeast Asia (n=30), Chumash off the central and southern California coast (n=13), Fuegians from the southern tip of South America (n=6), Khoe-San of South Africa (three different groups, n=43), and the Tigara from Point Hope, Alaska (n=25). The Andamanese Islanders and the Khoe-San are considered to have a mixed-diet subsistence economy, and rely on animal protein and plant foods in their diet. The Chumash, Fuegians, and Tigara rely mainly on animal protein for their subsistence. The researcher used 5 variables of scale-sensitive fractal analysis (SSFA) to analyze the tooth enamel: complexity (*Asfc*), anisotropy (*epLsar*), heterogeneity (*HAsfc*), textural fill volume (*Tfv*), and scale of maximum complexity (*Smc*). Out of the five groups, the Tigara had the most complex dental enamel. Though meat does not typically leave pitting on tooth enamel, the manner in which the Tigara prepared and stored their meat (cooking it uncovered, and storing it underground) allowed for extraneous abrasive materials, such as sand, to adhere to the meat. Meanwhile, the Fuegians and the Chumash demonstrated the lowest levels of complexity; this is due to their reliance on meat, and the lack of external abrasives introduced into their diet. The tooth enamel of the Chumash displayed more complexity and less anisotropy than that of the Fuegians. Of all five groups, the Fuegians displayed the highest levels of anisotropy. The Khoe-San showed intermediate levels of complex tooth enamel, lower than the Tigara, but higher than the Chumash and the Fuegians. The Khoe San incorporate hard food items such as nuts, seeds, and tubers into their diet, and rely on a mix of marine and terrestrial resources. The Andaman Islanders had the next highest level of tooth complexity next to

the Tigara; though they have a mixed-diet subsistence strategy, the Andamanese rely heavily on hunting and fishing for subsistence, and cook their food in the open. The author suggests that external abrasives may be the cause for such high levels of complex tooth enamel among this group. Of all SSFA variables that El Zaatari (2010) used, measurements of complexity (*Asfc*) appeared to do the best job at characterizing diet, while heterogeneity (*HAsfc*) was least successful.

Dental Microwear Analysis: Taphonomic Considerations

When undertaking a study of dental enamel from archaeological contexts, it is necessary to consider whether taphonomic changes of the tooth have occurred. Post-depositional alteration of the enamel surface may interfere with data collection, analysis, and interpretation of results. Experimental studies have shown that taphonomic processes are more likely to obliterate microscopic pits and scratches through polishing, abrasion, and erosion, rather than contribute scratch and pit marks to the archaeological sample (Gordon 1983, 1984c; King et al. 1999). Gordon (1983) conducted an experiment in which extracted human teeth were tumbled in vessels containing pea gravel, volcanic ash, and other unspecified materials to recreate the effect of sediment transport on teeth, and each experimental run contained a wet and dry component. The author initially reported no visible change in the tooth enamel surface with any of the “sediment” types (Gordon 1983), but after correcting for errors in the original experiment, noted that greater obliteration of dental microwear features occurred with larger particle sizes (Gordon 1984c). In no instance did any of the materials in the experiments overlay scratches or pits that could be confused with primary microwear,

and any secondary tooth surface alteration, such as erosion, was easily identified as taphonomic in origin. Because neither of these studies gave precise details about the duration of each experiment, nor a complete list of materials tested, future replication of this research remains difficult.

The importance of experimental research designs to the interpretation of data and the establishment of future questions cannot be overstated, however. One study by King et al. (1999) investigated similar taphonomic issues as the aforementioned study; however, their case researched the taphonomic effects of burial environment (rather than sediment transport) on tooth enamel. In the study, human teeth were treated to different acidic, alkaline, and abrasive “depositional environments” to observe both immediate and longitudinal effects on dental microwear (King et al. 1999). Of particular concern to the researchers was the identification of the source of wear on Miocene hominoid teeth recovered from an archaeological site in Turkey. The depositional environments that affected the integrity of tooth enamel most were hydrochloric acid (2.5% solution for 2.5 hours) and medium-sized sand (250 to 500 μm , tumbled for 16, 64, 256, and 512 hours). The hydrochloric acid had a profound erosive impact on the tooth surface, as primary microwear was almost completely eradicated, and enamel prisms were exposed. Medium-sized sand, on the other hand, was highly abrasive and caused heavy pitting of the enamel surface. Other environments had minimal effect on dental microwear. For example, coarse sand and quartz pebbles, though larger particles, caused far less obliteration of microwear features or damage to the tooth enamel than the medium-sized sand. As King et al. (1999) note, this result is in contrast to Gordon’s (1983, 1984c)

findings. Interestingly, after 238 hours, the alkaline environment (carbonatite ash in aqueous solution) appeared to clarify the microscopic features of the tooth. This last result is heartening for the present study, as I analyze teeth recovered from alkaline shell mounds.

Dental microwear analysis has progressed significantly over its nearly forty year history. Though small sample sizes, taphonomic considerations, repeatability of data gathering, and a dearth of detailed primatological and ethnographic field studies remain a problem for paleoanthropologists and bioarchaeologists alike, technological advancements in recent years have opened the door for new and exciting research questions. Dental microwear analysis, combined with other paleodietary research methods, such as stable isotope analysis, will continue to further our understanding of past diet, ecology, and behavior.

CHAPTER VIII

DENTAL MICROWEAR TEXTURE ANALYSIS: DATA COLLECTION, RESULTS AND DISCUSSION

To test the hypothesis that the appearance of pottery is associated with a change in diet and/or food processing techniques, I endeavored to collect and analyze dental microwear data on adult maxillary molars from Pre-Ceramic and Ceramic *sambaqui* site occupations. If coastal foragers exploited the same foods through time, i.e., stable carbon and nitrogen isotope values do not significantly change between Pre-Ceramic and Ceramic occupations, a study of dental microwear will indicate whether changes in cooking or food processing occurred with the adoption of pottery. For this investigation, I use dental microwear texture analysis, a method by which a 3-D image of the tooth enamel is measured for anisotropy (*Asfc*), which informs on the hardness of food, and complexity (*epLsar*), which informs on the toughness of food.

Research Expectations

I expect the texture of tooth enamel from Pre-Ceramic individuals to be complex, reflecting a hard and brittle hunting and gathering diet. I also expect Pre-Ceramic tooth enamel texture to display a high degree of anisotropy, reflecting a tough-food diet. If coastal forager diet changed with the adoption of ceramic technology, then I expect to observe less complexity and anisotropy of the tooth surface, as people are expected to use pottery to process and soften foods through cooking. If complexity and anisotropy of

the tooth surface do not significantly change after the introduction of ceramic technology, then pottery did not contribute to food processing.

The Dataset

I examined first and second maxillary molars from the following archaeological sites in Santa Catarina: Base Aérea, Cabeçuda, Enseada I, Forte Marechal Luz, Itacoara, Laranjeiras I, Laranjeiras II, Morro de Ouro, Rio Comprido, and Tapera. One archaeological site from the state of Rio de Janeiro, Zé Espinho, was also included in the analysis. I selected maxillary molars for use in this study because, for many of the museum collections that I visited, the cranium (with intact maxilla) was more likely to be preserved than the lower jaw. Recent dental microwear analyses using human teeth have also used maxillary molars for analysis (El Zaatari, 2010; Organ et al., 2005), and most microwear studies are comparable by the near universal employment of crushing facet 9 on permanent molars. When possible, I sampled teeth from adult skeletons; in three cases, however, older adolescents were used.

Though 98 individuals from 20 archaeological sites were originally sampled for dental microwear texture analysis, only 43 individuals from 11 sites displayed a sufficient level of enamel surface preservation necessary for accurate results. While the number of individuals available for analysis is fewer than anticipated, examination of diet through microscopic analysis of dental enamel remains unique for this time period, population, and study area, and will significantly add to a growing body of knowledge regarding the subsistence practices of coastal hunter-gatherers. Table 8.1 describes the

origin, age, sex, burial number, time period, tooth type, and tooth facet of each individual examined:

Table 8.1: Skeletal Populations, Including Site of Origin, Age, Sex, Burial, Time Period, Tooth, and Facet

Site¹	Age²	Sex³	Burial	Period⁴	Tooth	Facet
Base Aérea	Adult	Female	9	C	M ¹	X
Base Aérea	Adult	Male	16	C	M ²	9
Base Aérea	Adult	Male	34	C	M ²	9
Cabeçuda	Adult	Indet	1807	PC	M ¹	9
Enseada I	Adult	Indet	2	C	M ²	enamel rim
Enseada I	Adult	Indet	10	C	M ¹	center enamel
Enseada I	YA	Male	15	PC	M ¹	10n
Enseada I	Adol.	Indet	8638	C	M ¹	9
Enseada I	Adult	Indet	8693	C	M ²	center enamel
FML	Adol.	Indet	6	PC	M ¹	X
FML	Adult	Indet	22	PC	M ¹	enamel rim
FML	Adult	Male	53	C	M ²	10n
Itacoara	YA	Male	2	C	M ¹	9
Itacoara	Adult	Female	IA13	C	M ¹	X
Laranjeiras I	Adult	Female	136	PC	M ¹	10n
Laranjeiras I	Adult	Indet	140	PC	M ²	center enamel
Laranjeiras II	Adult	Female	37	C	M ¹	10n
Laranjeiras II	Adult	Female	92	C	M ²	X
Laranjeiras II	Adult	Male	107	C	M ²	X
Laranjeiras II	Adult	Male	112	C	M ²	X
Morro de Ouro	Adult	Indet	1	PC	M ¹	enamel center
Morro de Ouro	Adult	Indet	5	PC	M ²	9
Morro de Ouro	Adult	Female	9	PC	M ²	X
Morro de Ouro	Adult	Male	10	PC	M ¹	X
Morro de Ouro	Adult	Male	25	PC	M ²	X
Morro de Ouro	Adult	Female	27	PC	M ¹	X
Morro de Ouro	Adult	Female	28	PC	M ²	enamel band

Table 8.1 Continued.

Site	Age	Sex	Burial	Period	Tooth	Facet
Morro de Ouro	Adult	Male	31	PC	M ²	X
Morro de Ouro	Adult	Male	52	PC	M ²	center enamel
Morro de Ouro	Adult	Female	59	PC	M ²	9
Morro de Ouro	Adult	Male	60A	PC	M ²	X
Morro de Ouro	Adult	Male	80	PC	M ²	9
Morro de Ouro	Adult	Female	84A	PC	M ²	X
Rio Comprido	Adult	Indet	19	PC	M ¹	9
Rio Comprido	Adult	Indet	22	PC	M ²	enamel rim
Rio Comprido	Adult	Indet	23	PC	M ¹	9
Rio Comprido	Adult	Indet	54	PC	M ²	9
Tapera	Adult	Female	14	C	M ²	X
Tapera	Adult	Female	41	C	M ²	9
Zé Espinho	Adult	Indet	2057	PC	M ²	enamel rim
Zé Espinho	Adult	Indet	2063	PC	M ²	center enamel
Zé Espinho	Adol.	Indet	2069	PC	M ²	X
Zé Espinho	Adult	Indet	2070	PC	M ²	center enamel

1: FML=Forte Marechal Luz

2: YA=Young Adult

3: Indet=Indeterminate

4: PC=Pre-Ceramic; C=Ceramic

Data Collection: Methods

With the permission and assistance of colleagues at four museums in southeastern Brazil, I made dental molds of M¹ and M² using President's Jet Regular Body polysiloxane impression medium, manufactured by Coltène-Whaledent, from archaeological collections pertaining to this study. Once I returned to Texas A&M University, I made dental casts using a low viscosity epoxy called Epo-Tek 301 (Epoxy Technologies). The use of dental impression materials and casting epoxies have been shown to yield high quality replicas from which marks in tooth enamel can be studied (Grine 1986; Teaford and Oyen 1989). Specific materials, such as President's Jet impression medium and Epo-Tek 301, have commonly been used together in dental

microwear analyses (Ungar 1996; Organ et al., 2005) and recent studies of texture analysis (Scott et al., 2006; Scott et al., 2012; Ungar et al., 2012; El Zaatari et al., 2011). In preparation to begin collecting microwear data, I trained on the Olympus FV1000 confocal microscope with Dr. Stan Vitha at the Microscopy and Imaging Center at Texas A&M University. However, after completing microscopy training and imaging the first few teeth, it became clear that the equipment available at my university would not be able to capture the data I needed. Therefore, I sent my dental casts to the University of Arkansas, where Kristin Krueger, a PhD student from the department of Anthropology, scanned the dental casts using a Sensofar PL μ Confocal Imaging Profiler with a 100x objective.

The dental microwear method used in this study, called texture analysis, uses white-light confocal microscopy to capture 3-D scans of the tooth's surface. Four neighboring areas of the tooth enamel, labeled A, B, C, and D, are scanned separately to form a combined measured area of 204 x 276 microns. Depth profiles of each of the four scans are then created with SolarMap Universal software, which produces 0.005 μ m vertical slices of each scan, as well as lateral (x,y) samples at 0.18 μ m intervals (Scott et al., 2005). The scans are then analyzed using Sfrax, a scale-sensitive fractal analysis software program that measures the roughness of a surface based on different observations of scale. Measurement values for a given sample, or tooth, are based on the mean of scans A, B, C, and D. Figure 8.1 provides an example the composite scan of quadrant surfaces A, B, C, and D, and shows in fine detail the complex and anisotropic surfaces from the central enamel of M¹ from the Pre-Ceramic site Morro de Ouro.

Crushing facets x or 9 are preferred for dental microwear analysis; however, as in this case, the center enamel can be used when preservation precludes using crushing facets.

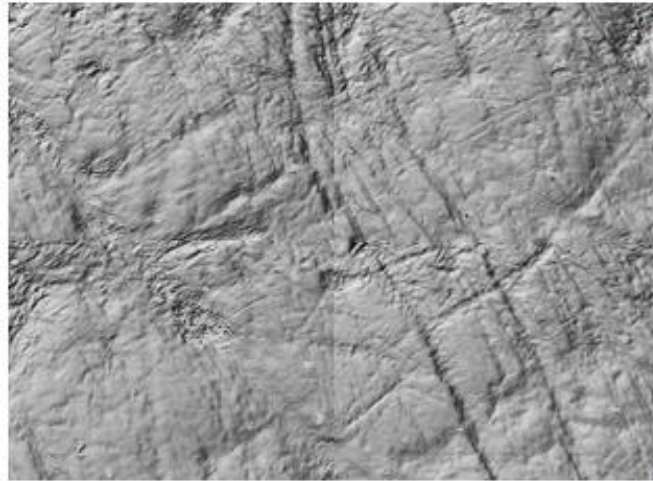


Figure 8.1 Surface Features from the Center Enamel of M¹ from Morro de Ouro, Burial 1, Adult of Indeterminate Sex; *Asfc*=1.25, *epLsar*=.0052; Area of Measurement Equals 204x276 microns

Figure 8.2 shows facet x of M¹ from a Pre-Ceramic burial from Forte Marechal Luz. The surface of this tooth displays high complexity, and less than average anisotropy.

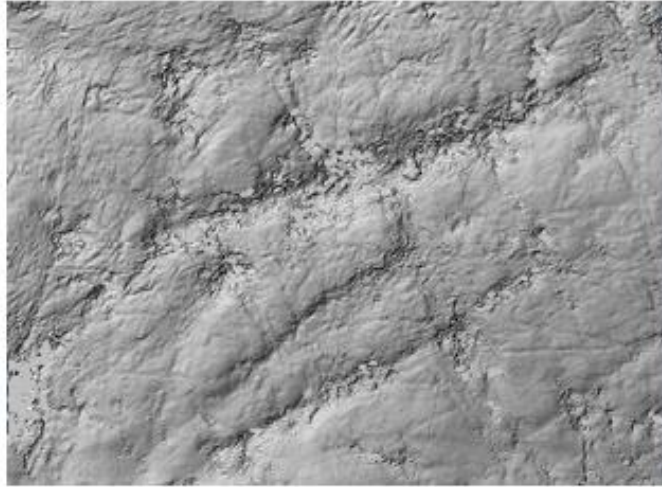


Figure 8.2 Surface Features from Facet x of M¹ from Forte Marechal Luz, Burial 6, Adolescent of Indeterminate Sex; *Asfc*=2.61, *epLsar*=.0024; 204x276 microns

Figure 8.3 shows facet 9 of M¹ from Itacoara, a Ceramic occupation site. Complexity of this individual is low, and anisotropy is high.

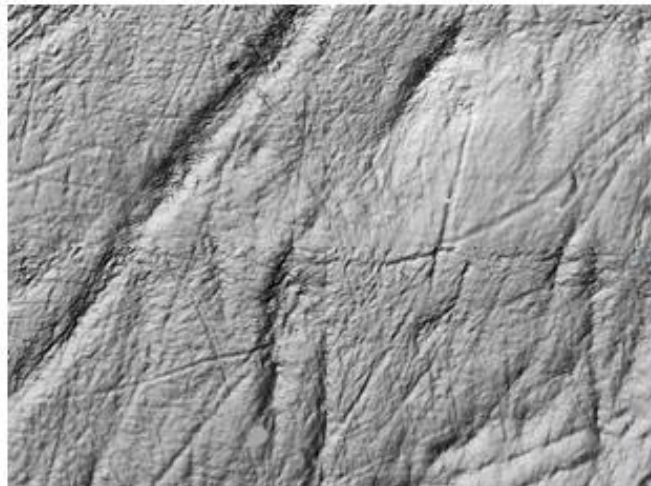


Figure 8.3 Surface Features from Facet 9 of M¹ from Itacoara, Burial 2, Young Adult Male; *Asfc*=.77, *epLsar*=.0059; 204x276 microns

When preservation permitted, images were retrieved from facet 9, a crushing surface of the maxillary molar. As mentioned earlier in this chapter, the choice to use facet 9 offers greatest comparability with other dental microwear studies. Other Phase II crushing/grinding enamel surfaces used in this study include facets 10n and x. I also used areas of the center enamel and band of enamel surrounding the molar in cases where preservation of tooth facets was compromised. Table 8.2 presents the mean and range of *Asfc* and *epLsar* measurements by site.

Table 8.2: Measurements of *Asfc* and *epLsar* According to Site and Period

Site	n	Occupation	<i>Asfc</i> Mean	<i>Asfc</i> High	<i>Asfc</i> Low	<i>epLsar</i> Mean	<i>epLsar</i> High	<i>epLsar</i> Low
Base Aérea	3	C	.75	1.16	.52	.0029	.0033	.0027
Cabeçuda	1	PC	--	.95	--	--	.0027	--
Enseada I	4	C	1.22	2.65	.49	.0032	.0053	.0021
Enseada I	1	PC	--	1.60	--	.0031	--	--
Forte Marechal Luz	2	PC	1.55	2.61	.50	.0030	.0036	.0024
Forte MarechalLuz	1	C	--	1.22	--	.0032	--	--
Itacoara	2	C	.67	.77	.57	.0042	.0059	.0024
Laranjeiras I	2	PC	.53	.66	.41	.0014	.0020	.0008
Laranjeiras II	4	C	1.07	1.52	.79	.0034	.0040	.0029
Morro de Ouro	13	PC	1.36	2.17	.79	.0043	.0061	.0023
Rio Comprido	4	PC	.95	1.12	.58	.0023	.0028	.0016
Tapera	2	C	.93	.96	.89	.0020	.0025	.0014
Zé Espinho	4	PC	.85	1.10	.63	.0024	.0041	.0013

Results: Measurements of Complexity (Asfc)

Area-scale fractal complexity, or *Asfc*, is a measurement of complexity, or roughness, of the tooth's surface. This measurement is achieved by examining a surface's roughness at different areas of scale, which change according to the depth interval at which the particular scan is examined. The changes of complexity of these relative areas, or *Asfc*, are calculated using Kfrax, a software program designed for the purposes of dental microwear texture analysis (Scott et al., 2005). After completing a study of *A. palliata* and *C. apella*, two primate species with known diets, Scott and colleagues (2005) discovered that *Asfc* could be used to characterize the degree of pitting and gouging of tooth enamel. Tooth enamel that displays a great deal of pitting and gouging will be associated with a relatively higher *Asfc* measurement, while a relatively lower *Asfc* measurement will correlate to a less complex surface. Through this analysis, the authors concluded that *Asfc* measurements reflect the consumption of hard and brittle foods, such that these food textures produce more complex tooth wear, and higher *Asfc* measurements. Figure 8.4 illustrates mean measures of *Asfc* for all facets and individuals according to archaeological site and time period.

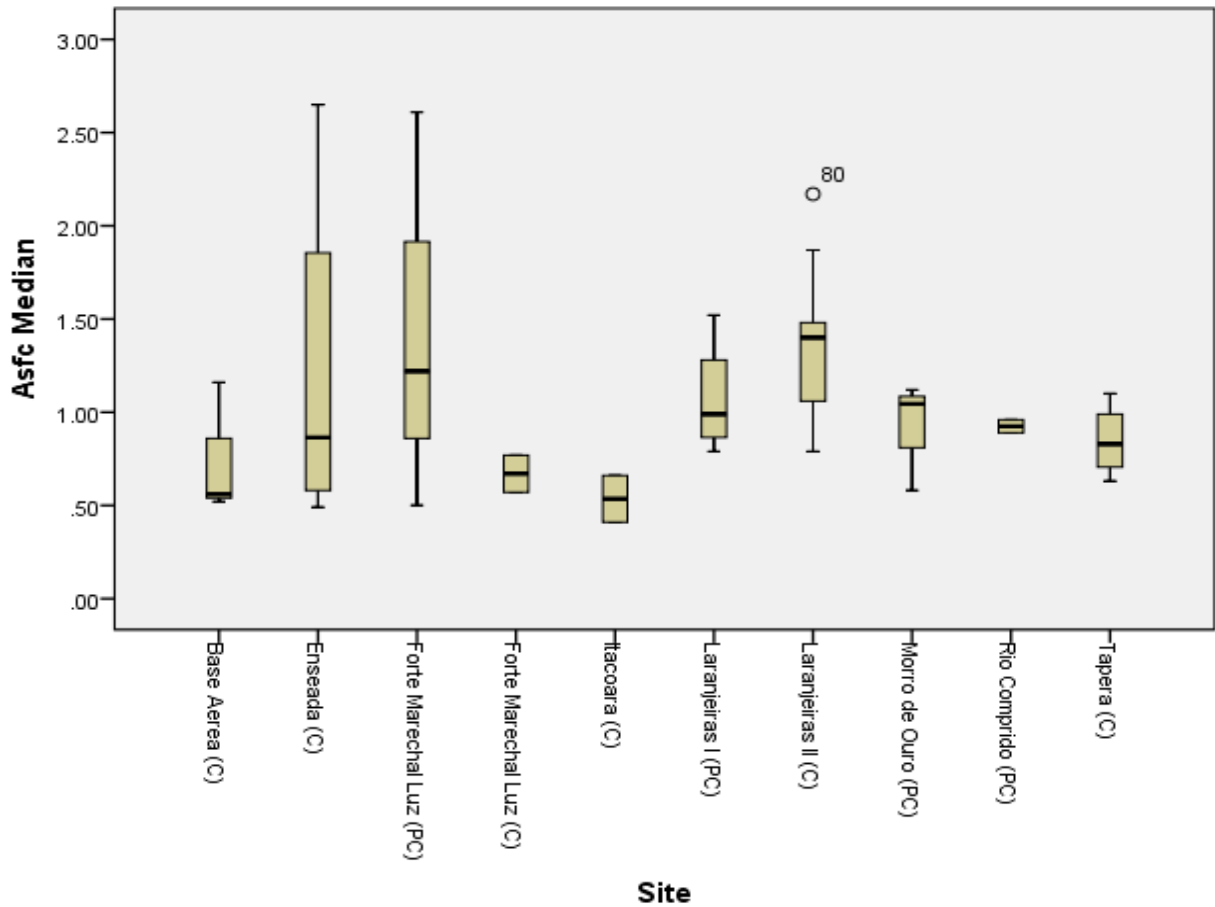


Figure 8.4 Mean Asfc by Archaeological Site (All Enamel Surfaces and Tooth Types)

I hypothesized that individuals from Pre-Ceramic sites would exhibit greater tooth enamel complexity than Ceramic occupation individuals, with the rationale that the latter population used pottery to process or cook food, thereby making it a softer and less forceful substance for tooth enamel to encounter.

Table 8.3 shows the Mann-Whitney U test results comparing Pre-Ceramic and Ceramic groups by sex and age. For this test, all enamel surfaces were used, and include facets x, 9, 10n, and the center enamel and enamel rim. This test also includes all tooth

types (M¹ or M²). When all individuals regardless of age, sex, or enamel surface are considered, the difference between the Pre-Ceramic and Ceramic groups is non-significant. The same result holds true when adolescents are excluded from the dataset, and only adults are considered in the analysis. When females from the Pre-Ceramic period are compared to females of the Ceramic period, the results are also not significantly different. However, when Pre-Ceramic occupation males are compared to Ceramic occupation males, a significant difference in the complexity of tooth enamel is observed. Likewise, when females and males from the Pre-Ceramic period are compared to females and males of the Ceramic period, the difference is significant. In both cases of statistical significance, the Pre-Ceramic measurement for complexity is higher than the Ceramic measurement of complexity.

Table 8.3 Mann-Whitney U Test of Complexity (*Asfc*) Comparing Pre-Ceramic and Ceramic Groups Using all Enamel Surfaces and Tooth Types

Group	Occupation	n	Mean <i>Asfc</i>	Mean Rank	U	p
All Individuals	Pre-Ceramic	27	1.17	24.09	159.5	.156
	Ceramic	16	.99	18.47		
Excluding Adolescents	Pre-Ceramic	25	1.12	23.02	124.5	.078
	Ceramic	15	.88	16.30		
Females	Pre-Ceramic	6	1.18	7.33	13.00	.485
	Ceramic	6	.98	5.67		
Males	Pre-Ceramic	7	1.46	9.14	6.00	.035
	Ceramic	6	.84	4.50		
Males and Females	Pre-Ceramic	13	1.33	16.19	36.5	.022
	Ceramic	12	.91	9.54		

For a tighter look at the dataset, I decided to examine the same groups as described above using only facets x and 9 to the exclusion of all other enamel surfaces. Facets x and 9 are crushing facets whose importance in dental microwear studies is examined in Chapter 6. For greater comparability between studies, and to ensure the greatest comparability within this dataset, I selected these facets for additional analysis. Table 8.4 shows the Mann-Whitney test results comparing Pre-Ceramic and Ceramic groups by age and sex using only facet x.

When all individuals with an *Asfc* measurement for facet x (regardless of age or sex) are considered, a significant difference between Pre-Ceramic and Ceramic complexity measurements is observed. Pre-Ceramic tooth enamel is significantly more complex than the tooth enamel for the Ceramic period. When adolescents are excluded from this test, and only adults of both sexes are considered, the results are also significant; the tooth enamel on facet 9 for the Pre-Ceramic period is more complex than that of the Ceramic period. The exact same result is seen when adult females and males from the Pre-Ceramic period are compared to those from the Ceramic period (the test population is the same as the one that excludes adolescents).

Table 8.5 displays the results of the Mann-Whitney test that uses facet 9 to compare measures of complexity between Pre-Ceramic and Ceramic occupation groups. The results show a significant difference between time periods when adolescents are excluded from the dataset, with greater enamel complexity among Pre-Ceramic adult males and females than Ceramic occupation adults.

Interestingly, while the data from Table 8.3 (using all enamel surfaces) show significant differences in enamel complexity related to the sex of the individual and time period, the data in Table 8.4 (using only facet x) and Table 8.5 (using only facet 9) show differences with regard to age and time period, and not sex of the individual and time period. This may be due to the fact that fifteen of the adults in the dataset are sex indeterminate.

Table 8.4 Mann-Whitney U Test of Complexity (*Asfc*) Using Facet x and All Tooth Types

Group	Occupation	n	Mean <i>Asfc</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	9	1.51	10.00	9.00	.036
	Ceramic	6	.91	5.00		
Excluding Adolescents	Pre-Ceramic	7	1.44	9.29	5.00	.022
	Ceramic	6	.91	4.33		
Females	Pre-Ceramic	3	1.37	5.67	1.00	.114
	Ceramic	4	.87	2.75		
Males	Pre-Ceramic	4	1.50	4.00	2.00	.533
	Ceramic	2	.99	2.50		
Males and Females	Pre-Ceramic	7	1.44	9.29	5.00	.022
	Ceramic	6	.91	4.33		

Table 8.5 Mann-Whitney U Test of Complexity (*Asfc*) Using Facet 9 and All Tooth Types

Group	Occupation	n	Mean <i>Asfc</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	7	1.12	7.57	10.00	.268
	Ceramic	5	1.08	5.00		
Excluding Adolescents	Pre-Ceramic	7	1.12	7.57	3.00	.042
	Ceramic	4	.69	3.25		
Males and Females	Pre-Ceramic	2	1.37	5.00	1.00	.267
	Ceramic	4	.69	2.75		

I also considered M^1 and M^2 separately in the analysis to determine if tooth type plays a role in patterns of significance observed between Pre-Ceramic and Ceramic occupation populations. For the following tests focusing on tooth type, all enamel surfaces (x, 9, 10n, center enamel, and enamel rim) are considered. When only the first maxillary molar is used for analysis, Mann-Whitney U test results show non-significance among all groups with regard to enamel complexity between time periods (see Table 8.6). However, test results are strikingly different when only M^2 is considered (see Table 8.7). When adolescents are excluded from the dataset, a significant difference in enamel complexity is observed between Pre-Ceramic and Ceramic groups, with Pre-Ceramic occupation individuals displaying greater complexity. Results are also significant when Pre-Ceramic occupation males are compared to Ceramic occupation males; males from the Pre-Ceramic occupation have greater tooth complexity than males from the Ceramic occupation. When males and females from each period are compared using M^2 , results are also significant, with measurements of complexity higher in Pre-Ceramic occupation individuals than Ceramic occupation individuals.

Though the number of M^1 teeth are fewer ($n=15$) than the number of M^2 teeth ($n=28$) in the dataset, it is unknown at this time why such a significant difference in test results is seen when each tooth is tested separately. It is possible that a biomechanical process is the cause of the observed differences.

Table 8.6 Mann-Whitney U Test of Complexity (*Asfc*) Using M¹ Only and All Surface Enamel Types

Group	Occupation	n	Mean <i>Asfc</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	10	1.19	8.10	24.00	.953
	Ceramic	5	1.28	7.80		
Excluding Adolescents	Pre-Ceramic	9	1.04	7.44	14.00	.604
	Ceramic	4	.94	6.00		
Females	Pre-Ceramic	3	1.21	3.50	2.00	.800
	Ceramic	2	1.08	2.67		
Males and Females	Pre-Ceramic	4	1.23	4.50	4.00	.629
	Ceramic	3	1.08	3.33		

Table 8.7 Mann-Whitney U Test of Complexity (*Asfc*) Using M² Only and All Surface Enamel Types

Group	Occupation	n	Mean <i>Asfc</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	17	1.16	16.91	52.5	.053
	Ceramic	11	.86	10.77		
Excluding Adolescents	Pre-Ceramic	16	1.17	16.59	46.5	.039
	Ceramic	11	.86	10.23		
Females	Pre-Ceramic	4	1.16	5.00	2.00	.229
	Ceramic	3	.88	2.67		
Males	Pre-Ceramic	5	1.55	8.40	3.00	.030
	Ceramic	6	.84	4.00		
Males and Females	Pre-Ceramic	9	1.38	12.72	11.5	.008
	Ceramic	9	.85	6.28		

When I examine the data using sex as the grouping variable for all periods, a Mann-Whitney U test shows no significant difference in measurements of *Asfc* (see Table 8.8). This data includes all surface enamel types (facets 9, x, 10n, center enamel and enamel rim), as well as tooth types (M¹ and M²). For the Pre-Ceramic period, no

significant difference in *Asfc* between males and females is observed. The same test for the Ceramic period also yields statistically non-significant results.

Table 8.8 Mann-Whitney U Test of Complexity (*Asfc*) Comparing Males and Females Using all Enamel Surfaces and Tooth Types

Occupation	Sex	n	Mean <i>Asfc</i>	Mean Rank	U	p
Pre-Ceramic and Ceramic	Male	13	1.18	13.38	73.00	.810
	Female	12	1.08	12.58		
Pre-Ceramic	Male	7	1.46	8.21	12.5	.234
	Female	6	1.18	5.58		
Ceramic	Male	6	.84	5.67	23.00	.485
	Female	6	.98	7.33		

In the section of this chapter discussing Table 8.3, I noted that when females from the Pre-Ceramic occupation are compared to females from the Ceramic occupation, no significant difference in tooth complexity is observed. However, when only males from each time period are considered, the differences in complexity are statistically significant. This result suggests a significant change in the diet and/or food processing techniques of hard objects among males in the Pre-Ceramic and Ceramic periods at coastal *sambaqui* sites.

Results: Measurements of Directionality (Exact Proportion Length-Scale Anisotropy of Relief, or epLsar)

epLsar (or anisotropy) is a measurement of the degree of directionality of enamel roughness, or complexity (Scott et al., 2005). Anisotropy describes the direction of complex features of a surface, and is calculated by measuring the relative lengths of

directionality at different orientations, or vectors. Vectors are calculated at each scale using 5 degree intervals and are normalized; greater wear features are associated with longer than normal relative length vectors for a given direction (Scott et al., 2005). This measurement of directionality can be compared to the analysis of ‘scratches’ in microwear analyses that use scanning electron microscopy, in that tough foods will be associated with more anisotropic enamel surfaces. As in *Asfc*, the higher the measurement of *epLsar*, the greater degree of directionality is observed. I hypothesized that a greater degree of anisotropy, or ‘scratching’, would be seen in the tooth enamel of individuals from the Pre-Ceramic period, with the rationale that food processed with pottery would be less abrasive for tooth enamel. Figure 8.5 shows mean measures of anisotropy using all enamel surfaces and tooth types by archaeological site and time period.

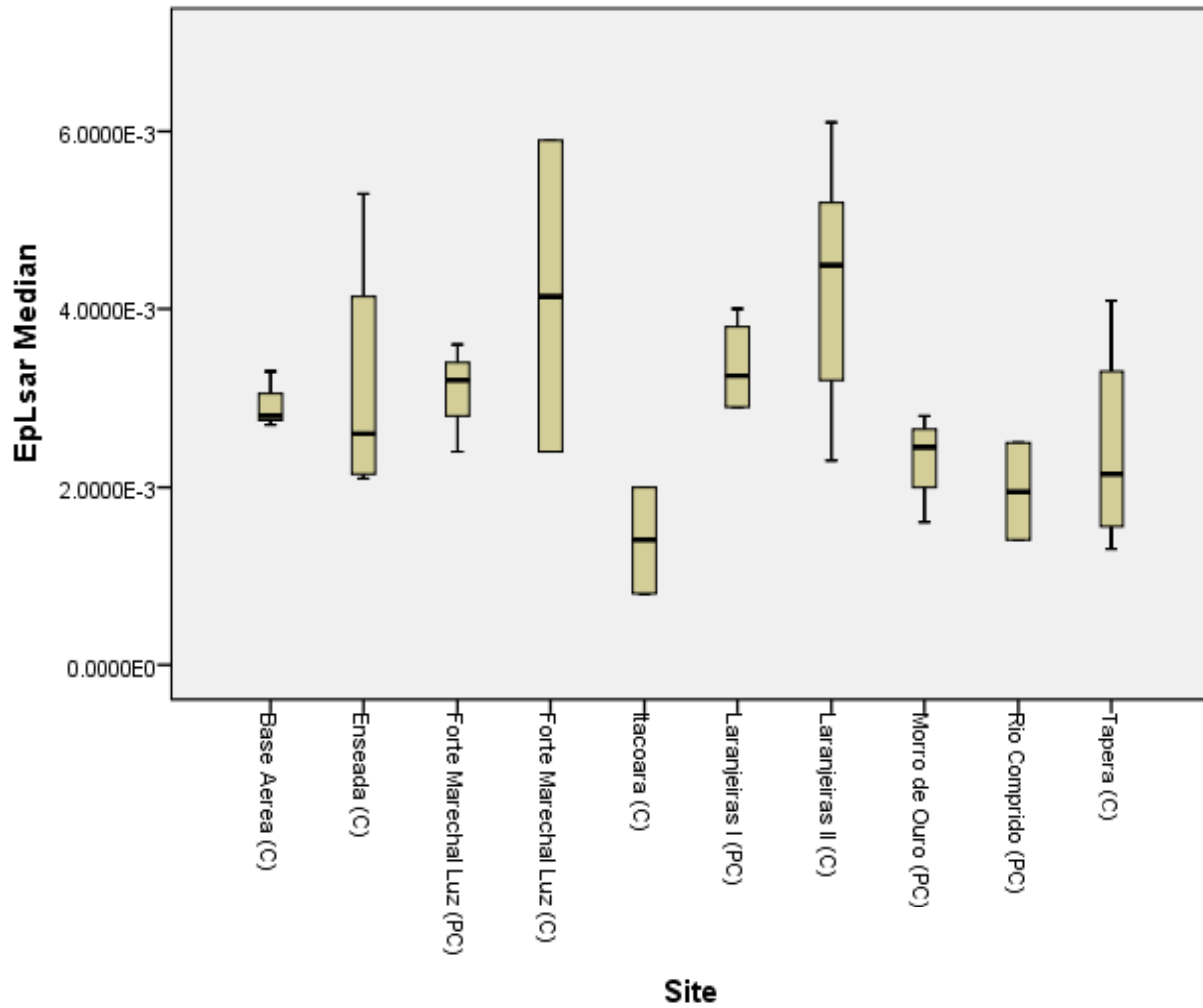


Figure 8.5 Mean epLsar by Archaeological Site (All Enamel Surfaces and Tooth Types)

A Mann-Whitney U non-parametric test of independent samples shows no significant difference between measurements of *epLsar* (anisotropy) between Pre-Ceramic and Ceramic occupations at *sambaqui* sites (see Table 8.9). Differences remain non-significant after excluding young adults and adolescents from the data set. When

only adults and young adults are considered in the test, no significant results are found.

The same result holds true when only sexed females and males are compared.

Table 8.9 Mann-Whitney U Test of Anisotropy (*epLsar*) Using All Enamel Surfaces and Tooth Types

Group	Occupation	n	Mean <i>epLsar</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	27	.0033	22.24	209.5	.870
	Ceramic	16	.0031	21.59		
Excluding Adolescents	Pre-Ceramic	25	.0034	21.46	163.5	.502
	Ceramic	15	.0030	18.90		
Females	Pre-Ceramic	6	.0033	8.00	9.00	.180
	Ceramic	6	.0026	5.00		
Males	Pre-Ceramic	7	.0041	7.29	19.00	.836
	Ceramic	6	.0037	6.67		
Males and Females	Pre-Ceramic	13	.0037	14.77	55.00	.225
	Ceramic	12	.0031	11.08		

As in the previous section of this chapter discussing complexity (*Asfc*), I also examined facets x and 9 for any significant differences in anisotropy between Pre-Ceramic and Ceramic occupations. For facet x, using all tooth types, there is no significant change in anisotropy across time (see Table 8.10). If I remove adolescents from the dataset, and focus on adults, no significant difference is observed; the result is the same when I conduct the test using only adult males and females (sexed individuals). Facet 9 also shows a non-significant difference in measurements of anisotropy between Pre-Ceramic and Ceramic occupations (see Table 8.11). Excluding adolescents from the test also yields no significant results, nor does examining only adult males and females.

Table 8.10 Mann-Whitney U test of anisotropy (*epLsar*) using facet x and all tooth types

Table 8.10 Mann-Whitney U Test of Anisotropy (*epLsar*) Using Facet x and All Tooth Types

Group	Occupation	n	Mean <i>epLsar</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	9	.0035	8.61	21.5	.529
	Ceramic	6	.0029	7.08		
Excluding Adolescents	Pre-Ceramic	7	.0038	8.14	13.00	.295
	Ceramic	6	.0029	5.67		
Females	Pre-Ceramic	3	.0037	5.50	1.50	.114
	Ceramic	4	.0026	2.88		
Males	Pre-Ceramic	4	.0039	3.50	4.00	1.00
	Ceramic	2	.0035	3.50		
Males and Females	Pre-Ceramic	7	.0038	8.14	13.00	.295
	Ceramic	6	.0029	5.67		

Table 8.11 Mann-Whitney U Test of Anisotropy (*epLsar*) Using Facet 9 and All Tooth Types

Group	Occupation	n	Mean <i>epLsar</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	7	.0035	6.00	21.00	.639
	Ceramic	5	.0039	7.20		
Excluding Adolescents	Pre-Ceramic	7	.0035	5.86	15.00	1.00
	Ceramic	4	.0036	6.25		
Males and Females	Pre-Ceramic	2	.0045	4.50	2.00	.533
	Ceramic	4	.0036	3.00		

I also analyzed measurements of anisotropy between Pre-Ceramic and Ceramic occupation groups by tooth type, using all enamel surfaces (facets 9, x, 10n, center enamel, and enamel rim). M^1 shows no statistically significant difference in anisotropy between occupations; M^2 is also not significant for any difference in anisotropy between the Pre-Ceramic and Ceramic periods. Excluding adolescents from the dataset for M^1

and M^2 (examining only adults) provides a non-significant result. If I perform the same tests using adult males and females only, differences in time period using M^1 and M^2 remain non-significant. Tables 8.12 and 8.13 summarize the test results.

Table 8.12 Mann-Whitney U Test of Anisotropy (*epLsar*) Using M^1 and All Enamel Surfaces

Group	Occupation	n	Mean <i>epLsar</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	10	.0031	8.15	23.5	.859
	Ceramic	5	.0031	7.70		
Excluding Adolescents	Pre-Ceramic	9	.0032	7.67	12.00	.414
	Ceramic	4	.0026	5.50		
Females	Pre-Ceramic	2	.0019	2.75	3.50	1.00
	Ceramic	3	.0027	3.17		
Males and Females	Pre-Ceramic	4	.0032	4.62	3.50	.400
	Ceramic	3	.0027	3.17		

Table 8.13 Mann-Whitney U Test of Anisotropy (*epLsar*) of M^2 and All Enamel Surfaces

Group	Occupation	n	Mean <i>epLsar</i>	Mean Rank	U	p
All individuals	Pre-Ceramic	17	.0034	14.82	88.00	.817
	Ceramic	11	.0031	14.00		
Excluding Adolescents	Pre-Ceramic	16	.0035	14.53	79.5	.680
	Ceramic	11	.0031	13.23		
Females	Pre-Ceramic	4	.0041	5.12	1.50	.114
	Ceramic	3	.0025	2.50		
Males	Pre-Ceramic	5	.0038	6.00	15.00	1.00
	Ceramic	6	.0037	6.00		
Male and Females	Pre-Ceramic	9	.0040	11.00	27.00	.258
	Ceramic	9	.0033	8.00		

When I examined the data using sex as the grouping variable and combine data for all periods, a Mann-Whitney U test shows no significant difference in measurements of anisotropy. For the Pre-Ceramic period, no significant difference in *epLsar* between males and females is observed. The same test for the Ceramic period also yields statistically non-significant results. When only adult males are considered, the differences in anisotropy between the two time periods are not statistically significant. When adult females are considered, the results also show no significant difference between the Pre-Ceramic and Ceramic occupations (see Table 8.14).

Table 8.14 Mann-Whitney U Test of Anisotropy (*epLsar*) Comparing Males and Females

Occupation	Sex	N	Mean <i>epLsar</i>	Mean Rank	U	p
Pre-Ceramic and Ceramic	Male	13	.0039	15.12	50.5	.137
	Female	12	.0030	10.71		
Pre-Ceramic	Male	7	.0041	7.57	17.00	.628
	Female	6	.0027	6.33		
Ceramic	Male	6	.0037	8.42	6.5	.065
	Female	6	.0026	4.58		

Interestingly, though statistically significant results were observed between Pre-Ceramic and Ceramic occupation groups with regard to measurements of complexity, none were statistically significant for measurements of anisotropy. This result suggests that diet and/or food processing techniques did not significantly change the toughness of food between the two time periods.

Dental Microwear Texture Analysis and Stable Isotope Analysis

Both of the paleodietary methods used in the present study are useful for determining changes in diet and cooking methods through time. When examined together, dental microwear texture analysis and stable carbon and nitrogen isotope analysis allow one to approach the data in a more complete manner. In the following figures, I plot the dental microwear data and stable isotope data against one another to see if any significant patterns can be observed. I was able to collect both sets of data for fourteen individuals from both time periods combined. For each plot, I compared the median Asfc and epLsar against carbon isotope ratios of apatite and collagen, as well as stable nitrogen isotope ratios.

When I compare Asfc and epLsar median measurements with carbon isotope ratios of collagen, no discernible pattern between the two types of data emerges. The same result occurs when I compare the dental microwear data with carbon isotope ratios of apatite.

When nitrogen isotope ratios are compared with median values of Asfc, no relationship is observed; however, a plot including nitrogen isotope ratios and median epLsar measurements does show lower epLsar values for many Ceramic occupation individuals who show higher $\delta^{15}\text{N}$, suggesting a relationship between the two measures (see figure 8.6).

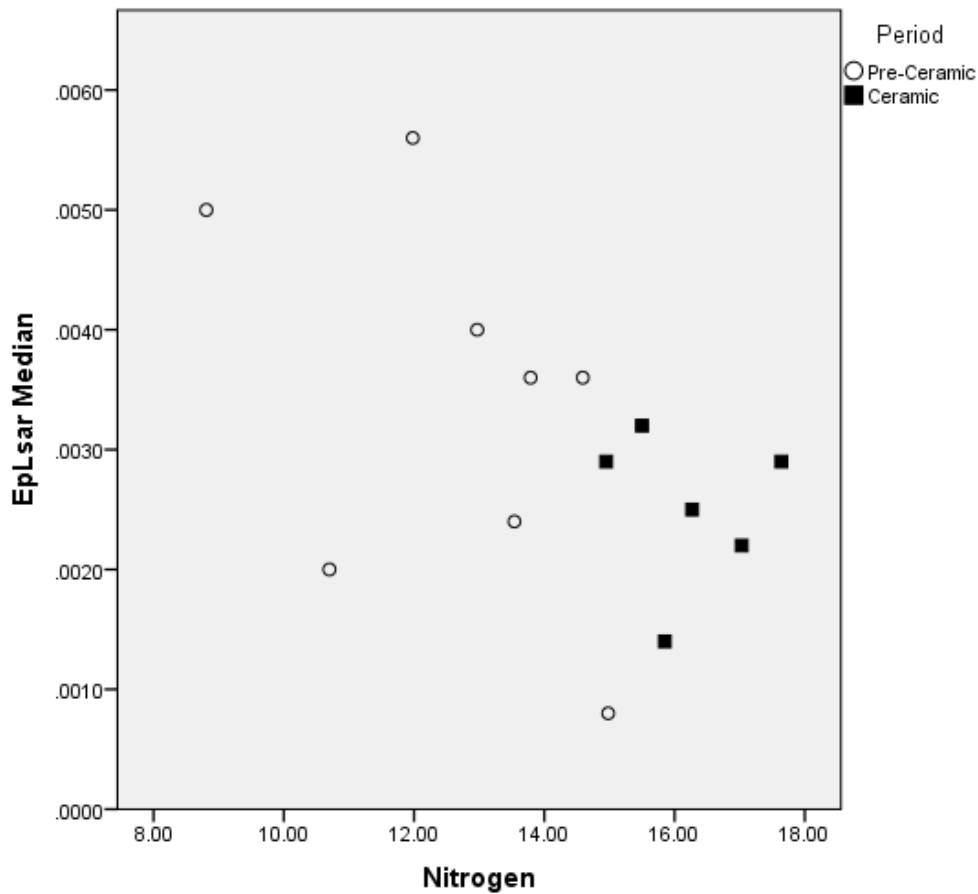


Figure 8.6: Plot of *epLsar* Median Measurements and Nitrogen Isotope Values for Pre-Ceramic and Ceramic Time Periods

Though the results comparing data from both methodologies is largely inconclusive, the plot comparing *epLsar* median values and nitrogen isotope values shows a promising trend for future investigations. Plotting both datasets together, one can see that individuals from the Pre-Ceramic period display higher *epLsar* values, in general, than individuals from the Ceramic period. This is interesting, given that the *epLsar* measurements are compared with nitrogen isotopes, a proxy for the consumption of marine resources for the study area. According to the plot, it appears that individuals

of the Pre-Ceramic period have higher anisotropy measurements (or greater ‘scratching’) along with lower consumption of marine foods, while Ceramic period individuals show less anisotropy, or scratching, along with higher consumption of marine foods. This plot mirrors the isotope data results for *sambaqui* populations, and elucidates a pattern in the anisotropy data that is not observed through statistical analysis.

Discussion

Two measurements of texture analysis described here include ‘complexity’ (or *Asfc*, area-scale fractal complexity) and ‘anisotropy’ (or *epLsar*, exact proportion length-scale anisotropy of relief). The first refers to the roughness of the tooth’s surface, and the latter to the directionality of the microwear features. Tooth surfaces with complex texture are associated with diets that include hard and brittle foods, while anisotropic tooth surfaces are associated with diets that contain tough foods. I hypothesized that the texture of the teeth from Pre-Ceramic populations would be more complex and display greater anisotropy than Ceramic occupation groups, with the rationale that cooking or processing food with pottery would make the diet softer and less abrasive. If confirmed, this would lend credence to a *subsistence model* for the adoption of ceramic technology. However, if no difference in texture were found between Pre-Ceramic and Ceramic *sambaqui* populations, then this would lend support to the *prestige model* for the adoption of ceramic technology. In the *prestige model*, pottery is not used for subsistence purposes among the greater population, but as a status item and marker of wealth by an elite few.

The results from statistical analysis of the data shows a significant difference in complex tooth surfaces between the Pre-Ceramic and Ceramic occupations, but no significant difference in anisotropy between time periods. Examination of tooth complexity (*Asfc*) consistently shows that certain Pre-Ceramic measurements of complexity are greater than Ceramic measurements. This phenomenon did not occur in the reverse; that is, none of the Ceramic occupation groups and sub-groups show greater complexity than do Pre-Ceramic groups and sub-groups. In this study, Pre-Ceramic occupation males had greater complexity than Ceramic occupation males, and this male difference is responsible for a parallel difference between the occupations when the sexes are combined. Significant differences are also seen in facet x, where Pre-Ceramic measurements of complexity are greater than in many Ceramic occupation groups and sub-groups. Facet 9 Pre-Ceramic measurements of complexity are also higher when excluding adolescents from the dataset. Finally, complex tooth enamel texture of M^2 for the Pre-Ceramic skeletons is also largely greater than Ceramic occupation groups and sub-groups.

Interestingly, measurements of anisotropy (*epLsar*) showed no statistical difference for any of these categories according to time period.

The results of this study suggest a change in diet and/or food processing techniques between the Pre-Ceramic and Ceramic occupations at *sambaqui* sites, and lend support to the *subsistence model* for the adoption of ceramic technology among *sambaqui* hunters and gatherers. Interestingly, males show a significant change in enamel complexity associated with the consumption of hard foods through time. The

same is not true for females. However, while the hardness of food appears to have changed for males between time periods, the toughness of food seems to have remained the same through time for all groups and sub-groups. In other words, “pitting” of tooth enamel changed between the Pre-Ceramic and Ceramic periods, but “scratching” stayed the same.

CHAPTER IX

DISCUSSION AND SUMMARY

The object of this study is to test the *subsistence model* for the adoption of ceramic technology among fisher-hunter-gatherer groups along the southeastern coast of Brazil. For the *subsistence model*, I propose a model whereby a change in diet and/or food processing techniques occurred after the introduction of pottery among *sambaqui* populations. An alternative to this model is the *prestige model*, whereby coastal groups initially used pottery as status-bearing items in competitive feasting or as serving vessels for elite members of the group. To test the *subsistence model*, I conducted an analysis of stable carbon and nitrogen isotopes and an examination of dental microwear of human skeletal remains from Pre-Ceramic and Ceramic *sambaqui* sites located in the modern states of Santa Catarina and Rio de Janeiro.

If significant changes in isotope ratios and dental microwear are observed after the introduction of pottery, then the *subsistence model* is supported. If significant changes in dental microwear are observed *without* changes in stable carbon and nitrogen isotopes, then the *subsistence model* is also supported, as pottery may be correlated to changes in food processing techniques. If *no* significant changes in carbon and nitrogen isotopes or dental microwear are observed between the Pre-Ceramic and Ceramic occupations, then the *prestige model* for the adoption of ceramic technology should receive more consideration.

In this section, I will discuss the results of the stable carbon and nitrogen isotope analysis and examination of dental microwear that I presented here, and relate these results with the most current research in the field. I will also discuss how this work contributes to the field of anthropology, and to the ongoing research in *sambaqui* archaeology in Brazil.

Summary of Isotope Analysis and Dental Microwear Analysis Results

I find no statistically significant difference in stable carbon isotope ratios of collagen and apatite when all individuals from the Pre-Ceramic and Ceramic occupations are compared. Pre-Ceramic occupation males have significantly enriched carbon isotope ratios of collagen and apatite compared to Pre-Ceramic occupation females. No such sex difference in carbon isotope ratios is observed for the Ceramic period.

Nitrogen isotope ratios are significantly higher among members of the Ceramic period than those from the Pre-Ceramic period when all individuals are considered. The same result holds true when those who died in adolescence are excluded from the dataset. Though not statistically significant ($p=.083$), some Pre-Ceramic occupation males display higher nitrogen isotope ratios than females from the Pre-Ceramic period.

I find no statistically significant difference in $\Delta^{13}C_{CA-CO}$ between Pre-Ceramic and Ceramic occupations, nor between males and females for each time period.

I find no statistically significant difference in measurements of tooth enamel facet complexity (*Asfc*) when all individuals from the Pre-Ceramic and Ceramic occupations are compared using all enamel surfaces and tooth types. However, Pre-

Ceramic occupation males show significantly greater tooth enamel complexity (*Asfc*) than Ceramic occupation males for all enamel surfaces and tooth types.

Pre-Ceramic occupation measurements of complexity (*Asfc*) are significantly higher than Ceramic occupation measurements when all individuals are considered using facet x from all tooth types. The same result is achieved by excluding adolescents from the dataset, and by comparing Pre-Ceramic occupation males and females to Ceramic occupation males and females. Pre-Ceramic occupation measurements of complexity (*Asfc*) using facet 9 from all tooth types are significantly higher than Ceramic occupation measurements when adolescents are excluded from the dataset.

Pre-Ceramic measurements of complexity (*Asfc*) of M² are significantly higher than Ceramic occupation measurements when adolescents are excluded from the dataset. Pre-Ceramic occupation males have significantly more complex M² tooth enamel than Ceramic occupation males, and the same pattern holds true for the combined measurements of males and females of the Pre-Ceramic period compared to the Ceramic period. When all individuals are considered, the results are nearly significant (p=.053) for greater complexity of M² tooth enamel among Pre-Ceramic populations. I find no statistically significant difference among Pre-Ceramic and Ceramic occupations in measurements of complexity (*Asfc*) when M¹ is considered alone, using all facets.

I find no statistically significant difference in complexity (*Asfc*) between the sexes of the Pre-Ceramic and Ceramic periods when all enamel surfaces and tooth types are compared.

I find no statistically significant difference in measurements of anisotropy (*epLsar*) between the Pre-Ceramic and Ceramic occupations when using all enamel surfaces and tooth types. I also find no difference between the occupations when facet x, facet 9, M¹, and M² are examined separately.

I find no statistically significant differences between the sexes of the Pre-Ceramic and Ceramic occupations for measurements of anisotropy (*epLsar*) using all enamel surfaces and tooth types.

When plotted together, dental microwear texture analysis results and stable carbon and nitrogen isotope results show little paleodietary patterning. However, *epLsar* median measurements, when plotted against nitrogen isotope ratios, do show some difference between individuals of both time periods. Ceramic occupation individuals generally plot lower for measurements of anisotropy and higher for marine food consumption, while Pre-Ceramic occupation individuals plot higher for anisotropy and lower for marine food consumption.

Stable Carbon and Nitrogen Isotope Analysis: Discussion

The results of the stable carbon and nitrogen isotope analysis show some support the *subsistence model* for the adoption of ceramic technology among *sambaqui* coastal foragers. Though no significant difference in carbon isotope ratios of collagen and apatite were found between the Pre-Ceramic and Ceramic occupations when all individuals were tested, an unexpected result involving sex differences in diet for the Pre-Ceramic period emerged. The data shows that males of the Pre-Ceramic period

consumed greater quantities of marine foods than females of the same time period; the trend towards statistical significance in nitrogen isotope ratios supports this.

However, I find no significant difference in $\delta^{13}\text{C}_{\text{COL}}$ or $\delta^{13}\text{C}_{\text{AP}}$ between males and females of the Ceramic period. These results suggest a sex-based dietary difference for the Pre-Ceramic period, followed by a more parallel dietary pattern between the sexes during the Ceramic period. In the case of the coastal foragers of Southeastern Brazil, the appearance of pottery may not be a marker for greater social stratification and hierarchical structure, at least when the dietary data are considered. Of course, dietary discrepancies between the sexes of the Pre-Ceramic period may not necessarily reflect hierarchical social status differences; mechanical and practical issues related to fishing and/or storing marine foodstuffs may have led to immediate differential access to these foods. At this point in time, it is not possible to know how the arrival of pottery at *sambaqui* sites coincides with the leveling of access to marine foods among males and females of the Ceramic occupation.

Along with the trend toward greater consumption of marine foods among males of the Pre-Ceramic period compared to females, nitrogen isotope ratios also show that, when all individuals are tested, Ceramic occupation populations consumed significantly greater quantities of marine foods than those of the Pre-Ceramic occupation. This is interesting because it demonstrates that ceramic technology does not correlate with an intensification of plant foods, as one might expect, but rather appears to correspond with an intensification of marine foods. This intersection of pottery and marine resources is seen in the residual analyses of food remains on Itataré pottery, largely caused by the

cooking of fish, although evidence for plant remains was also found (Hansel 2004).

Pottery is also found in the context of fish bones and cracked pebbles at Forte Marechal Luz (Bryan 1993), and food encrustations and soot-covered pottery fragments reinforce the hypothesis that *sambaqui* inhabitants used ceramic technology for cooking (Schmitz et al. 1993; Silva et al. 1990). While coastal groups may have used pottery to process plant foods, isotopic results and archaeological data indicate a heavier reliance on marine resources.

Though Weselowski et al. (2010) discovered evidence for the consumption of yam, Paraná pine, sweet potato, and maize in the dental calculus of individuals from Prehistoric *sambaqui* sites, evidence that populations relied on these food extensively is not observed in the isotopic record. However, the presence of maize in this Prehistoric context demonstrates that this cultigen was part of the diet during this time. I also found two Pre-Ceramic individuals from Morro de Ouro, and two Ceramic occupation individuals from Enseada I that show heavier consumption of C₃ foods than others from their respective time periods. Weselowski and colleagues (2010) found starch grains of yam, and possibly sweet potato, from Morro de Ouro, and sweet potato, altered maize, and possibly Paraná pine at Enseada I. According to stable carbon and nitrogen isotope analysis, a few individuals at *sambaqui* sites, such as Laranjeiras I (Pre-Ceramic) and Laranjeiras II (Ceramic) and Tapera (Ceramic), also show a greater reliance on C₃ foods than at most *sambaqui* sites. When looking at site-wide averages of carbon and nitrogen isotope values for the *sambaqui* sites tested here, Pre-Ceramic site Morro de Ouro shows the least amount of reliance on marine foods than any of the other sites ($\delta^{15}\text{N}$ of 12.06,

$\delta^{13}\text{C}_{\text{COL}}$ of -15.24); the next two lowest nitrogen isotope values come from the Pre-Ceramic sites of Zé Espinho and Rio Comprido at $\delta^{15}\text{N}$ 13.89 and 13.95, respectively. In addition, higher than average dental caries rates at Morro do Ouro and Rio Comprido demonstrate consumption of starchy foods (Neves and Weselowski 2002). Few carious lesions were found at Forte Marechal Luz (for either time period), Itacoara (Ceramic period), and Enseada I (Ceramic period) (Neves and Weselowski 2002), and all of these show a high reliance on marine foods according to the isotopic analysis. In addition, dental pathologies at Cabeçuda are almost nonexistent (Rodrigues 1997), and the isotopic analysis shows heavy consumption of marine foods. Again, the results of the stable isotope analysis show that the appearance of pottery does not coincide with an intensification of C_3 or C_4 plant resources. Paleodietary studies such as these broaden our understanding of coastal forager diet, and offer solid evidence that these groups, though most reliant on marine foods, also exploited, and likely cultivated, plant foods.

Dental Microwear Analysis: Discussion

The results of the dental microwear texture analysis also show some support the *subsistence model* for the adoption of ceramic technology among *sambaqui* coastal foragers. When all individuals are considered, there is no statistical evidence to support a difference in the complexity and anisotropy (pitting and scratching) of tooth enamel between the Pre-Ceramic and Ceramic occupations. This finding parallels the results of stable carbon isotope ratios when all individuals in the dataset are compared. This dental microwear finding therefore suggests that the adoption of pottery is not associated with a dramatic change in cooking and/or food processing techniques. However, just as with

the isotopic data, the results change when one compares individuals according to sex and time period. Males of the Pre-Ceramic period show higher complexity of tooth enamel (pitting) than males of the Ceramic period, but no difference in measurements of anisotropy (scratching) is observed. This finding indicates that males of the Pre-Ceramic period engaged in an activity, or several activities, that produced a significantly greater amount of pitting on their tooth enamel than anyone else in the population, through time. When females are considered in the test, no difference in complexity or anisotropy is found; therefore, the activity associated with high tooth enamel complexity is limited to males of the Pre-Ceramic occupation.

What activity caused this pitting, and what dietary practice or behavior changed for males between the Pre-Ceramic and Ceramic periods? If the pitting among Pre-Ceramic period males is associated with a diet high in marine foods, then one would expect even greater pitting among males of the Ceramic period, when the consumption of marine foods was even greater. Unfortunately, there is no clear evidence that a particular hard and crunchy plant food (such as nuts) was exploited by males of the earlier period, but that remains a possibility. If this were the case, however, might not females have access to the same plant foods? Another explanation for high tooth enamel complexity in this sub-group may be activity related; Pre-Ceramic occupation males may have engaged in activities that no other sub-group through time participated in, or were exposed to more extraneous grit in the diet than other sub-groups. For example, the manner in which food was prepared away from home may have contributed to the differences in tooth enamel surfaces of this sub-group, as mollusks contain grit that, if

not carefully cleaned, may have caused pitting of the tooth enamel. Or perhaps these dental enamel features are related to fishing or hunting techniques, or tool manufacture, that males of the Ceramic period either did not perform, or performed differently.

Interestingly, measurements of complexity for facet x, which are significantly higher for the Pre-Ceramic period when all individuals, adults, and males and females are considered, do not show differences based on sex. Facet x is an anterior extension of facet 9 (see Figure 6.1 for an illustration), and forms part of the grinding action of Phase II mastication. For these populations, facet 9 shows higher complexity measurements for only one sub-group, Pre-Ceramic occupation adults (excluding adolescents).

Measurements of complexity taken from M^1 show no statistically significant difference for any sub-group of the Pre-Ceramic and Ceramic periods, but M^2 shows significantly higher complexity when adults, males, and males and females are considered. Complex tooth enamel among Pre-Ceramic occupation males compared to Ceramic occupation males drives most of the significance that is observed here. Therefore, the mechanical action that causes tooth enamel complexity to be so high in this sub-group is also relegated to one tooth type, M^2 .

I did not find any significant differences for any sub-groups, tooth type, or facet type in either time period for measurements of anisotropy in this study. This result indicates that all individuals were exposed to, or experienced, the same degree of dietary toughness through time. El-Zaatari (2010), in her dental microwear texture analysis of pre-agricultural groups of known dietary histories, discovered that diets relying on high meat intake had the highest measurements of anisotropy, due to the toughness of the

meat. Marine foods, on the other hand, did not score the teeth in the same way. Overall, however, El-Zaatari (2010) found that measurements of complexity (*Asfc*) proved to be the most accurate indicator of diet for the populations she studied.

When plotted together in a graph for this study, stable carbon and nitrogen isotope ratios and dental microwear texture analysis showed little relationship to one another. However, a relationship between nitrogen isotope ratios and epLsar (anisotropy) did emerge, whereby Ceramic occupation individuals with high $\delta^{15}\text{N}$ also had lower epLsar measurements than Pre-Ceramic occupation individuals, who had lower $\delta^{15}\text{N}$ and generally higher measurements of epLsar. This relationship shows less scratching of the tooth enamel surface among Ceramic occupation individuals, concomitant the consumption of marine foods, and therefore provides additional support for the *subsistence model* for the adoption of pottery among *sambaqui* populations. Statistical analysis of each data set did not reveal this pattern; rather, it was only when both datasets were joined that the relationship was elucidated. This result shows promise for future studies involving both methods.

The paleodietary methodologies that I employed in this study each contributed to the assessments of Pre-Ceramic and Ceramic *sambaqui* populations. For this analysis, the carbon and nitrogen isotope data yielded clearer results for what people were eating than the microwear data did for how food was processed, or cooked. While the dental microwear texture analysis showed differences between sub-groups, some questions regarding tooth wear and dietary practices still persist. Though Pre-Ceramic occupation

males showed greater pitting on molar surfaces than Ceramic occupation males, questions regarding the cause of this difference remain open for debate.

Social Implications for the Adoption of Pottery

Though the data I present in this work largely supports the *subsistence model* for the adoption of ceramic technology among coastal foragers, the social aspects related to the acquisition of a new technology cannot be ignored. In other words, questions of subsistence often correspond to questions of social relationships, both within the community and outside the community. Coastal *sambaqui* populations shared the greater landscape with nearby horticultural groups, and it appears that there may have been an exchange relationship with these outside groups (Bastos et al. 2011; Hubbe et al. 2009; Neves and Cocilovo 1989). Bastos et al. (2011) have shown that some individuals (one from the Pre-Ceramic and two from the Ceramic) at one *sambaqui* site (Forte Marechal Luz) were of non-local origin, but the numbers of these individuals are relatively low. Neves and Cocilovo (1989) demonstrate gene flow from an outside group at the same time as the arrival of pottery, and Hubbe et al. (2009) support the idea that the adoption of ceramic technology among the coastal foragers was accompanied by a cultural subjugation, as well as a possible physical encroachment by outsiders, whereby matrilineal post-marital residence practices were replaced by patrilineal ones.

While my data might not speak directly to questions of migration or diffusion, it would not be inconsistent with a shift in social organization with the adoption of pottery. The stable carbon and nitrogen isotope data, as well as the dental microwear data, demonstrate a noticeable shift in the diet and/or food processing techniques of males at

the *sambaqui* sites studied here. During the Pre-Ceramic period, males had significantly enriched carbon isotope ratios of collagen and apatite compared to females; during the Ceramic period, however, no difference in carbon enrichment between the sexes is observed. Nitrogen isotope ratios support this observation, though the results only approached significance. However, nitrogen isotope ratios among all individuals increased during the Ceramic period, so this likely dampened the sex difference results that one observed for the Pre-Ceramic period. Likewise, males of the Pre-Ceramic period showed significantly higher complex tooth enamel than males of the Ceramic period.

The adoption of ceramic technology, therefore, appears to coincide with a more egalitarian access to foodstuffs, particularly marine foods, than had existed during the Pre-Ceramic period. At least according to dietary regime, people began to look more alike than they did different. However, questions remain. If one entertains the idea that post-marital residence patterns did shift after the adoption of pottery, as Hubbe et al. (2009) hypothesize, my dietary data suggests that males, and not females, shifted residence patterns. Whatever the case, my data could be interpreted to show some support for a possible reorganization of social practices with the adoption of ceramic technology.

After discussing the physical characteristics of pottery recovered from *sambaqui* sites, and comparing these to the physical properties associated with prestige ware (Pratt 1999; Rice 1999), I concur that Itataré pottery appears to be utilitarian ware used for the purposes of cooking. However, it is possible that utilitarian ware retains special status as

a technological innovation among people who do not produce pottery. It is unclear from the present study if Itataré pottery held such special significance, or whether it was an everyday technology that was brought in by a neighboring horticultural group. If anything, this pottery does not appear to be associated with an intensification of plant foods, but rather an increase in the consumption of marine foods. If horticultural individuals did arrive on the coast with their pottery, they appear not to have used it primarily to cook plant foods.

Models of competitive feasting may explain why the arrival of pottery is not associated with an intensification of plant foods. As Hoopes (1995) and Hayden (1990) observe, populations living in areas of abundance, particularly with access to marine foods, are less motivated to develop horticultural methods of subsistence. However, coastal groups may form exchange relationships with outside horticultural populations to supplement their protein heavy diet with plant foods. Items of trade from the coast may come in the form of seafood (perhaps dried), shark tooth pendants, and shell ornaments. Aggrandizers with abundant resources may be able to form close trading relationships with external groups, thus promoting their social status and reinforcing existing hierarchies within the group (Hoopes 1995; Hayden 1990). This type of political aggrandizement may have occurred during the Pre-Ceramic period at the local level, when especially large *sambaqui* structures that dominate the landscape were built (Gaspar et al. 2008). Political aggrandizement may have been as equally important for internal politics (within the greater coastal *sambaqui* political grouping) during the Pre-Ceramic period as external trade relationships may have been during the Ceramic period.

More studies involving the interaction between coastal and interior groups are needed in order to investigate models of competitive feasting, migration, and diffusion.

Given the results of the stable carbon and nitrogen analysis and dental microwear texture analysis, I find that this paleodietary study partially supports the *subsistence model* for the adoption of ceramic technology among the coastal foragers of Southeastern Brazil. While dietary differences between the Pre-Ceramic and Ceramic time periods are not statistically significant when all individuals are considered, tests show significant differences based on sex. However, questions regarding the social implications of the adoption of pottery cannot be ignored, and there is room in the data to explore ideas related to changes in social and political organization with the arrival of pottery.

Limitations of the Present Study

The present study is limited by the sample sizes of the skeletal population, particularly for the dental microwear texture analysis. The mortuary practice related to secondary burials was a limiting factor in selecting burials for analysis, as I wanted to be able to identify the age and sex from one individual recovered for that burial number. Ideally, it would be advantageous to have selected a greater number of archaeological sites for investigation, but time and resources were limiting factors.

Contribution of the Study

To date, this is the most extensive paleodietary analysis of *sambaqui* populations using stable carbon and nitrogen isotope ratios, and it is the first to use dental microwear texture analysis. I chose to use a two-pronged approach when asking my research

questions, because each method had the potential to explain different aspects of paleodiet: the isotope analysis helps answer the ‘what’ of what was eaten and the texture analysis helps answer the ‘how’ of what was eaten. This study will serve to inform other research of *sambaqui* populations, and make a contribution to Brazilian archaeology as a whole. From a theoretical perspective, this study contributes to the body of knowledge related to the adoption of pottery among foragers, fisher-hunter-gatherer diet, resource intensification, hunter-gatherer social organization, and hunter-gatherer social and political complexity.

Suggestions for Further Research

As I mentioned earlier in this chapter, it would be helpful if the relationship between horticultural groups of the interior and coastal groups were further explored. The recent analysis by Bastos et al. (2011), which used strontium isotope analysis to identify non-local individuals from Forte Marechal Luz, is an example of the manner in which this can be achieved. I would also recommend continuing the investigation of paleodietary patterns using stable carbon and nitrogen isotope analysis and dental microwear texture analysis, as the work in this dissertation examines only a portion of *sambaqui* archaeological data.

Summary

In this study, I tested the *subsistence model* for the adoption of ceramic technology among coastal *sambaqui* foragers of southeastern Brazil using stable carbon and nitrogen isotope analysis and dental microwear texture analysis. The *subsistence model* proposes that a change in diet and/or food processing techniques occurred with

the adoption of pottery, possibly related the adoption of agriculture, whereas an alternative model, the *prestige model*, proposes that coastal foragers used pottery as status-bearing items for competitive feasting or as serving vessels for elite members of the group. If significant changes in stable carbon and nitrogen isotope ratios and dental microwear texture analysis are observed after the introduction of pottery, then the *subsistence model* is supported. This model would also be supported if I were to find a difference in dental microwear texture analysis between Pre-Ceramic and Ceramic occupations without finding a difference using stable isotope analysis. If neither methodology finds evidence for a change in diet and/or food processing techniques, then the *prestige model* for the adoption of pottery should receive greater attention.

For the stable carbon and nitrogen isotope analysis, I sampled 86 individuals for the collagen fraction of bone, and 104 individuals for the apatite fraction of bone. Results indicate no significant difference in carbon isotope ratios between the Pre-Ceramic and Ceramic time periods when all individuals are considered in the test. However, when analyzed by sex, Pre-Ceramic period males show significantly more enriched carbon isotope values than Pre-Ceramic females; nitrogen isotope ratios mirror the same pattern, though the results are not significant. However, all Ceramic period individuals display significantly more enriched nitrogen isotope ratios than all Pre-Ceramic individuals. These results suggest that Pre-Ceramic males ate significantly more marine foods than females of the same time period, and that all individuals ate significantly more marine foods during the Ceramic period. While differences in diet

according to sex are observed for the Pre-Ceramic period, these differences disappear for members of the Ceramic period.

I examined M¹ and M² from 43 individuals using dental microwear texture analysis, a technique that creates a 3-D image of the tooth for the purposes of measuring *Asfc* (complexity, or “pitting”, of the tooth enamel) and *epLsar* (anisotropy, or “scratching”, of the tooth enamel). If Ceramic period *sambaqui* groups used pottery for cooking, I expected to see a decrease in the degree of complexity and anisotropy of tooth enamel after the adoption of pottery. In other words, Pre-Ceramic individuals should display significantly higher measurements of *Asfc* and *epLsar* than Ceramic occupation individuals. The results of this study indicate no significant difference in measurements of complexity and anisotropy between the Pre-Ceramic and Ceramic occupations when all individuals are considered, and all facet types are considered. However, when the populations are examined based on sex, Pre-Ceramic males display significantly more complex tooth enamel than Ceramic occupation males. *Asfc* is also significantly higher for Pre-Ceramic populations using facet x when all individuals are considered in the analysis, and for facet 9 when only adults are considered in the analysis. When only M² is considered in the dental microwear texture analysis, measurements of complexity are significantly higher for Pre-Ceramic groups than Ceramic groups when examining, adults, males and females, and males.

The results of the stable carbon and nitrogen isotope analysis and dental microwear texture analysis show some support for the *subsistence model* for the adoption of ceramic technology among the coastal foragers of southeastern Brazil. While

the statistical results of each methodology are not significant when all individuals are included in the tests, significant results are observed when the sex of the individual is considered. For the dental microwear texture analysis, tooth type and facet type also appear to be important factors when analyzing the data. Though the results do not show support for the *prestige model* for the adoption of ceramic technology, further investigation into the arrival and adoption of pottery among *sambaqui* inhabitants is warranted.

REFERENCES CITED

- Allem, Antonio C.
2002 The Origins and Taxonomy of Cassava. In *Cassava: Biology, Production, and Utilization*, edited by R.J. Hillocks, J.M. Thresh, and A.C. Bellotti, pp. 1-16. CABI Publishing, Colombia.
- Álvarez, Myrian, Ivan Briz Godino, Andrea Balbo, and Marco Madella
2011 Shell Middens as Archives of Past Environments, Human Dispersal, and Specialized Resource Management. *Quaternary International* 239: 1-7.
- Ambrose, Stanley H.
1986 Stable Carbon and Nitrogen Isotope Analysis of Human and Animal Diet in Africa. *Journal of Human Evolution* 707-731.
- Ambrose, Stanley H.
1987 Bone Nitrogen Isotope Composition and Climate. *Nature* 325: 201.
- Ambrose, Stanley H.
1990 Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science* 17: 431-451.
- Ambrose, Stanley H.
1991 Effects of Diet, Climate and Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs. *Journal of Archaeological Science* 18: 293-317.
- Ambrose, Stanley H.
1993 Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. In *Investigations of Ancient Human Tissue: Chemical Analyses in Anthropology*, edited by Mary K. Sandford, pp. 59-129. Gordon and Breach Science, Langhorne, Pennsylvania.
- Ambrose, Stanley H.
2000 Controlled Diet and Climate Experiments on Nitrogen Isotope Ratios of Rats. In *Biogeochemical Approaches to Paleodietary Analysis*, edited by Stanley H. Ambrose and M. Anne Katzenberg, pp. 243-259. Plenum Publishers, New York.

- Ambrose, Stanley H. and Lynett Norr
 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 *Prehistoric Human Bone: Archaeology at the Molecular Level*, edited by Joseph B. Lambert and Gisela Grupe, pp. 1-37. Springer-Verlage, New York.
- Ambrose, Stanley H., Jane Buikstra, and Harold W. Krueger
 2003 Status and Gender Differences in Diet at Mound 72, Cahokia, Revealed by Isotopic Analysis of Bone. *Journal of Anthropological Archaeology* 22: 217-226.
- Ames, Kenneth M.
 1985 Hierarchies, Stress, and Logistical Strategies Among Hunter-Gatherers in Northwestern North America. In *Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity*, edited by T. Douglas Price and James A. Brown, pp. 155-180. Academic Press, Orlando.
- Ames, Kenneth M.
 1991 The Archaeology of the Longue Durée: Temporal and Spatial Scale in the Evolution of Social Complexity on the Southern Northwest Coast. *Antiquity* 65: 935-945.
- Ames, Kenneth M.
 1994 The Northwest Coast: Complex Hunter-Gatherers, Ecology, and Social Evolution. *Annual Review of Anthropology* 23: 209-229.
- Angulo, Rodolfo J., Paulo C. F. Giannini, Kenitiro Suguio, and Luiz C.R. Pessenda
 1999 Relative Sea-Level Changes in the Last 5500 Years in Southern Brazil Laguna-Imbituba Region, Santa Catarina State Based on Vermetid ¹⁴C Ages. *Marine Geology* 159: 323-339.
- Araújo, Edson Medeiros
 1970 Hipercementose e Abrasão das Populações Pré-Históricas do Litoral de Santa Catarina. *Anais do Museu de Antropologia* 3: 71-90.
- Araujo, Astolfo Gomes de Mello
 2007 A Tradição Cerâmica Itararé-Taquara: Características, Área de Ocorrência e algumas Hipóteses Sobre a Expansão dos Grupos Jê no Sudeste do Brasil. *Revista de Arqueologia*, 20: 9-38
- Arnold, Dean E.
 1985 *Ceramic theory and cultural process*. Cambridge University Press, Cambridge, United Kingdom.

- Arnold, Jeanne E.
1992 Complex Hunter-Gatherer-Fishers of Prehistoric California: Chiefs, Specialists, and Maritime Adaptations of the Channel Islands. *American Antiquity* 57 (1): 60-84.
- Arnold, Jeanne E.
1996 The Archaeology of Complex Hunter-Gatherers. *Journal of Archaeological Method and Theory* 3 (2): 77-126.
- Bandeira, Dione da Rocha
1992 *Mudança na Estratégia de Subsistência. O Sítio Arqueológico Enseada I—Um Estudo de Caso*. Unpublished master's thesis, Department of Anthropology, Federal University of Santa Catarina, Florianópolis.
- Bandeira, Dione da Rocha, Giana Sobral Maciel dos Santos, and Anna Kelly Krassota
2013 Sambaquis Fluviais em Santa Catarina: Reflexões a Partir da Pesquisa da Fauna do Sítio Itacoara. *Tempos Acadêmicos* 11: 68-83.
- Barbosa M., Gaspar M.D., and Barbosa D.R.
1994 A Organização Especial das Estruturas Habitacionais e Distribuição dos Artefatos no Sítio Ilha da Boa Vista I, Cabo Frio, RJ. *Revista do Museu de Arqueologia e Etnologia* 4:31-38
- Barnett, William K.
1990 Small-Scale Transport of Early Neolithic Pottery in the Western Mediterranean. *Antiquity* 64: 859-865.
- Barreto, Cristiana
2005 *Social Complexity and Inequality in Ancient Amerindian Societies: Perspectives from the Brazilian Lowlands*. Centre for Brazilian Studies, University of Oxford, United Kingdom.
- Bastos, Murilo Q. R., Sheila M. F. Mendonça de Souza, Roberto V. Santos, Bárbara A. F. Lima, Ricardo V. Santos, and Claudia Rodrigues-Carvalho
2011 Human Mobility on the Brazilian Coast: An Analysis of Strontium Isotopes in Archaeological Human Remains from Forte Marechal Luz Sambaqui. *Anais da Academia Brasileira de Ciências* 83 (2): 731-743.
- Beasley, M.M., A.M. Martinez, D.D. Simons, and E.J. Bartelink
2013 Paleodietary Analysis of a San Francisco Bay Area Shellmound: Stable Carbon and Nitrogen Isotope Analysis of Late Holocene Humans from the Ellis Landing Site (CA-CCO-295). *Journal of Archaeological Science* 40: 2084-2094.

- Beber, Marcus Vinícius
 2004 *O Sistema de Assentamento dos Grupos Ceramistas do Planalto Sul-Brasileiro: O Caso da Tradição Taquara/ Itataré*. Unpublished Ph.D. Dissertation, Department of History, Universidade do Vale do Rio dos Sinos, São Leopoldo.
- Beck, Anamaria, Edson Medeiros Araújo, and Gerusa Maria Duarte
 1970 Síntese da Arqueologia do Litoral Norte de Santa Catarina, IV Simpósio de Pré-História Brasileira during the XXII Reunião da Sociedade Brasileira Para o Progresso da Ciência (SBPC), Salvador.
- Beck, Anamaria
 1972 *A Variação do Conteúdo Cultural dos Sambaquis Litoral de Santa Catarina*. Unpublished Ph.D. Dissertation, Department of Social Sciences, University of São Paulo.
- Behling, Hermann, and Martin Lichte
 1997 Evidence of Dry and Cold Climatic Conditions at Glacial Times in Tropical Southeastern Brazil. *Quaternary Research* 48 (3): 348-358.
- Behling, Hermann
 1998 Late Quaternary Vegetational and Climatic Changes in Brazil. *Review of Palaeobotany and Palynology* 99 (2): 143-156.
- Behling, Hermann, and Raquel R.B. Negrelle
 2001 Tropical Rain Forest and Climate Dynamics of the Atlantic Lowland, Southern Brazil, during the Late Quaternary. *Quaternary Research* 56 (3): 383-389.
- Bigarella, João José
 1954 Os Sambaquis na Evolução da Paisagem Litorânea Sul-Brasileira. *Arquivos de Biologia e Tecnologia* 9: 199-221.
- Blaeuer, M.W., and J.C. Rose
 1982 Bioarchaeology of the Powell Canal Site. In *Powell Canal, Arkansas Archaeological Survey Publication No. 19*, edited by J.H. House, pp. 72-84. Arkansas Archaeological Survey, Fayetteville, Arkansas.
- Boyde, A., and M. Fortelius
 1991 New Confocal LM Method for Studying Local Relative Microrelief with Special Reference to Wear Studies. *Scanning* 13: 429-430.

- Braun, David P.
 1987 Coevolution of sedentism, pottery technology, and horticulture in the central Midwest, 200 BC-AD 600. In *Emergent Horticultural Economies of the Eastern Woodlands*, edited by William E. Keegan, pp.153-181. Carbondale: Occasional Paper 7. Center for Archaeological Investigations, Southern Illinois University.
- Bryan, Alan, L.
 1977 Resumo da Arqueologia do Sambaqui de Forte Marechal Luz. *Arquivos do Museu de Historia Natural Belo Horizonte* 2: 9-30.
- Bryan, Alan L.
 1993 *Brazilian Studies: The Sambaqui at Forte Marechal Luz, State of Santa Catarina, Brazil*. Center for the Study of the First Americans, Portland, Oregon.
- Bullington, Jill
 1991 Deciduous Dental Microwear of Prehistoric Juveniles from the Lower Illinois River Valley. *American Journal of Physical Anthropology* 84 (1): 59-73.
- Calandra, Ivan, Ellen Schulz, Mona Pinnow, Susanne Krohn, and Thomas M. Kaiser
 2012 Teasing Apart the Contributions of Hard Dietary Items on 3D Dental Microtextures in Primates. *Journal of Human Evolution* 63: 85-98.
- Castilho, Pedro Volkmer
 2008 Utilization of Cetaceans in Shell Mounds from the Southern Coast of Brazil. *Quaternary International* 180: 107-114.
- Childe, V. Gordon
 1951 *Man Makes Himself*. Mentor Book, New American Library, Ontario.
- Chmyz, Igor
 1976 A Ocupação do Litoral dos Estados do Paraná e Santa Catarina por Povos Ceramistas. *Estudos Brasileiros* 1: 7-43.
- Choy, Kyungcheol, Ok-Ryun Jeon, Benjamin T. Fuller, and Michael P. Richards
 2010 Isotopic Evidence of Dietary Variations and Weaning Practices in the Gaya Cemetery at Yeanri, Gimhae, South Korea. *American Journal of Physical Anthropology* 142: 74-84.
- Clark, John E. and Michael Blake
 1994 The Power of Prestige: Competitive Generosity and the Emergence of Rank Societies in Lowland Mesoamerica. In *Factional Competition and Political Development in the New World*, edited by Elizabeth M. Brumfiel and John W. Fox, pp.17-30. Cambridge University Press, New York.

- Cohen, Mark Nathan
 1985 Prehistoric Hunter-Gatherers: The Meaning of Social Complexity. In *Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity*, edited by T. Douglas Price and James A. Brown, pp. 99-119. Academic Press, Orlando.
- Covert, Herbert H., and Richard F. Kay
 1981 Dental Microwear and Diet: Implications for Determining the Feeding Behaviors for Extinct Primates, With a Comment on the Dietary Pattern of *Sivapithecus*. *American Journal of Physical Anthropology* 55 (3): 331-336.
- Cox, Glenda, Judith Sealy, Carmel Schrire, and Alan Morris.
 2001 Stable Carbon and Nitrogen Isotopic Analyses of the Underclass at the Colonial Cape of Good Hope in the Eighteenth and Nineteenth Centuries. *World Archaeology* 33 (1): 73-97.
- Crown, Patricia L., and W.H. Wills
 1995 Economic Intensification and the Origins of Ceramic Containers in the American Southwest. In *The Emergence of Pottery: Technology and Innovation in Ancient Societies*, edited by William K. Barnett and John W. Hoopes, pp. 241-251. Smithsonian Institution Press, Washington, D.C.
- De Blasis, Paulo, Suzanne K. Fish, Maria Dulce Gaspar, and Paul R. Fish
 1998 Some References for the Discussion of Complexity among the Sambaqui Moundbuilders from the Southern Shores of Brasil. *Revista de Arqueología Americana* 15:75-105.
- De Masi, Marco
 1999 *Prehistoric Hunter-Gatherer Mobility on the Southern Brazilian Coast: Santa Catarina Island*. Unpublished PhD Dissertation, Department of Anthropology, Stanford University.
- De Niro, Michael J. and Samuel Epstein
 1978 Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica* 42: 495-506.
- De Niro, Michael J. and Samuel Epstein
 1981 Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica* 45: 341-351.
- De Niro, Michael J.
 1985 Postmortem Preservation and Alteration of in vivo Bone Collagen Isotope Ratios in Relation to Paleodietary Reconstruction. *Nature* 317 (31): 806-809.

- de Souza, Sheila Maria Ferraz Mendonça
 1995 *Estresse, Doença e Adptabilidade: Estudo Comparativo de Dois Grupos Pre-Históricos em Perspectiva Biocultural*. Unpublished Ph. D. Dissertation, Department of Public Health, National School of Public Health at the Foundation Oswaldo Cruz, Rio de Janeiro.
- de Souza, Sheila Maria Ferraz Mendonça
 2011 Brazil/Brasil. In *The Routledge Handbook of Archaeological Human Remains and Legislation: An International Guide to Laws and Practice in the Excavation and Treatment of Archaeological Human Remains*, edited by Nicholas Márquez-Grant and Linda Fibiger, pp. 587-593. Routledge, New York.
- Dennis, John C., Peter S. Ungar, Mark F. Teaford, and Kenneth E. Glander
 2004 Dental Topography and Molar Wear in *Alouatta palliata* from Costa Rica. *American Journal of Physical Anthropology* 125: 152-161.
- Dupras, Tosha L., Henry P. Schwarcz, and Scott I. Fairgrieve
 2001 Infant Feeding and Weaning Practices in Roman Egypt. *American Journal of Physical Anthropology* 115: 204-212.
- Eerkens, Jelmer W.
 2003 Residential mobility and pottery use in the Western Great Basin. *Current Anthropology* 44: 728-738.
- Eerkens, Jelmer W.
 2004 Small-Seed Intensification, and the Origins of Pottery in the Western Great Basin. *American Antiquity* 69 (4): 653-670.
- Eggers, S., C.C. Petronilho, K. Brandt, C. Jerico-Daminello, J. Filippini, and K. J. Reinhard
 2008 How Does a Riverine Setting Affect the Lifestyle of Shellmound Builders in Brazil? *HOMO-Journal of Comparative Human Biology* 59 (6): 405-427.
- Eggers, Sabine, Maria Parks, Gisela Grupe, and Karl J. Reinhard
 2011 Paleoamerican Diet, Migration and Morphology in Brazil: Archaeological Complexity of the Earliest Americans. *PLoS ONE* 6 (9): 1-8.
- El Zaatari, Sireen, Frederick E. Grine, Mark F. Teaford, and Heather F. Smith
 2005 Molar Microwear and Dietary Reconstructions of Fossil Cercopithecoidea from the Plio-Pleistocene Deposits of South Africa. *Journal of Human Evolution* 49 (2): 180-205.

- El Zaatari, S.
2010 Occlusal Microwear Texture Analysis and the Diets of Historical/Prehistoric Hunter-Gatherers. *International Journal of Osteoarchaeology* 20: 67-87.
- El Zaatari, Sireen, Frederick E. Grine, Peter S. Ungar, and Jean-Jacques Hublin
2011 Ecogeographic Variation in Neandertal Dietary Habits: Evidence from Occlusal Molar Microwear Texture Analysis. *Journal of Human Evolution* 61: 411-424.
- Emery, Kitty F., Lori E. Wright, and Henry Schwarcz
2000 Isotopic Analysis of Ancient Deer Bone: Biotic Stability in Collapse Period Maya Land Use. *Journal of Archaeological Science* 27: 537-550.
- Eshed, Vered, Avi Gopher, and Israel Hershkovitz
2006 Tooth Wear and Dental Pathology at the Advent of Agriculture: New Evidence from the Levant. *American Journal of Physical Anthropology* 130 (2): 145-159.
- Figuti, Levi
1989 Estudos dos Vestígios Faunísticos do Sambaqui Cosipa—3, Cubatão—SP. *Revista de Pré-História* 7: 112-126.
- Figuti, Levi
1993 O Homem Pré-Histórico, O Molusco e O Sambaqui: Considerações Sobre a Subsistência dos Povos Sambaqueiros. *Revista do Museu de Arqueologia e Etnologia* 3: 67-80.
- Figuti, Levi
1999 5,000 years, before the Portuguese, before the Tupinamba—The First Inhabitants of the Brazilian Shores. *Ciência e Cultura* 51 (3/4): 236-244.
- Finstad, Kari M., B. Lynn Ingram, Peter Schweikhardt, Kent G. Lightfoot, Edward M. Luby, and George R. Coles
2013 New Insights about the Construction and Use of Shell Mounds from the Geochemical Analysis of Mollusks: An Example from the Greater San Francisco Bay. *Journal of Archaeological Science* 40: 2648-2658.
- Fish, Suzanne K., Paulo De Blasis, Maria Dulce Gaspar, and Paul R. Fish
2000 Eventos Incrementais na Construção de Sambaquis, Litoral Sul do Estado do Santa Catarina. *Revista do Museu de Arqueologia e Etnologia* 10: 69-87.
- Flannery, Kent V.
1969 Origins and Ecological Effects of Early Domestication in Iran and the Near East. In *The Domestication and Exploitation of Plants and Animals*, edited by Peter J. Ucko and G.W. Dimbleby, pp. 73-100. Aldine Publishing Company, Chicago.

- Freitas, Fabio O., and Paulo S. Martins
2000 FOCUS: Calcite Crystals Inside Archaeological Plant Tissues. *Journal of Archaeological Science* 27: 981-985.
- Freitas, Fabio Oliveira, Gerhard Bendel, Robin G. Allaby, and Terence A. Brown
2003 DNA from Primitive Maize Landraces and Archaeological Remains: Implications for the Domestication of Maize and Its Expansion into South America. *Journal of Archaeological Science* 30: 901-908.
- Froehle, A. W., C. M. Kellner, and M. J. Schoeninger
2012 Multivariate Carbon and Nitrogen Stable Isotope Model for the Reconstruction of Prehistoric Human Diet. *American Journal of Physical Anthropology* 147: 352-369.
- Fry, Brian
2006 *Stable Isotope Ecology*. Springer, New York.
- Fuller, B.T., J. L. Fuller, D. A. Harris, and R. E. M. Hedges
2006 Detection of Breastfeeding and Weaning in Modern Human Infants with Carbon and Nitrogen Stable Isotope Ratios. *American Journal of Physical Anthropology* 129: 279-293.
- Gaspar, Maria Dulce
1992 Aspectos de Organização Social de Um Grupo de Pescadores, Coletores, e Caçadores que Ocupou o Litoral do Estado do Rio de Janeiro. *Paleopatologia e Paleoepidemiologia: Estudos Multidisciplinares*: 95-109.
- Gaspar, Maria Dulce
1996 Datações, Construção de Sambaqui e Identidade Social dos Pescadores, Coletores, e Caçadores. *Anais da VIII Reunião Científica da Sociedade de Arqueologia Brasileira*, pp. 811-820. Porto Alegre, Brasil.
- Gaspar, Maria Dulce
1998 Considerations of the Sambaquis of the Brazilian Coast. *Antiquity* 72: 592-615.
- Gaspar, Maria Dulce, Paulo De Blasis, Suzanne K. Fish, and Paul R. Fish
2008 Sambaqui (Shell Mound) Societies of Coastal Brazil. In *Handbook of South American Archaeology*, edited by Helaine Silverman and William H. Isbell, pp. 319-335. Springer, New York.
- Gil, A.F., G.A. Neme, R. H. Tykot, P. Novellino, V. Cortegoso, and V. Durán. Stable Isotopes and Maize Consumption in Central Western Argentina. *International Journal of Osteoarchaeology* 19: 215-236.

- González, Erika Marion Robrahn
1998 Regional Pottery-Making Groups of Southern Brazil. *Antiquity* 72: 616-624.
- Gordon, Kathleen D.
1982 A Study of Microwear On Chimpanzee Molars: Implications for Dental Microwear Analysis. *American Journal of Physical Anthropology* 59 (2); 195-215.
- Gordon, Kathleen D.
1983 Taphonomy of Dental Microwear: Can Fossil Microwear Be Studied Productively? *American Journal of Physical Anthropology* 60: 200.
- Gordon, Kathleen D.
1984a Hominoid Dental Microwear Complicaitons in the Use of Microwear Analysis to Detect Diet. *Journal of Dental Research* 63 (8); 1043-1046.
- Gordon, Kathleen D.
1984b The Assessment of Jaw Movement Direction from Dental Microwear. *American Journal of Physical Anthropology* 63 (1): 77-84.
- Gordon, Kathleen D.
1984c Taphonomy of Dental Microwear. *American Journal of Physical Anthropology* 64: 164-165.
- Gordon, Kathleen D.
1986 Dental Microwear Analysis to Detect Human Diet. *American Journal of Physical Anthropology* 69: 206-207.
- Gordon, Kathleen D.
1988 A Review of Methodology and Quantification in Dental Microwear Analysis. *Scanning Microscopy* 2 (2): 1139.
- Gordon, Kathleen D., and Alan C. Walker
1983 Playing 'Possum: A Microwear Experiment. *American Journal of Physical Anthropology* 60 (1): 109-112.
- Gould, Richard A.
1985 Now Let's Invent Agriculture...: A Critical Review of Concepts of Complexity Among Hunter-Gatherers. In *Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity*, edited by T. Douglas Price and James A. Brown, pp. 427-442. Academic Press, San Diego.

- Grine, Frederick E.
1977 Analysis of Early Hominid Deciduous Molar Wear by Scanning Electron Microscopy: A Preliminary Report. *Proceedings of the Electron Microscopy Society, South Africa* 7: 157-158.
- Grine, Frederick E.
1986 Dental Evidence for Dietary Differences in *Australopithecus* and *Paranthropus*: A Quantitative Analysis of Permanent Molar Microwear. *Journal of Human Evolution* 15 (8): 783-822.
- Grine, Frederick E.
1987a Quantitative Analysis of Occlusal Microwear in *Australopithecus* and *Paranthropus*. *Scanning Microscopy* 1 (2): 647.
- Grine, Frederick E., and Richard F. Kay
1988 Early Hominid Diets from Quantitative Image Analysis of Dental Microwear. *Nature* 333: 765-768.
- Grine, F. E., P.S. Ungar, and M.F. Teaford
2002 Error Rates in Dental Microwear Quantification Using Scanning Electron Microscopy. *Scanning* 24: 144-153.
- Gügel, Irene Luise, Gisela Grupe, and Karl-Heinz Kunzelmann
2001 Simulation of Dental Microwear: Characteristic Traces by Opal Phytoliths Give Clues to Ancient Human Dietary Behavior. *American Journal of Physical Anthropology* 114: 124-138.
- Habu, Junko
2008 Growth and Decline in Complex Hunter-Gatherer Societies: A Case Study from the Jomon Period Sannai Maruyama Site, Japan. *Antiquity* 82: 571-584.
- Hansel, Fabricio Augusto
2004 *Arqueología Biomolecular: Análise dos Resíduos Orgânicos Preservados em Ecofatos e Artefatos Recuperados de Sítios Arqueológicos Costeiros Pré-Coloniais Jê-SC*. Unpublished Ph.D. Dissertation, Department of Chemistry, Universidade de Federal de Santa Catarina, Florianópolis, Brasil.
- Hard, Robert J., Karen R. Adams, John R. Roney, Kari M. Schmidt, and Gayle J. Fritz
2008 The Emergence of Maize Farming in Northwest Mexico. In *Case Studies in Environmental Archaeology*, edited by Elizabeth J. Reitz, Lee A. Newsom, and Sylvia J. Scudder, pp. 315-333. Springer, New York.

- Harmon, Anna M. and Jerome C. Rose
 1988 The Role of Dental Microwear Analysis in the Reconstruction of Prehistoric Diet. In *Diet and Subsistence: Current Archaeological Perspectives*, pp. 267-272. Archaeological Association of the University of Calgary, Calgary, Canada.
- Harrison, Roman G., and M. Anne Katzenberg
 2003 Paleodiet Studies Using Stable Carbon Isotopes from Bone Apatite and Collagen; Examples from Southern Ontario and San Nicolas Island, California. *Journal of Anthropological Archaeology* 22: 227-244.
- Hayden, Brian
 1990 Nimrods, Piscators, Pluckers, and Planters: The Emergence of Food Production. *Journal of Anthropological Archaeology* 9: 31-69.
- Hayden, Brian
 1995 Pathways to Power. In *Foundations of Social Inequality*, edited by T. Douglas Price and Gary M. Feinman, pp. 15-86. Plenum Press, New York.
- Heaton, Tim H. E., John C. Vogel, Gertrud von la Chevallerie, and Gill Collett
 1986 Climatic Influence on the Isotopic Composition of Bone Nitrogen. *Nature* 322: 822-823.
- Heaton, T. H. E.
 1987 The $^{15}\text{N}/^{14}\text{N}$ Ratios of Plants in South Africa and Namibia: Relationship to Climate and Coastal/Saline Environments. *Oecologia* 74: 236-246.
- Herring, D. Ann, S. R. Saunders, and M. A. Katzenberg
 1998 Investigating the Weaning Process in Past Populations. *American Journal of Physical Anthropology* 105: 425-439.
- Hoopes, John W.
 1995 Interaction in Hunting and Gathering Societies as a Context for the Emergence of Pottery in the Central American Isthmus. In *The Emergence of Pottery: Technology and Innovation in Ancient Societies*, edited by William K. Barnett and John W. Hoopes, pp. 185-198. Smithsonian Institution Press, Washington, D.C.
- Hubbe, Mark, Walter Alves Neves, Emiliano Castro de Oliveira, and André Strauss
 2009 Postmarital Residence Practice in Southern Brazilian Coastal Groups: Continuity and Change. *Latin American Antiquity* 20 (2): 1-12.
- Hurt, Wesley R.
 1974 *The Interrelationships between the Natural Environment and Four Sambaquis*. Coast of Santa Catarina, Brazil. Occasional Papers and Monographs No. 1, Indiana University Museum, Bloomington.

- Hutchinson, Dale L., Clark Spencer Larsen, Margaret J. Schoeninger, and Lynette Norr
 1998 Regional Variation in the Pattern of Maize Adoption and Use in Florida and Georgia. *American Antiquity* 63 (3): 397-416.
- Iriarte, José, Irene Holst, Oscar Marozzi, Claudia Listopad, Eduardo Alonso, Andrés Rinderknecht, and Juan Montaña.
 2004 Evidence for Cultivar Adoption and Emerging Complexity During the Mid-Holocene in the La Plata Basin. *Nature* 432 (2): 614-617.
- Irish, Joel D., and Christy G. Turner II
 1997 Brief Communication: First Evidence of LSAMAT in Non-Native Americans: Historic Senegalese from West Africa. *American Journal of Physical Anthropology* 102 (1): 141-146.
- Jay, Mandy, and Michael P. Richards
 2006 Diet in the Iron Age Cemetery Population at Wetwang Slack, East Yorkshire, UK: Carbon and Nitrogen Stable Isotope Evidence. *Journal of Archaeological Science* 33: 653-662.
- Jerardino, Antonieta
 2010 Large Shell Middens in Lamberts Bay, South Africa: A Case of Hunter-Gatherer Resource Intensification. *Journal of Archaeological Science* 37: 2291-2302.
- Jernvall, Jukka and Lena Selanne
 1999 Laser Confocal Microscopy and Geographic Information Systems in the Study of Dental Morphology. *Palaeontologia Electronica* 2 (1): 18.
- Katzenberg, M. Anne
 1992 Advances in Stable Isotope Analysis of Prehistoric Bones. In *Skeletal Biology of Past Peoples: Research Methods*, edited by Shelley R. Saunders and M. Anne Katzenberg, pp. 105-119. Wiley-Liss, New York.
- Katzenberg, M. Anne
 2000 Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In *Biological Anthropology of the Human Skeleton*, edited by Shelley R. Saunders and M. Anne Katzenberg, pp. 305-327. Wiley-Liss, New York.
- Katzenberg, M. Anne, Shelley R. Saunders, and William R. Fitzgerald
 1993 Age Differences in Stable Carbon and Nitrogen Isotope Ratios in a Population of Prehistoric Maize Horticulturalists. *American Journal of Physical Anthropology* 90: 267-281.

- Katzenberg, M. Anne, Henry P. Schwarcz, Martin Knyf, and F. Jerome Melbye
1995 Stable Isotope Evidence for Maize Horticulture and Paleodiet in Southern Ontario, Canada. *American Antiquity* 60 (2): 335-350.
- Katzenberg, M. Anne, D. Ann Herring, and Shelley R. Saunders
1996 Weaning and Infant Mortality: Evaluating the Skeletal Evidence. *Yearbook of Physical Anthropology* 39: 177-199.
- Kay, Richard F.
1977 The Evolution of Molar Occlusion in the Cercopithecidae and early Catarrhines. *American Journal of Physical Anthropology* 46: 327-352.
- Kay, Richard F.
1987 Analysis of Primate Dental Microwear Using Image Processing Techniques. *Scanning Microscopy* 1 (2): 657-662.
- Kay, Richard F., and Karen M. Hiiemae
1974 Jaw Movement and Tooth Use in Recent and Fossil Primates. *American Journal of Physical Anthropology* 40: 227-256.
- Kay, Richard F., and Herbert H. Covert
1983 True Grit: A Microwear Experiment. *American Journal of Physical Anthropology* 61: 33-38.
- Kay, Richard F., and Herbert H. Covert
1984 Anatomy and Behaviour of Extinct Primates. In *Food Acquisition and Processing in Primates*, edited by David J. Chivers, Bernard A. Wood, and Alan Bilsborough, pp. 467-508. Springer, New York.
- Kay, Richard F., and Frederick E. Grine
1988 Tooth Morphology, Wear and Diet in Australopithecus and Paranthropus from Southern Africa. In *Evolutionary History of the "Robust" Australopithecines*, edited by Frederick E. Grine, pp. 427-447. Aldine Transaction, New York.
- Keeley, Lawrence H.
1988 Hunter-Gatherer Economic Complexity and "Population Pressure": A Cross-Cultural Analysis. *Journal of Anthropological Archaeology* 7: 373-411.
- Kellner, Corina M., and Margaret J. Schoeninger
2007 A Simple Carbon Isotope Model for Reconstructing Prehistoric Human Diet. *American Journal of Physical Anthropology* 133: 1112-1127.

- Kellner, Corina M., and Margaret J. Schoeninger
 2008 Wari's Imperial Influence on Local Nasca Diet: The Stable Isotope Evidence. *Journal of Anthropological Archaeology* 27: 226-243.
- Kennett, Douglas J., and James P. Kennett
 2000 Competitive and Cooperative Responses to Climatic Instability in Coastal Southern California. *American Antiquity* 65 (2): 379-395.
- Kieser, J.A., K. J. Dennison, John Aristidis Kaidonis, D. Huang, P.G.P. Herbison, and N.G. Tayles
 2001 Patterns of Dental Wear in the Early Maori Dentition. *International Journal of Osteoarchaeology* 11 (3): 206-217.
- King, Tania, Peter Andrews, and Basak Boz
 1999 Effect of Taphonomic Processes on Dental Microwear. *American Journal of Physical Anthropology* 108: 359-373.
- Klukkert, Zachary S., Mark F. Teaford, and Peter S. Ungar
 2012 A Dental Topographic Analysis of Chimpanzees. *American Journal of Physical Anthropology* 148: 276-284.
- Kneip, Lina Maria
 1987 Artefatos de Osso e de Concha do Sambaqui Zé Espinho. In *Coletores e Pescadores Pré-Históricos de Guaratiba, Rio de Janeiro*, Museu Nacional, UFRJ, pp.153-164, Rio de Janeiro.
- Koch, Paul L., Noreen Tuross, and Marilyn L. Fogel
 1997 The Effects of Sample Treatment and Diagenesis on the Isotopic Integrity of Carbonate in Biogenic Hydroxylapatite. *Journal of Archaeological Science* 24: 417-429.
- Krigbaum, John
 2003 Neolithic Subsistence Patterns in Northern Borneo Reconstructed with Stable Carbon Isotopes of Enamel. *Journal of Anthropological Archaeology* 22: 292-204.
- Krueger, Harold W. and Charles H. Sullivan
 1984 Models for Carbon Isotope Fractionation Between Diet and Bone. *Stable Isotopes in Nutrition*, based on a symposium sponsored by the Division of Agricultural and Food Chemistry at the 186th Meeting of the American Chemical Society, pp. 205-220. Washington, D.C.
- Krueger, Kristin L., Jessica R. Scott, Richard F. Kay, and Peter S. Ungar
 2008 Technical Note: Dental Microwear Textures of "Phase I" and "Phase II" Facets. *American Journal of Physical Anthropology* 137: 485-490.

- Lalueza Fox, C., J. Juan, and R.M. Albert
1996 Phytolith Analysis on Dental Calculus, Enamel Surface, and Burial Soil: Information About Diet and Palaeoenvironment. *American Journal of Physical Anthropology* 101: 101-113.
- Larsen, Clark Spencer, Margaret J. Schoeninger, Nikolaas J. van der Merwe, Katherine M. Moore, and Julia A. Lee-Thorp
1992 Carbon and Nitrogen Stable Isotopic Signatures of Human Dietary Change in the Georgia Bight. *American Journal of Physical Anthropology* 89: 197-214.
- Larsen, Clark Spencer
1995 Biological changes in human populations with agriculture. *Annual Review of Anthropology* 24: 185-213.
- Larsen, Clark Spencer, Robert L. Kelly, Christopher B. Ruff, Margaret J. Schoeninger, Dale L. Hutchinson, and Brian E. Hemphill.
2008 Living on the Margins: Biobehavioral Adaptations in the Western Great Basin. In *Case Studies in Environmental Archaeology*, edited by Elizabeth J. Reitz, Lee A. Newsom, and Sylvia J. Scudder, pp. 315-333. Springer, New York.
- Lee-Thorp, Julia A, Judith C. Sealy, and Nikolaas J. van der Merwe
1989 Stable Carbon Isotope Ratio Differences Between Bone Collagen and Bone Apatite, and their Relationship to Diet. *Journal of Archaeological Science* 16: 585-599.
- Lessa, Andrea
2011a Daily Risks: A Biocultural Approach to Acute Trauma in Pre-colonial Coastal Populations from Brazil. *International Journal of Osteoarchaeology* 21: 159-172.
- Lessa, Andrea
2011b Spondylolysis and Lifestyle among Prehistoric Coastal Groups from Brazil. *International Journal of Osteoarchaeology* 21: 660-668.
- Lima, Tania Andrade
1999-2000 Em Busca dos Frutos do Mar: Os Pescadores-Coletores do Litoral Centro-Sul do Brasil. *Revista USP* 44: 270-327.
- Littleton, Judith, and Bruno Frohlich
1993 Fish-Eaters and Farmers: Dental Pathology in the Arabian Gulf. *American Journal of Physical Anthropology* 92: 427-447.

- Lucas, P.W., and M.F. Teaford
 1995 Significance of Silica in Leaves to Long-Tailed Macaques (*Macaca fascicularis*). *Folia Primatologica* 64 (1-2): 30-36.
- Maas, Mary C.
 1991 Enamel Structure and Microwear: An Experimental Study of the Response of Enamel to Shearing Force. *American Journal of Physical Anthropology* 85 (1): 31-49.
- Mahoney, Patrick
 2006a Dental Microwear from Natufian Hunter-Gatherers and Early Neolithic Farmers: Comparisons Within and Between Samples. *American Journal of Physical Anthropology* 130 (3): 308-319.
- Mahoney, Patrick
 2006b Brief Communication: Intertooth and Intrafacet Dental Microwear Variation in an Archaeological Sample of Modern Humans from the Jordan Valley. *American Journal of Physical Anthropology* 129 (1): 39-44.
- Mahoney, Patrick
 2006c Microwear and Morphology: Functional Relationships Between Human Dental Microwear and the Mandible. *Journal of Human Evolution* 50 (4): 452-459.
- Mahoney, Patrick
 2007 Microwear Studies of Diet in Early Bronze Age Burials from Scotland. *BAR International Series* 1692: 83.
- Maier, W., and G. Schneck
 1982 Functional Morphology of Hominoid Dentitions. *Journal of Human Evolution* 11: 693-696.
- Marinho, Anderson Nonato do Rosario, Newton Cardoso Miranda, Valéria Braz, Ândrea Kely Ribeiro-dos-Santos, Sheila Maria Ferraz Mendonça de Souza
 2006 Paleogenetic and Taphonomic Analysis of Human Bones from Moa, Beirada, and Zé Espinho Sambaquis, Rio de Janeiro, Brazil. *Memoria Instituto de Oswaldo Cruz* 101: 15-23.
- Marquardt, William H.
 1986 The Development of Cultural Complexity in Southwest Florida: Elements of a Critique. *Southeastern Archaeology* 5 (1): 63-70.

- Marquet, Pablo A., Calogero M. Santoro, Claudio Latorre, Vivien G. Standen, Sebastián R. Abades, Marcelo M. Rivadeneira, Bernardo Arriaza, and Michael E. Hochberg.
2012 Emergence of Social Complexity Among Coastal Hunter-Gatherers in the Atacama Desert of Northern Chile. *PNAS* 109 (37): 14754-14760.
- Martin, Louis, Kenitiro Suguio, Jean-Marie Flexor, José ML Dominguez, and Abilio CSP Bittencourt
1996 Quaternary Sea-Level History and Variation in Dynamics along the Central Brazilian Coast: Consequences on Coastal Plain Construction. *Anais da Academia Brasileira de Ciências* 68 (3) 303-354.
- Martins, Paulo Sodero
1994 Biodiversity and Agriculture: Patterns of Domestication of Brazilian Native Plant Species. *Anais da Academia Brasileira de Ciências* 66: 219-224.
- Merceron, Gildas, Cecile Blondel, Louis De Bonis, Georges D. Koufous, ad Laurent Viriot
2005 A New Method of Dental Microwear Analysis: Application to Extant Primates and *Ouranopithecus macedoniensis* (Late Miocene of Greece). *Palaios* 20 (6): 551-561.
- M'kirera, Francis, and Peter S. Ungar
2003 Occlusal Relief Changes with Molar Wear in Pan troglodytes troglodytes and Gorilla gorilla gorilla. *American Journal of Primatology* 60 (2): 31-41.
- Molleson, T., K. Jones, and S. Jones
1993 Dietary Change and the Effect of Food Preparation on Microwear Patterns in the Late Neolithic at Abu Hureya, northern Syria. *Journal of Human Evolution* 24: 455-468.
- Morcote-Rios, Gaspar, and Rodrigo Bernal
2001 Remains of Palms (Palmae) at Archaeological Sites in the New World: A Review. *The Botanical Review* 67 (3): 309-350.
- Morellato L.P.C., Talora D.C., Takahashi A., Bencke C.C., Romera E.C., and Zipparro V.B.
2002 Phenology of Atlantic Rain Forest Trees: A Comparative Study. *Biotropica* 32: 811-823.
- Neves, Walter Alves, and José A. Cocilovo
1989 Componentes craneofuncionales y microdiferenciación de las poblaciones prehistóricas del litoral centro-sur de Brasil. *Ciência e Cultura* 41 (11): 1071-1085.

- Neves, Walter Alves, and Verônica Weselowski
 2002 Economy, Nutrition, and Disease in Prehistoric Coastal Brazil. *In The Backbone of History: Health and Nutrition in the Western Hemisphere*, edited by Richard G. Steckel and Jerome Rose, pp.376-400. Cambridge University Press, United Kingdom.
- Nitsch, Erika K., Louise T. Humphrey, and Robert E. M. Hedges
 2011 Using Stable Isotope Analysis to Examine the Effect of Economic Change on Breastfeeding Practices in Spitalfields, London, UK. *American Journal of Physical Anthropology* 146: 619-628.
- O'Brien, Michael J.
 1987 Sedentism, Population Growth, and Resource Selection in the Woodland Midwest: A Review of Coevolutionary Developments. *Current Anthropology* 28: 177-197.
- O'Leary, Marion H.
 1981 Carbon Isotope Fractionation in Plants. *Phytochemistry* 20 (4): 553-567.
- Okumura, Mercedes
 2013 Populações Sambaquianas Costeiras: Saúde e Afinidades Biológicas dentro de um Contexto Geográfico e Temporal. *Tempos Acadêmicos* 11: 38-53.
- Okumura, M.M.M., and S. Eggers
 2005 The People of Jabuticabeira II: Reconstruction of the Way of Life in a Brazilian Shellmound. *HOMO—Journal of Comparative Human Biology* 55: 263-281.
- Olsen, Kenneth M. and Barbara A. Schaal
 2001 Microsatellite Variation in Cassava (*Manihot Esculenta*, Euphorbiaceae) and Its Wild Relatives: Further Evidence for a Southern Amazonian Origin of Domestication. *American Journal of Botany* 88 (1): 131-142.
- Organ, Jason M., Mark F. Teaford, and Clark Spencer Larsen
 2005 Dietary Inferences from Dental Occlusal Microwear at Mission San Luis de Apalachee. *American Journal of Physical Anthropology* 128: 801-811.
- Organ, Jason M., Christopher B. Ruff, Mark F. Teaford, and Richard A. Nisbett
 2006 Do Mandibular Cross-Sectional Properties and Dental Microwear Give Similar Dietary Signals? *American Journal of Physical Anthropology* 130 (4): 501-507.

Oyuela-Caycedo, Augusto

1995 Rock Versus Clay: The Evolution of Pottery Technology in the Case of San Jacinto I, Colombia. In *The Emergence of Pottery: Technology and Innovation in Ancient Societies*, edited by William K. Barnett and John W. Hoopes, pp. 133-144. Smithsonian Institution Press, Washington, D.C.

Papathanasiou, Anastasia, Clark Spencer Larsen, and Lynette Norr

2000 Bioarchaeological Inferences From a Neolithic Ossuary From Alepotrypa Cave, Diros, Greece. *International Journal of Osteoarchaeology* 10: 210-228.

Pearson, J.A., R.E.M. Hedges, T.I. Molleson, and M. Ozbek.

2010 Exploring the Relationship Between Weaning and Infant Mortality: An Isotope Case Study from Asikli Hoyuk and CayonuTepesi. *American Journal of Physical Anthropology* 143: 448-457.

Perlman, Stephen M.

1980 An Optimum Diet Model, Coastal Variability, and Hunter-Gatherer Behavior. *Advances in Archaeological Method and Theory* 3: 257-310.

Puech, Pierre-François, and Henri Albertini

1984 Dental Microwear and Mechanisms in Early Hominids from Laetoli and Hadar. *American Journal of Physical Anthropology* 65 (1): 87-91.

Piazza, Walter

1974 Dados sobre a Arqueologia do Litoral Norte e do Planalto de Camboinhas. *Publicações Avulsas* 26: 53-66.

Piperno, Dolores R. and Irene Holst

1998 The Presence of Starch Grains on Prehistoric Stone Tools from the Humid Neotropics: Indications of Early Tuber Use and Agriculture in Panama. *Journal of Archaeological Science* 25: 765-776.

Piperno, Dolores R.

2003 A Few Kernels Short of a Cob: On the Staller and Thompson Late Entry Scenario for the Introduction of Maize into Northern South America. *Journal of Archaeological Science* 30: 831-836.

Pontzer, Herman, Jessica R. Scott, David Lordkipanidze, and Peter S. Ungar

2011 Dental Microwear Texture Analysis and Diet in the Dmanisi Hominins. *Journal of Human Evolution* 61: 683-687.

- Porcasi, Judith F., and Harumi Fujita
2000 The Dolphin Hunters: A Specialized Prehistoric Maritime Adaptation in the Southern California Channel Islands and Baja California. *American Antiquity* 65 (3): 543-566.
- Pratt, Jo Ann F.
1999 Determining the Function of One of the New World's Earliest Pottery Assemblages: The Case of San Jacinto, Colombia. *Latin American Antiquity* 10 (1): 71-85.
- Price, T. Douglas, and James A. Brown
1985 Aspects of Hunter-Gatherer Complexity. In *Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity*, edited by T. Douglas Price and James A. Brown, pp. 427-442. Academic Press, San Diego.
- Privat, Karen L., and Tamsin C. O'Connell
2002 Stable Isotope Analysis of Human and Faunal Remains from the Anglo-Saxon Cemetery at Berinsfield, Oxfordshire: Dietary and Social Implications. *Journal of Archaeological Science* 29: 779-790.
- Prous, André
1991 *Arqueologia Brasileira*. Editora Universidade de Brasília, Brasília.
- Rafferty, K.L., M.F. Teaford, and W.L. Jungers
2002 Molar Microwear of Subfossil Lemurs: Improving the Resolution of Dietary Inferences. *Journal of Human Evolution* 43: 645-657.
- Reid, Kenneth C.
1989 A Materials Science Perspective on Hunter-Gatherer Pottery. In *Pottery Technology: Ideas and Approaches*, edited by Gordon Bronitsky, pp. 167-180. Westview Press, Boulder.
- Rice, Prudence M.
1999 On the Origins of Pottery. *Journal of Archaeological Method and Theory* 6 (1): 1-54.
- Renouf, M. A. P.
1984 Northern Coastal Hunter-Fishers: An Archaeological Model. *World Archaeology* 16 (1): 18-27.
- Rick, Torben C., Jon M. Erlandson, René L. Vellanoweth, and Todd J. Braje
2005 From Pleistocene Mariners to Complex Hunter-Gatherers: The Archaeology of the California Channel Islands. *Journal of World Prehistory* 19: 169-228.

Rodrigues, Claudia Duarte

1997 *Patologias e Processos Dento-Maxilares em Remanescentes Esqueléticos de Dois Sítios Pré-Históricos no Brasil: O Cemitério de Furna do Estrago (PE) e O Sambaqui de Cabeçuda (SC)*. Ph. D. Dissertation, National School of Health, Department of Public Health, Institute of Oswaldo Cruz, Rio de Janeiro.

Rose, Jerome C., and Peter S. Ungar

1998 Gross Dental Wear and Dental Microwear in *Historical Perspective*. In *Dental Anthropology: Fundamentals, Limits, Perspectives*, edited by Kurt W. Alt, Friedrich W. Rosing, and Maria Teschler-Nicola, pp. 349-386. Gustav Fischer Publishers, Stuttgart.

Rose, J.C., M.K. Marks, and L.L. Tieszen

1991 Bioarchaeology and Subsistence in the Central and Lower Portions of the Mississippi Valley. In *What Mean These Bones? Studies in Southeastern Bioarchaeology*, edited by M.L. Powell, P.S. Bridges, and A.M.W. Mires, pp. 7-21. University of Alabama Press, Tuscaloosa.

Sassaman, Kenneth E.

1993 *Early pottery in the Southeast: Tradition and innovation in cooking technology*. University of Alabama Press, Tuscaloosa.

Sassaman, Kenneth E.

1995 The Social Contradictions of Traditional and Innovative Cooking Technologies in the Prehistoric American Southeast. In *The Emergence of Pottery: Technology and Innovation in Ancient Societies*, edited by William K. Barnett and John W. Hoopes, pp. 223-239. Smithsonian Institution Press, Washington, D.C.

Sassaman, Kenneth E.

2004 Complex Hunter-Gatherers in Evolution and History: A North American Perspective. *Journal of Archaeological Research* 12: 227-280.

Scheel-Ybert, Rita

2000 Vegetation Stability in the Southeastern Brazilian Coastal Area from 5500 to 1400 ¹⁴C yr BP Deduced from Charcoal Analysis. *Review of Palaeobotany and Palynology* 110 (1-2): 111-138.

Scheel-Ybert, Rita

2001 Man and Vegetation in Southeastern Brazil during the Late Holocene. *Journal of Archaeological Science* 28 (5): 471-480.

Scheinsohn, Vivian

2003 Hunter-Gatherer Archaeology in South America. *Annual Review of Anthropology* 32: 339-361.

- Schmidt, Christopher W.
2001 Dental Microwear Evidence for a Dietary Shift Between Two Nonmaize-Reliant Prehistoric Human Populations from Indiana. *American Journal of Physical Anthropology* 114: 139-145.
- Schmitz, Pedro Ignácio, Ivone Verardi, Marco Aurélio Nadal de Masi, Jairo Henrique Rogge, and André Luiz Jacobus
1993 *Escavações Arqueológicas do Pe. João Alfredo Rohr, S. J. Escavações da Praia das Laranjeiras II. Uma Aldeia da Tradição Ceramista Itataré. Antropologia* No. 49, Instituto Anchieta de Pesquisas, São Leopoldo, Brasil.
- Schmitz, Pedro Ignácio
1999 Arqueologia do Planalto Sul-Brasileiro. *Revista de Arqueologia Americana* 17: 51-74.
- Schoeniger, Margaret J. and Michael J. De Niro
1983 Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science* 220: 1381-1383.
- Schoeninger, Margaret J. and Michael J. De Niro
1984 Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica Acta* 48: 625-639.
- Schoeninger, Margaret J.
2009 Stable Isotope Evidence for the Adoption of Maize Agriculture. *Current Anthropology* 50 (5): 633-640.
- Schubert, B.W., P.S. Ungar, and L.R.G. DeSantis
2010 Carnassial Microwear and Dietary Behaviour in Large Carnivorans. *Journal of Zoology* 280: 257-263.
- Schulz, Ellen, Ivan Calandra, and Thomas M. Kaiser
2010 Applying Tribology to Teeth and Hoofed Mammals. *Scanning* 32: 162-182.
- Schurr, Mark R.
1997 Stable Nitrogen Isotopes as Evidence for the Age of Weaning at the Angel Site: A Comparison of Isotopic and Demographic Measures of Weaning Age. *Journal of Archaeological Science* 24: 919-927.
- Schurr, Mark R. and Mary Lucas Powell
2005 The Role of Changing Childhood Diets in the Prehistoric Evolution of Food Production: An Isotopic Assessment. *American Journal of Physical Anthropology* 126: 278-294.

- Schwarcz, Henry P., Jerry Melbye, M. Anne Katzenberg, and Martin Knyf
 1985 Stable Isotopes in Human Skeletons of Southern Ontario: Reconstructing Paleodiet. *Journal of Archaeological Science* 12: 187-206.
- Schwarcz, Henry P. and Margaret J. Schoeninger
 1991 Stable Isotope Analyses in Human Nutritional Ecology. *Yearbook of Physical Anthropology* 34: 283-321.
- Schwarcz, Henry P., Tosha L. Dupras, and Scott I. Fairgrieve
 1999 ¹⁵N Enrichment in the Sahara: In Search of a Global Relationship. *Journal of Archaeological Science* 26: 629-636.
- Scott, Robert S., Peter S. Ungar, Torbjorn S. Borgstrom, Christopher A. Brown, Frederick E. Grine, Mark F. Teaford, and Alan Walker
 2005 Dental Microwear Texture Analysis Shows Within-Species Diet Variability in Fossil Hominins. *Nature* 436(4): 693-695.
- Scott, Robert S., Peter S. Ungar, Torbjorn S. Bergstrom, Christopher A. Brown, Benjamin E. Childs, Mark F. Teaford, and Alan Walker
 2006 Dental Microwear Texture Analysis: Technical Considerations. *Journal of Human Evolution* 51: 339-349.
- Scott, J.R., L.R. Godfrey, W.L. Jungers, R.S. Scott, E.L. Simons, M.F. Teaford, P.S. Ungar, and A. Walker
 2009 Dental Microwear Texture Analysis of Two Families of Subfossil Lemurs from Madagascar. *Journal of Human Evolution* 56: 405-416.
- Scott, Robert S., Mark F. Teaford, and Peter S. Ungar
 2012 Dental Microwear Texture and Anthropoid Diets. *American Journal of Physical Anthropology* 147: 551-579.
- Service, Elman, R.
 1975 *The Origins of the State and Civilization*. W.W. Norton & Co., New York.
- Sillen, Andrew, Judith C. Sealy, and Nikolaas J. van der Merwe
 1989 Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity* 54 (3): 504-512.
- Silva, Sérgio Baptista, Pedro Ignácio Schmitz, Jairo Henrique Rogge, Marco Aurélio de Masi, and André Luiz Jacobus
 1990 *Escavações Arqueológicas do Pe. João Alfredo Rohr, S. J. O Sítio Arqueológico da Praia da Tapera: Um Assentamento Itataré e Tupiguarani*. *Antropologia* No. 45, Instituto Anchieta de Pesquisas, São Leopoldo.

- Smith, B. Holly
 1984 Patterns in Molar Wear in Hunter-Gatherers and Agriculturalists. *American Journal of Physical Anthropology* 63: 39-56.
- Sponheimer, M., T. Robinson, L. Ayliffe, B. Roeder, J. Hammer, B. Passey, A. West, T. Cerling, D. Dearing, and J. Ehleringer
 2003 Nitrogen Isotopes in Mammalian Herbivores: Hair $\delta^{15}\text{N}$ Values from a Controlled Feeding Study. *International Journal of Osteoarchaeology* 13: 80-87.
- Staller, John E. and Robert G. Thompson
 2002 A Multidisciplinary Approach to Understanding the Initial Introduction of Maize into Coastal Ecuador. *Journal of Archaeological Science* 29: 33-50.
- Staller, John E.
 2003 An Examination of the Palaeobotanical and Chronological Evidence for an Early Introduction of Maize (*Zea mays* L.) into South America: A Response to Pearsall. *Journal of Archaeological Science* 30: 373-380.
- Suguio, Kenitiro, M.L. Absy, J.M. Flexor, M.P. Ledru, L. Martin, A. Sifeddine, F. Soubiès, B. Turcq, and J.P. Ybert
 1993 The Evolution of the Continental and Coastal Environments During the Last Climatic Cycle in Brazil (120 Ky. B.P. to Present). *Boletim IG-USP, Série Científica*. 24: 27-41.
- Sullivan, Charles H. and Harold W. Krueger
 1981 Carbon Isotope Analysis of Separate Chemical Phases in Modern and Fossil Bone. *Nature* 292: 333-335.
- Teaford, Mark F.
 1985 Molar Microwear and Diet in the Genus *Cebus*. *American Journal of Physical Anthropology* 66: 363-370.
- Teaford, Mark F.
 1988a A Review of Dental Microwear and Diet in Modern Animals. *Scanning Microscopy* 2: 1149-1166.
- Teaford, Mark F.
 1988b Scanning Electron Microscope Diagnosis of Wear Patterns Versus Artifacts Fossil Teeth. *Scanning Microscopy* 2: 1167-1175.
- Teaford, Mark F.
 1994 Dental Microwear and Dental Function. *Evolutionary Anthropology* 3 (1): 17-30.

- Teaford, Mark F., and Alan Walker
1984 Quantitative Differences in Dental Microwear Between Primate Species with Different Diets and a Comment on the Presumed Diet of Sivapithecus. *American Journal of Physical Anthropology* 64 (2): 191-200.
- Teaford, Mark F., and Ordean J. Oyen
1989 In Vivo and In Vitro Turnover in Dental Microwear. *American Journal of Physical Anthropology* 80 (4): 447-460.
- Teaford, Mark F., and Kenneth E. Glander
1991 Dental Microwear in Live, Wild-Trapped *Alouatta palliata* from Costa Rica. *American Journal of Physical Anthropology* 85 (3): 313-319.
- Teaford, Mark F., and James D. Lytle
1996 Brief Communication: Diet-Induced Changes in Rates of Human Tooth Microwear: A Case Study Involving Stone-Ground Maize. *American Journal of Physical Anthropology* 100: 143-147.
- Teaford, Mark F., and Peter S. Ungar
2000 Diet and the Evolution of the Earliest Human Ancestors. *Proceedings of the National Academy of Sciences* 97: 13506-13511.
- Tenório, Maria Cristina
1998 Abandonment of Brazilian Coastal Sites: Why Leave Eden? In *Explorations in American Archaeology: Essays in Honor of Wesley R. Hurt*, edited by Mark G. Plew, pp. 221-257. University Press of America.
- Testart, Alain
1982 The Significance of Food Storage Among Hunter-Gatherers: Residence Patterns, Population Densities, and Social Inequalities. *Current Anthropology* 23 (5): 523-537.
- Tiburtius, Guilherme, Alsedo Leprevost, and João José Bigarella
1949 Sobre a Ocorrência de Bula Timpânica de Baleia e Artefatos Derivados nos Sambaquis dos Estados do Paraná e Santa Catarina. *Arquivos de Biologia e Tecnologia* 4: 87-93.
- Tiburtius, Guilherme, and Iris Koehler Bigarella
1953 Nota sobre os Anzóis de Osso da Jazida Paleo-Etnográfica de Itacoara, Santa Catarina. *Revista do Museu Paulista* 7: 381-387.

- Tieszen, Larry L.
1991 Natural Variations in the Carbon Isotope Values of Plants: Implications for Archaeology, Ecology, and Paleoecology. *Journal of Archaeological Science* 18: 227-248.
- Tieszen, Larry L. and Tim Fagre
1993 Effect of Diet Quality and Composition on the Isotopic Composition of Respiratory CO₂, Bone Collagen, Bioapatite, and Soft Tissues. In *Prehistoric Human Bone: Archaeology at the Molecular Level*, edited by Joseph B. Lambert and Gisela Grupe, pp. 121-155. Springer-Verlage, New York.
- Tomczak, Paula D.
2003 Prehistoric Diet and Socioeconomic Relationships Within the Osmore Valley of Southern Peru. *Journal of Anthropological Archaeology* 22: 262-278.
- Turner II, Christy G. and Lilia M. Cheuiche Machado
1983 A New Dental Wear Pattern and Evidence for High Carbohydrate Consumption in a Brazilian Archaic Skeletal Population. *American Journal of Physical Anthropology* 61: 125-130.
- Tykot, Robert H.
2006 Isotope Analyses and the Histories of Maize. In *Histories of Maize: Multidisciplinary Approaches to the Prehistory, Linguistics, Biogeography, Domestication, and Evolution of Maize*, edited by John Staller, Robert Tykot, and Bruce Benz, pp.131-142. Academic Press.
- Ubelaker, D. H., M.A. Katzenberg, and L. G. Doyon
1995 Status and Diet in Precontact Highland Ecuador. *American Journal of Physical Anthropology* 97: 403-411.
- Ungar, Peter S.
1996 Dental Microwear of European Miocene Catarrhines: Evidence for Diets and Tooth Use. *Journal of Human Evolution* 31: 335-366.
- Ungar, Peter S.
2001 *Microware 4.0. A Semiautomated Image Analysis Procedure for the Quantification of Dental Microwear* (privately published). Fayetteville, AR.
- Ungar, Peter
2004 Dental Topography and Diets of *Australopithecus afarensis* and early *Homo*. *Journal of Human Evolution* 46: 605-622.

- Ungar, Peter S., Mark F. Teaford, Kenneth E. Glander, and Robert F. Pastor
 1995 Dust Accumulation in the Canopy: A Potential Cause of Dental Microwear in Primates. *American Journal of Physical Anthropology* 97 (2): 93-99.
- Ungar, Peter S., and Mark A. Spencer
 1999 Incisor Microwear, Diet, and Tooth Use in Three Amerindian Populations. *American Journal of Physical Anthropology* 109: 387-396.
- Ungar, Peter, and Malcolm Williamson
 2000 Exploring the Effects of Tooth Wear on Functional Morphology: A Preliminary Study Using Dental Topographic Analysis. *Palaeontologia Electronica* 3 (1): 1-18.
- Ungar, Peter S., Christopher A. Brown, Torbjorn S. Bergstrom, and Alan Walker
 2003 Quantification of Dental Microwear by Tandem Scanning Confocal Microscopy and Scale-Sensitive Fractal Analyses. *Scanning* 25 (4): 185-193.
- Ungar, Peter S., Frederick E. Grine, and Mark F. Teaford
 2008 Dental Microwear and Diet of the Plio-Pleistocene Hominin *Paranthropus boisei*. *PLoS ONE* 3 (4): 1-6.
- Ungar, Peter S., Robert S. Scott, Frederick E. Grine, and Mark F. Teaford
 2010 Molar Microwear Textures and the Diets of *Australopithecus anamensis* and *Australopithecus afarensis*. *Philosophical Transactions of the Royal Society* 365: 3345-3354.
- Ungar, Peter S., Kristin L. Krueger, Robert J. Blumenshine, Jackson Njau, and Robert S. Scott
 2012 Dental Microwear Texture Analysis of Hominins Recovered by the Olduvai Landscape Paleoanthropology Project, 1995-2007. *Journal of Human Evolution* 63: 429-437.
- van der Merwe, Nikolaas J., and Ernesto Medina
 1989 Photosynthesis and $^{13}\text{C}/^{12}\text{C}$ Ratios in Amazonian Rain Forests. *Geochimica et Cosmochimica Acta* 53 (5): 1091-1094.
- van der Merwe, Nikolaas J., and Ernesto Medina
 1991 The Canopy Effect, Carbon Isotope Ratios and Foodwebs in Amazonia. *Journal of Archaeological Science* 18 (3): 249-259.
- van Klinken, G, J.
 1999 Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26: 687-695.

- Vogel, J. C. and Nikolaas J. van der Merwe
 1977 Isotopic Evidence for Early Maize Cultivation in New York State. *American Antiquity* 42 (2): 238-242.
- Wagner, Gustavo, Klaus Hilbert, Dione Bandeira, Maria Cristina Tenório, and Maria Mercedes Okumura
 2011 Sambaquis (shell mounds) of the Brazilian Coast. *Quaternary International* 239: 51-60.
- Walker, P.L.
 1976 Wear Striations on the Incisors of Cercopithecoid Monkeys as an Index of Diet and Habitat Preference. *American Journal of Physical Anthropology* 45: 299-308.
- Walker, Philip L. and Michael J. De Niro
 1986 Stable Nitrogen and Carbon Isotope Ratios in Bone Collagen as Indices of Prehistoric Dietary Dependence on Marine and Terrestrial Resources in Southern California. *American Journal of Physical Anthropology* 71: 51-61.
- Walker, Philip L. and E.H. Hagen
 1994 A Topographical Approach to Dental Microwear Analysis. *American Journal of Physical Anthropology Supplemental* 18: 200.
- Walker, Alan, Hendrick N. Hoeck, and Linda Perez
 1978 Microwear of Mammalian Teeth as an Indicator of Diet. *Science* 201: 908-910.
- Walker, Alan, and Mark Teaford
 1989 Inferences from Quantitative Analysis of Dental Microwear. *Folia Primatologica* 53 (1-4): 177-189.
- Warinner, Christina, and Noreen Tuross
 2009 Alkaline Cooking and Stable Isotope Tissue-Diet Spacing in Swine: Archaeological Implications. *Journal of Archaeological Science* 36 (8): 1690-1697.
- Weselowski, Verônica
 2008 Cáries, Desgaste, Cálculos Dentários e Micro-Resíduos da Dieta entre Grupos Pré-Históricos do Litoral Norte de Santa Catarina: É Possível Comer Amido e Não Ter Cárie? *Revista de Arqueologia* 21: 157-159.
- Weselowski, Verônica, Sheila Maria Ferraz Mendonça de Souza, Karl J. Reinhard, and Gregório Ceccantini
 2010 Evaluating Microfossil Content of Dental Calculus from Brazilian Sambaquis. *Journal of Archaeological Science* 37: 1326-1338.

- White, Christine D., Paul F. Healy, and Henry P. Schwarcz
 1993 Intensive Agriculture, Social Status, and Maya Diet at Pacbitun, Belize. *Journal of Anthropological Research* 49 (4): 347-375.
- White, Christine D., and George J. Armelagos
 1997 Osteopenia and Stable Isotope Ratios in Bone Collagen of Nubian Female Mummies. *American Journal of Physical Anthropology* 103 (2): 185-199.
- White, Christine D., David M. Pendergast, Fred J. Longstaffe, and Kimberley R. Law
 2001 Social Complexity and Food Systems at Altun Ha, Belize: The Isotopic Evidence. *Latin American Antiquity* 12 (4): 371-393.
- Willey, Gordon Randolph
 1966 *An Introduction to American Archaeology*. Prentice-Hall: Englewood Cliffs, New Jersey.
- Wood, James W., George R. Milner, Henry C. Harpending, Kenneth M. Weiss, et al.
 1992 The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples. *Current Anthropology* 33 (4): 343-370.
- Wright, Lori E. and Henry P. Schwarcz
 1996 Infrared and Isotopic Evidence for Diagenesis of Bone Apatite and Dos Pilas, Guatemala: Paleodietary Implications. *Journal of Archaeological Science* 23: 933-944.
- Wright, Lori E. and Henry P. Schwarcz
 1998 Stable Carbon and Oxygen Isotopes in Human Tooth Enamel: Identifying Breastfeeding and Weaning in Prehistory. *American Journal of Physical Anthropology* 106: 1-18.
- Wright, Lori E. and Henry P. Schwarcz
 1999 Correspondence Between Stable Carbon Oxygen and Nitrogen Isotopes in Human Tooth Enamel and Dentine: Infant Diets and Kaminaljuyu. *Journal of Archaeological Science* 26 (9): 1159-1170.
- Wright, Lori E., and Christine D. White
 1996 Human Biology in the Classic Maya Collapse: Evidence from Paleopathology and Paleodiet. *Journal of World Prehistory* 10 (2): 147-198.
- Ybert, Jean-Pierre, Walter Mareschi Bissa, Eduardo Luís Martins Catharino, and Miryam Kutner
 2003 Environmental and Sea-Level Variations on the Southeastern Brazilian Coast during the Late Holocene with Comments on Prehistoric Human Occupation. *Palaeogeography, Palaeoclimatology, Palaeoecology* 189 (1-2): 11-24.

- Yesner, David R.
1980 Maritime Hunter-Gatherers: Ecology and Prehistory. *Current Anthropology* 21: 727-750.
- Yesner, David R.
1984 Population Pressure in Coastal Environments: An Archaeological Test. *World Archaeology* 16 (1): 108-127.
- Yesner, David R., Maria Jose Figuerero Torres, Ricardo A. Guichon, and Luis A. Borrero
2003 Stable Isotope Analysis of Human Bone and Ethnohistoric Subsistence Patterns in Tierra del Fuego. *Journal of Anthropological Archaeology* 22: 279-291.
- Yoder, Cassady J.
2012 Let Them Eat Cake? Status-Based Differences in Diet in Medieval Denmark. *Journal of Archaeological Science* 39: 1183-1193.
- Zuccotti, Flynn L., Malcolm D. Williamson, W. Frederick Limp, and Peter S. Ungar
1998 Modeling Primate Occlusal Topography Using Geographic Information Systems Technology. *American Journal of Physical Anthropology* 107: 137-142.