INVESTIGATIONS OF MICRO- AND MACROSCOPIC DENTAL DEFECTS IN PRE-HISPANIC MAYA CAVE AND ROCKSHELTER BURIALS IN CENTRAL BELIZE

By

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ABSTRACT

INVESTIGATIONS OF MICRO- AND MACROSCOPIC DENTAL DEFECTS IN PRE-HISPANIC MAYA CAVE AND ROCKSHELTER BURIALS IN CENTRAL BELIZE

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This dissertation utilizes indicators of childhood growth disruptions in the form of micro- and macroscopic dental defects to test questions aimed at defining aspects of social and economic organization of Classic period (AD 250 – 900) Maya populations in west-central Belize. The variations found in dental health data may be understood as reflecting a complex interaction of two general sets of influences: cultural and methodological. First, analyses of biological data were used to elucidate the nature and meaning of different burial locations that help to clarify ongoing questions about the usage of these spaces and the social identity of those individuals buried within. Second, methodologically, the biological data were used to bolster previous studies of the dental microstructure and to identify problems with (and resolutions for) histological imaging and techniques.

Investigations focused primarily on dental samples derived from dark-zone cave and rockshelter sites in west-central Belize, which contain extensive evidence of diverse mortuary rituals. Additionally, comparative samples from two civic ceremonial urban centers (Pacbitun, Belize and Tikal, Guatemala) were included. The nature and meaning of mortuary cave ritual among the Maya is still widely debated, and previous interpretations of variability have focused on ethnic affiliation, social class, mortuary processes, and sacrifice. Recent investigations of cave and rockshelter sites in west-central Belize have utilized an identity approach for understanding patterns of mortuary variability among sites. Data from age and sex distributions, dental and cranial modifications, and reconstructions of mortuary pathways have helped define the nature

and meaning of cave use. In general, these studies have shown that rockshelters appear to have been utilized by rural, non-elite agricultural communities, while dark zone caves often show more diversity and mortuary elaboration, as well as evidence of restricted access, suggesting use by higher-status social groups.

This dissertation contributes to the ongoing study of mortuary variability in west-central Belize by elucidating patterns of defect formation frequency between site types, age of defect formation between site types, and sex differences in defect formation to answer anthropological questions about differential health experience between individuals buried in caves, rockshelters, and surface sites. Health status is frequently used as a proxy for social status, though there are many more interesting interpretations to be made from these data, which are expanded upon in this dissertation study. Three tooth classes (maxillary central incisors, mandibular canines, and third molars) were assessed for dental defects (caries, enamel hypoplasias, and Wilson bands) in a sample of individuals distinguished in death by their burial locations. The sample size for this dissertation (n=176; 64 teeth from caves, 39 teeth from rockshelters, 73 teeth from surface sites representing a total of 110 individuals) can be considered large for a dental histology study. Results comparing the formation of macrodefects were variable, with one surface site significantly less affected than the cave and rockshelter sites. In contrast, there were generally no significant differences in age at microdefect formation between the sites. The results of this study underscore the premise that, while distinct in burial location, individuals interred in caves and rockshelters did not have significantly poorer health experiences than those persons buried at surface sites. While it may be tempting to suggest that these results indicate no social differences between burial groups, it is clear that biases introduced from sampling and current methodologies may partially obscure such patterns.

For Mommy Dot and Tadpole – I love you both forever.
For my friends – I cannot wait to see what you do with your lives.
"Keep your faith in the path that's growing narrow." – MLIW

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I think I am supposed to keep this part short. I cannot; I simply know too many inspiring and important people and I hope this manuscript reaches them all.

I did not find Anthropology until I was 21 when I was well into a reckless and directionless youth. I took a gen-ed Anthropology course after scanning class listings at the last possible second of the enrollment period. I nearly failed. In my second course, Introduction to Prehistory, I received a C-. The third Anthropology course I took was Introduction to Physical Anthropology where the professor, Dr. Robert Franciscus, told the class that race did not exist and showed us pictures of fossil hominid casts. I was blown away. Four years earlier, I was sitting in a (public!) high school with an all-white student body and teachers that refused to teach us about evolution and gave us extra credit if we went to church events. I knew there was something wrong, but I did not have the words or framework or critical thinking skills to articulate what I felt. Anthropology gave that to me. Being an anthropology student provided some much needed structure to my life. Through anthropology, I started to care about learning, my future, and most importantly, other people. I will never forget that Dr. Franciscus took a chance on me after I worked up the courage to ask him for a meeting. When he easily could have dismissed me because of my grades, he instead offered to let me work in the University of Iowa Paleoanthropology Lab and he lobbied to get me into the Honors Program even though my grades were so far below average. Here, finally, I was not judged on past failures but rather my present and future contributions. This was an extension of kindness that I will carry forever.

My graduate committee has continued this theme of acceptance, always treating me like I had something valuable to offer. I think the importance of having that feeling as a graduate student

cannot be understated – it shored up my tenacity and buoyed me through the sometimes very dark personal setbacks I had during my time at Michigan State. I came to MSU as a curious and enthusiastic student, but I was unfocused and under-educated. My committee, as well as the other professors and graduate students at MSU, made me an anthropologist.

Dr. Gabriel Wrobel met with me in 2009 and offered me the chance to go to Belize. I walked out of the office thinking that would be exciting, but never believing it would shape my future. Thank you, Gabe, for being a supportive and fun advisor who I can shoot "nerd lightning" with. Your belief in, and excitement about, this project has been instrumental in getting it done. Thank you for introducing me to a part of the world I never dreamed I would work in and, even more importantly, for allowing me to find my own stride as a researcher. I have learned so much from you. I appreciate it all.

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Dr. Bill Lovis provided some much needed humor, guidance, and lab access during the data collection and analysis process. Dr. Lovis may not admit this, but he also gave me the (highly appropriate) working subtitle for this dissertation: "Desperately Seeking Science." Thank you, rogue professor!

Dr. Shawn Morton, my friend, I am proud to say that I follow you in this CBAS-oriented dissertation. Thank you for all the laughs in the field. I will always admire your brain (but never your taste in music). Hand hug me!

I have four wonderful parents. My mom and dad gave me one of the greatest gifts I have ever known: stability. They never made me feel anything less than completely safe. I have never questioned my value to them or their love for me, and I think that speaks to just what truly exceptional and selfless people they are. Juliann Lee Matthews and William David Michael, you are my heroes. When my parents could have ostracized me or criticized me during my youth, they chose not to – in fact, they always, *always* chose kindness. That is true unconditional support.

Thank you to my step-parents and my close family. I realize that I have an exceptional family, one that did not put pressure on me to ever "make something" of myself (though I am sure you're all happy I gave it a shot). My family always celebrated my accomplishments with

the proper amount of "good job!" and "we do not understand it, but we are proud of you!" sentiments. I appreciate their ability to let me be who I needed to be at every point in my life, whether that was blue haired vagabond or grad school hermit. I know that I am a restless ghost sometimes, but my family always took my calls from the road in stride ("Wait…you are going where?!"). Thank you all for being the kind of people that appreciated the workload that comes along with graduate school and for never making me feel guilty. I completed this dissertation not *for* you, because I am proud to say that you all encouraged me to achieve this for myself. I am so lucky.

No words could ever come close to approximating what David Stepanavicius has done for me. Thank you for giving me a second wind when I needed it most to finish this degree. I hope this finished product makes you proud too.

My Grandma and Grandpa Mike made me a reader and a writer. I may not have been really fast or really good at much of anything growing up, but I am 100% curious about the world and I owe it to my grandparents for fostering that in me. Thank you both for my first typewriter and the never-ending mountain of books you supplied me. I wish I could deliver this dissertation to you in person. I miss you both so much. We will meet again someday.

I cannot express how grateful I am to my graduate school friends for never succumbing to this competitive academic world. Study sessions in coffee shops, endless "why do we do this?" conversations that terminate in new ideas for research ("oh yeah, that is why we do this!"), late nights in labs, harried texts asking for favors, laughs and tears over Woody's and Pablo's, "cool ppl", scrounging for vegan food in the field, disgusting "would you rather" sessions, watching bad reality TV on a laptop during study breaks, Sparty-sized diet soda breaks, sitting around the table in McDonel, kicking bags in taekwondo – these moments have saved me from

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Dr. Marie Danforth allowed me access to her Tikal samples and was kind enough to offer me tutorials on data collection. Dr. Melinda Frame was integral in helping to set up and calibrate the microscope used in during data collection. Dr. Paul Healy allowed me access to the Pacbitun collections at Trent University. Dr. Terry Powis approved my proposal to study the remains from

Pacbitun. The Institute of Archaeology in Belize allowed me access to the dental remains analyzed in this dissertation. Dr. Maria Teresa Tersigni-Tarrant taught me about histology and encouraged me to pursue this sub-sub-field. The past and present MSU graduate secretaries, Nancy Smith and Joan Reid, were kept me on track with the bureaucratic side of things and I thank them both for their attention to detail and timely response to questions.

This dissertation research would not have been possible with the generous funding of the Center for Gender in Global Context (MSU), the Caves Research Foundation, the Center for Latin American and Caribbean Studies (MSU), and the MSU Anthropology Department. I would also add that Dr. Lynne Goldstein and Dr. Renate Snider were instrumental in keeping me employed so that I could stop worrying about paying bills and, instead, focus on my dissertation work.

Agatha Christie Mallowan's words bounce around in my head every time I am fortunate enough to do archaeology: "It is the question, too, that Archaeology asks of the Past – Come, tell me how you lived*?"* Doing archaeological work is such a privilege. I aim to always view it as such and to take the responsibility to tell one version of the story of the past very seriously. I would be remiss not to acknowledge the prehistoric peoples who constituted what we term The Maya. Much gratitude goes toward the ancestors and descendants. Far removed from me in culture, time, and space, I am still humbled by the Maya and the world they built. We may never be able to know the specifics of their reality, but the process of trying to figure it out is so fulfilling. To paraphrase something I was once told, "science is not necessarily right – it is the successive and incremental reduction of the unknown." In this dissertation I hope I have erased just a small bit more of the unknown.

Finally, in Tristes Tropiques, Claude Levi-Strauss wrote something that has always stuck with me as the calendar years tick by and anthropology remains a constant in my life: "Anthropology affords me intellectual satisfaction: as a form of history, linking up at opposite ends with world history and my own history, it thus reveals the rationale common to both. In proposing the study of mankind, anthropology frees me from doubt, since it examines those differences and changes in mankind which have a meaning for all men, and excludes those peculiar to a single civilization, which dissolve into nothingness in the gaze of the outside observer. *Lastly, it appeases that restless and destructive appetite which I have already referred to, by assuring me a virtually inexhaustible supply of material, thanks to the diversity of manners, customs, and institutions. It allows me to reconcile my character with my life*." (italics my own)

Sic transit Gloria Mundi. I am grateful for this entire journey. On to the next.

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CHAPTER 1: INTRODUCTION TO THE STUDY

This research project examined dental indicators of childhood health evident in the teeth of pre-Hispanic Maya burial populations from west-central Belize and the civic ceremonial center of Tikal in western Guatemala. Using microscopic and macroscopic methods, three tooth classes (mandibular canines, maxillary and mandibular third molars, and maxillary central incisors) were assessed for dental defects indicating developmental disruptions in a sample of individuals distinguished in death by their burials at three site types: caves, rockshelters, and surface sites. The selected teeth form during early childhood and adolescence allowing for the analysis of a range of ages per individual. The study of permanent adult teeth, which are generally resistant to taphonomic modification, from the mortuary record of past populations allows bioarchaeologists to answer questions related to childhood even when subadult skeletal remains are unavailable for study due to poor preservation. Because the human dentition develops on a regular chronological schedule, dental pathologies can be linked to particular ages at formation.

Dental indicators of childhood health are frequently used by bioarchaeologists to understand health experience during life, but these data can also be used to interpret biological differences between and among burial populations. Skeletal remains are often poorly or differentially preserved throughout the tropical environment of Central America, but teeth withstand the taphonomic conditions and have historically been used in large studies of Maya bioarchaeology (Buikstra 2006; Cucina and Tiesler 2003; Cucina 2015; Danforth 1989; Jacobi 2000; Wright 1993; Wrobel 2004). Variations in health indicators in the Maya area can illustrate differences in health experience that may be linked to larger social, political, and economic factors that distinguish particular regions or ethnic groups.

Dental histology, the microscopic study of the dental tissues, is particularly well-suited to the study of health in past populations because teeth are substantially more resistant to post-mortem degeneration than bone. Unlike bones, which constantly remodel throughout life leading to the potential erasure of evidence of stress or disease, developmental defects in the teeth are permanently recorded. When the microstructure of teeth from the same dentition is understood in combination with other bioarchaeological methodologies, a more sophisticated picture of individual health experience can be drawn. Essentially, the biological expression of health (or non-health) as read through the teeth can be employed as an interpretative tool in understanding mortuary variation throughout west-central Belize. This study presents health data on the frequency and interaction of three variables, caries, enamel hypoplasias, and Wilson bands, in these understudied mortuary populations. The data presented here can articulate with the larger questions of Late Classic social, political, and economic organization of ancient Maya populations in Central Belize that are being explored by the Central Belize Archaeological Survey (CBAS) project and other Mayanists.

The study area from which these samples originate is particularly rich in pre-Hispanic Maya sites, with many rockshelters and caves containing human remains (Awe 1998; Awe and Helmke 1998; Bonor 2002; Brady and Kieffer 2012; Chase et al. 2014; Davis 1980; Gibbs 1998, 2000; Glassman and Bonor 2005; Helmke 2009; Helmke and Wrobel 2012; Heyden 2005; Jack 2004; Kieffer 2015; McAnany 1998; Michael and Wrobel 2011; Michael and Burbank 2013; Prufer 2002; Reents 1980; Roberts 1990; Moyes and Brady 2012; Saul et al. 2005; Scott and Brady 2005; Wrobel et al. 2007; Wrobel et al. 2009; Wrobel 2013a; Wrobel et al. 2013b; Wrobel et al. 2014). The widely varied mortuary ritual practices of the ancient Maya, along with the non-cultural taphonomic issues concomitant with the tropical environment, have resulted in differential preservation and movement of the remains. Upon excavation at rockshelters, primary burials were often disturbed by successive interments or looting, while interments in caves were often disturbed by post-mortem movement of remains, looting, and exposure on the cave surface. These issues affected data collection insofar as the desired sample of one maxillary central incisor, one mandibular canine, and one third molar per individual was rarely achieved. While the sample was not ideal, the methods used in this study still provided dental health data that was useful for the exploration of this sample as well as for comparison to other Maya dental samples. The cave and rockshelter sample, as well as the comparative surface site samples, were chosen to explore several current debates relating to the nature of Maya social organization and mortuary ritual. Maya archaeologists have not yet resolved the question of social origin of cave burials, and there is competing and often contradictory archaeological evidence suggesting a host of different reasons for cave interment. By selecting and analyzing teeth from cave burials and comparing the remains to rockshelter and surface sites, it is possible that dental defect patterns indicative of larger social processes may help to further understand pre-Hispanic Classic period mortuary variation.

In addition to the traditional macroscopic data collection methods of enamel hypoplasia and caries frequency and type observations, each tooth in the sample was assessed for micropathologies called Wilson bands. Beyond identification and quantification of Wilson bands, this research also associated the micropathologies with age at formation to understand patterns of health stress related to age within and between site types. In addition to biocultural questions, the large sample in this study allows for the exploration of several methodological questions related to understanding the meaning and interaction of non-specific indicators of developmental stress. This histological approach was chosen because the application of this little-used technique allows for the generation of more dental data that otherwise cannot be accessed via traditional methods. In taking a histological approach, a relatively unique perspective on health can be ascertained.

Outline of chapters

First, the significant contributions of the research are summarized, followed by a brief discussion of the materials and methods used in the study. Next, the research questions, justifications, and hypotheses are presented along with the expected outcomes. Following, two osteological models and a social theory borne of World Systems Theory are defined and presented (further exploration of each theme occurs in the Discussion chapter). Finally, a brief synopsis of the content of each chapter of the dissertation concludes this introduction.

The remainder of the dissertation is organized by a summary of the natural and cultural environment of the study area in central Belize and the other study sites (Chapter 2), followed by a discussion of dental growth and development (Chapter 3) and the measurement of health in human populations with emphasis on the ancient Maya (Chapter 4). Chapters 5 and 6 are the Materials and Methods chapters, respectively, which summarize the specifics of the study sample and the methodological techniques used with a focus on dental histology. In Chapter 7, the research questions are answered and the results are presented. Chapter 8, the Discussion section, is focused on the interpretation of the results through traditional bioarchaeological frameworks as well as an archaeological theory. Finally, in Chapter 9 conclusions and limitations of the study are summarized and future research directions are suggested.

Original contributions of the study

This study uniquely contributes to the existing Maya bioarchaeology literature in three ways: 1) comparison of varying site types that can be classed as likely low-status/rural (rockshelters), higher-status/urban (surface sites), and unknown social status (caves); 2) exploration of the meaning of cave burials through the comparison of burials at other site types; 3) assessment of non-elite burials; and 4) re-appraisal of methodological techniques and issues in dental histology.

First, the comparison of dental materials from rural mortuary sites (rockshelters) and widely debated mortuary sites (caves) to the burials at surface sites distinguishes this study, as the histological methods presented here have never been used to analyze cave and rockshelter burials in the Maya area. Health data on cave and rockshelter burials in Belize has been sporadically pursued, and studies are often composed of small sample sizes or descriptive analyses (see Caves Branch Archaeological Survey field reports). The ritual and mortuary function of caves is still being debated in the literature, and so biological data on cave burials is much needed to further explicate distinctions or similarities between cave burials and other mortuary populations on the ancient landscape. The mortuary significance of rockshelters is less contentious, with most researchers concluding that rockshelters were repositories for lower status rural groups (Glassman and Bonor 2005; Prufer 2002; Wrobel et al. 2007; Wrobel 2008; Wrobel et al. 2009).

The second contribution of the study is in the addition of data on the meaning and nature of cave burials, a topic that researchers have widely and regularly speculated on since the 1980s (Becker 1993; Brady 1997; Kunen et al. 2002; Prufer 2002; Prufer and Brady 2005; Prufer and Dunham 2009; Prufer and Hurst 2007). Cave burials have been variably interpreted as sacrificial victims or elites from nearby settlements, though commingling, surface deposition, taphonomic factors, and looting complicate the mortuary reconstruction of cave burials. Because there is no real consensus regarding the social identity of individuals found within caves, the biological variable of dental health is investigated here in comparison with other site types to determine if there is a perceptible difference between caves and other site types that can be linked to larger social or cultural processes.

Third, the incorporation of rockshelter burials in this study allows for a non-elite perspective as well as a comparison to the individuals of unknown status in the caves. Unlike those interments from caves and surface sites, rockshelter burials have received comparatively little attention in the Maya literature. The burials from two well-studied surface sites, Tikal and Pacbitun, are used as a type of biological control in this study as both sites are conclusively believed to be comprised of elite classes (Danforth 1989; Haviland 1972, 1977; Healy et al. 2007). The biological data from each site type can be used to elucidate patterns between burial locations that may help to clarify ongoing questions about the usage of these spaces and the social identity of those individuals buried within. Methodologically, the biological data can be used to bolster previous studies of the dental microstructure of the Maya by adding a non-elite sample to the existing elite dental histology studies (Danforth 1989; Wright 1990).

To illustrate the lack of dental data from non-elite populations, there are only two other other large-scale dental histology studies of the pre-Hispanic Maya (Danforth 1989; Wright 1990), neither of which focused on individuals buried outside of residential centers. Previous archaeological and bioarchaeological research on the ancient Maya has disproportionately prioritized the elite and middle classes buried at surface sites. Often, elites were interred in spaces that provided some protection from the elements or, minimally, from extensive commingling in burial deposits. These cultural buffers, as well as archaeologists' occasionally singular interest in large elite complexes and their residential satellites, has resulted in a body of knowledge that is lacking in information about the non-elite Maya. Therefore, the histological data presented in this dissertation adds critical information on non-elite and unknown status mortuary populations (rockshelters and caves, respectively) that can be used in comparative analyses. Further, a number of the sites sampled in this study originate from earlier time periods than those sites previously published on in the literature.

Finally, this study contributes to the overall methodological conversation in the literature about the use of dental histology in bioarchaeological research. Most dental histology studies utilize only one or two tooth classes for analysis; in contrast, this study sampled three adult tooth classes. One deciduous tooth class, mandibular canines, was included for study as well but few individuals were recovered with this particular element. All together, the large sample size in this dissertation exceeds most all dental histology studies published in journals, as well as meets (or exceeds) the number of samples in previous dental histology dissertations on non-Maya populations. Due to the sizable sample, patterns of dental micropathologies were noted and explored in addition to the standard frequency counts and age at formation assessments. These patterns, as well as the difficulties in analysis addressed in the Methods chapter, can help future researchers refine histological techniques.

Research questions and expectations

The research questions in the study are briefly presented here to illustrate that the project investigated both biocultural themes that centered on the interaction of the defects and social variables, as well as methodological themes that focused on biological principles and dental defect patterns. When the presence, frequency, and location of dental defects are combined with anthropological questions, histological methods can serve to explain health disruptions at particular ages that may be associated with cultural and social processes. Both the methodological and biocultural research questions addressed in this study were hindered by incomplete samples and complex burial contexts. Traditional biological profile data (e.g. age and sex) could not always be collected for all individuals. Other variables, such as time period and burial location within sites, were confidently known for some samples but not others. Even when time periods were known, the dates were often assembled from ceramic typologies resulting in a long period of time that likely reflected only site use not necessarily the dates of individual burials. Here, the questions are separated, but in the Results and Discussion chapters the inquiries are combined and interpreted as a whole when the questions relate to or nest within each other. When applicable, a hypothesis for the expected results is provided and a justification for those hypotheses is presented based on previously published literature and data trends. Some questions were simply investigatory in nature and did not necessitate a hypothesis.

Methodological questions

I address methodological questions first, since the answer to these can affect the interpretation of data used in answering biocultural questions. The methodological questions explored here center on three themes: 1) co-occurrence of defect types; 2) identification of macro-defects using traditional methods; and 3) location of defect formation.

Question 1: Is there a correlation between Wilson bands and LEHs?

Hypothesis: There is no significant correlation between defect type formation.

Justification: Previous research has demonstrated a weak link between Wilson bands and LEHs, suggesting the defects have different etiologies (Simpson 1999). However, Simpson's paper is one of the only studies that has focused on the relationship, if any, between micro- and macrodefects. Due to the size and disparate population structure of this dissertation sample, further exploration is warranted here.

Question 2: In how many instances were LEHs viewed only microscopically?

Hypothesis: LEHs that are slight in expression will not be counted macroscopically, but can be seen microscopically. The number of hypoplasias counted macroscopically will not be reflective of the true number of hypoplasias.

Justification: Collection of LEH data is subjective, based on the "thumbnail" test or impressing the tooth into putty. Because there is no standard of minimum expression, some researchers may interpret a band as an enhanced perikymata, whereas other may call it a hypoplasia. Interobserver error issues in LEH data collection have been noted in the literature (Danforth et al. 1993). Viewing the possible defects in cross section enhanced by microscopy alleviates confusion over true enamel defects and enhanced perikymata.

Question 3: Are Wilson bands most prevalent in the middle third of permanent incisors and canines? Third molars were not included due to later formation period and different architecture. Deciduous canines were not included due to small sample size.

Hypothesis: Microdefects occur most frequently in the middle third of incisors and canines.

Justification: Previous researchers (Goodman and Rose 1990:74; Simpson 1999:242) found that macrodefects are most prevalent in the middle third of the tooth. This could be due to the internal architecture, susceptibility at particular ages of development, or a combination of both. While likely born of different etiologies, it is hypothesized that Wilson bands will also be more prevalent in the middle portion due to heightened susceptibility at the age ranges connected to this area.

Biocultural questions

The biocultural questions explored in the study centered on the interaction of dental defects and chronological age. The earliest, latest, and mean ages of defect formation by tooth type and site were recorded, as well as the prevalence of defects in later years of dental development. The occurrence of defects by age range and frequency of hyper-events was also examined.

Question 4: What is the overall mean age of defect formation at each site (by tooth type)? At which site do individuals show earliest age of defect formation (by tooth type)? Latest?

Hypothesis: It is hypothesized that site types will group together so that overall mean age of expression in particular tooth classes is perhaps discriminated by burial type. A prediction about age of physiological stress onset between caves, rockshelters, and surface sites is difficult due to a host of factors such as social status, disease load, division of labor, and other cultural forces that are widely unknown in the past.

Question 5: Are there significant differences (by tooth type) in mean ages at defect formation between sites?

Hypothesis: Similarly to Question 4, external and internal cultural forces are difficult to predict. If differences occur between sites, predictions about these differences must be made with respect to a variety of factors.

Question 6: Will third molars exhibit fewer pathological striae as compared to maxillary central incisors and mandibular canines?

Hypothesis: Due to their later development (i.e. after the weaning age and well into the age of semi-independence), third molars will exhibit significantly fewer defects due to their later development.

Justification: Danforth (1989) discussed the peaks of health disruption in childhood as the time between birth and weaning. As third molars form after this vulnerable period, it is expected that they will not be as susceptible to health stress.

Question 7: How many individuals at each site experienced hyper-events?

Hypothesis: There will be variability within individuals between sites, but the patterns of that variability are difficult to predict. Hyper-events could be grouped by sex, age, or site type (or a combination of all).

Question 8: In cases where sex is estimated, are Wilson bands and LEHs more correlated with males or females?

Hypothesis: Males and females form enamel defects at similar rates with no significant differences.

Justification: Previous research has demonstrated that there are no significant differences in defect formation between the sexes.

Question 9: In cases where time period is known, which time period produces the most Wilson bands? LEHs?

Hypothesis: There will be variability within individuals between sites and by time period, but the patterns of that variability are difficult to predict. Hyper-events could be grouped by sex, age, site type, or time period (or a combination of all).

Question 10: Is there a significant relationship between the formation of microdefects and site type?

Hypothesis: Microdefects will be most significantly represented at rockshelter sites.

Justification: Rockshelter burials reflect individuals buried on the periphery of major urban centers who may have suffered more acute health stress due to their lower social status.

Expectations

A reasonable, yet simplistic, expectation would be that elite Maya groups experienced less health stress than non-elite groups due to their social status and ability to procure and secure food resources, as well as protect against health stress and disease. The justifications for several hypotheses outlined above are written to reflect this expectation. It is known from previous research that elites often do not benefit biologically from their social status (further discussion on this statement can be found in Chapter 5), though the expectation is still upheld in this study's hypotheses due to the incorporation of different site types than in previous research. Additionally, interpretations of the skeletal remains of individuals from different social classes becomes more complicated when the Terminal Classic is considered, a period during which divine kingships begin to falter and the Maya enter a period of sociopolitical unrest.

A second reasonable expectation is that individuals within and between sites will exhibit significantly different health patterns in the teeth. There are many reasons why individuals may exhibit particular health patterns within the same burial site and between burial sites, not the least of which is individual genetic susceptibility, an issue that bioarchaeologists cannot control for in their studies. While it is not appropriate to assume that differences in health between individuals automatically relates to differential treatment during life, disparate health patterns do allow for thoughtful anthropological interpretation of cultural, biological, and environmental factors affecting prehistoric persons. The biological data explored in this study opens another path to interpretation of pre-Hispanic Maya health.

Incorporation of osteological models in the study

For this study, the research results will be analyzed through the lens of two osteological models, the osteological paradox and Barker's hypothesis, as well as through an archaeological theory called negotiated peripherality. First, a discussion of the osteological paradox and Barker's hypothesis highlights the issues that must be considered in a bioarchaeological sample such as the one in this study. Second, a summary of the negotiated peripherality theory, born from World Systems Theory, is presented as a potential model for understanding the overwhelmingly non-significant results in defect age at formation and frequency between caves, rockshelters, and surface sites.

The osteological paradox

Wood et al. (1992) first wrote of the paradox to better explain bioarchaeological health studies that focused on pathological skeletal manifestations. Generally stated, the osteological paradox explains that those individuals with skeletal lesions, while in poor health at some point in their lives, were healthy enough to survive the stress. In contrast, those individuals without skeletal lesions may have succumbed to their illness before a bony response could be initiated in the skeletal tissues. Wood et al. (1992) urged anthropologists to reconsider possible factors acting on bioarchaeological populations such as demographic nonstationarity, selective mortality, and hidden heterogeneity. Nonstationary populations are heavily influenced by fluctuations in fertility. Selective mortality refers to the inherent exclusion of the whole population in a death assemblage; that is, the entire population does not get buried in any one particular mortuary site. The study of larger sample sizes does not solve this problem. Hidden heterogeneity refers to the mix of individuals in a given sample that were susceptible to disease or other risks (this number cannot be known). Factors like genetics and social status may play into disease susceptibility in certain individuals in a population. Wood and co-authors warned against the oversimplification of data and contended that anthropologists should work with clinicians to understand disease etiology and pathology in modern skeletons before attempting to diagnose quality of health in past populations. Additionally, it was suggested that the expression of frailty in modern populations be explored and used as a possible proxy for archaeological burial populations. For the Maya sample presented here, the osteological paradox should be considered with regard to the expression of dental defects. Although no mortality profiles were constructed for these samples and no claims were made as to the life span of the individuals in the sample, the presence of enamel defects cannot be uncritically associated with poor health.

It is worth noting that in a study of dental microdefects Antonova (2014) found no association between the number of Wilson bands and an increased risk of death at an early age, but these relationships have not been widely explored in the literature. Until more studies investigate the link, if any, between dental microdefects and age at death, it cannot be said that there is a consistent relationship between these variables. If further studies do demonstrate that dental microdefects and early age at death are not related, perhaps it can be concluded that the individuals with the most microdefects were the persons able to stave off chronic health stress, resulting only in the formation of acute defects. Because so few of the individuals in this study could be accurately aged due to poor preservation or commingling, conclusive statements about the effects of dental defects on life span cannot be suggested for this study. Further exploration of the effects of the Osteological Paradox on the Maya dental sample is presented in the Discussion chapter.

Barker's hypothesis

Barker's hypothesis states that childhood development is inhibited by early stressors that affect the normal development of the immune system (Barker et al. 1989). When the immune system is compromised in the beginning years of life, the individual is more prone to infection and health problems that could result in an earlier age at death. Bioarchaeologists have demonstrated that the development of dental macrodefects in early childhood may have long term biological consequences and may be linked to decreased life span (Cook and Buikstra 1979; Goodman and Armelagos 1988; Rose et al. 1978). Barker's hypothesis is considered for this study only as a suggestion that, if age estimations were known of this sample, early dental defect expression may be shown to be related to decreased life span. However, as stated above, age estimations for these samples were difficult to achieve or necessarily broad (e.g. young, middle, old) due to taphonomic and cultural factors inhibiting estimation of age. Perhaps with the inclusion of more deciduous teeth and early-forming adult dentition from other sites, a better understanding of the effect of early childhood stress could be drawn.

Integration of social theory in the study

It is suggested here that the application of negotiated peripherality (NP) theory, originating from World Systems Theory (WST), may be used to understand bioarchaeological studies of health when comparing populations that can be understood as residents of cores and peripheries. Three results in particular demonstrate the application of NP theory to the sample: 1) no significant differences in microdefect formation between site types; 2) formation of hyper-events at all site types; and 3) no significant differences in age at defect formation across all site types. Understanding the application of NP to the sample necessarily involves a brief review of WST below.

World Systems Theory

Social theorists have debated the ways in which culture change occurs, especially when historically embedded events affect a culture (e.g. environmental disruptions leading to "collapse") or when two or more cultures begin to interact with one another (e.g. Spanish contact period in the Maya world). One social model commonly applied to archaeological populations is that of WST, first developed by Wallerstein (1976). WST examined how historical and contemporary cultures are structurally integrated under the dominating practice of capitalism; Wallerstein (1976) contended that the nature of the modern world economy was influenced and guided by economic exchange rather than economic production, meaning that economic trade is responsible for system dynamics rather than economic production.

Three zones of the world system were identified by Wallerstein (1976): the core, the periphery, and the semi-periphery. In the core, agents organize, manage, and profit from the world system that is in place, leading to a marked division in labor in the events of production within the core. The peripheral zones serve as areas from which raw production materials are sourced, while the semi-peripheral zones serve as intermediaries between the core and outlying peripheries. Individuals occupying these different zones hold various positions in the social hierarchy, with the agents in the core benefiting most from the world system (Wallerstein 1976).

WST was applied to archaeology first in Schneider's (1977) examination of world systems in prehistory. Schneider tailored Wallerstein's model to address the pre-capitalist societies of prehistory. Whereas Wallerstein postulated that the dynamics of pre-capitalist societies were predicated on the trade of bulk goods that structured the world system, Schneider drew on archaeological evidence to hypothesize that prehistoric societies relied on items associated with affluence to structure and maintain political relationships and personal status. Schneider also examined the manner in which cultural groups interacted with empires, resulting in a nested and multilayered socio-political dynamic of influence, buffering and management of complex relationships between ethnic groups and ruling empires.

The precept of WST is the inherent hierarchy that is thought to exist between the core and the periphery, or the dominating and the subjugated. Because WST emphasizes the role of economic exchange in hierarchical societies, this model (with Schneider's modifications for prehistoric societies) is particularly applicable to the Classic Period Maya who favored the trade of food and goods between and among kingships (the core) to create and preserve status-based social and political relationships. The existence of a Maya middle class (Chase 1986; Chase

1992; Masson and Peraza Lope 2004; Marcus 2004) as well as rural farming communities outside of the core likely provided some amount of materials and resources for core consumption and trade. In this vein, Morton (2015) proposed that the Maya center of Tipan Chen Uitz in the CBAS study area was strategically placed at the intersection of several distinct resource zones, a presumably conscious choice which allowed for the exchange of goods, trade, and labor.

The modified WST model seems to be somewhat germane in understanding the nature of pre-Hispanic Maya social interactions, though the model has only been applied sporadically in Mesoamerica (Kepecs et al. 1994; Smith and Berdan 2000). This is likely due to a traditional focus on single sites or small networks of sites, but with the incorporation of regional analyses the WST approach may be useful in examining the interaction between site cores and peripheral zones (Kepecs et al. 1994). Since Schneider's (1977) truncation of WST, other researchers (Abu-Lughod 1989; Algaze 1993; Chase-Dunn and Hall 1997; Peregrine 1996) have re-addressed the limitations of the WST model. It has also been argued that the model itself is too restrictive to be appropriately applied to all archaeological populations, though concepts generated from the model (e.g. exchange of goods and information) can inform of cultural interaction practices that transcend political boundaries during particular periods of time (Smith and Berdan 2000). For example, Smith and Berdan (2000) found that the WST model as related to exchange of goods and information was useful for understanding site cores in Postclassic Mesoamerica where exchange was intensive. These authors argued that core/periphery distinctions were not useful outside of the cases of empires, because of the intrinsic (and erroneous) hierarchy that is associated with the core/periphery model. Peregrine (1996) argued that cores did not always dominate peripheries, but rather that these zones were distinct in their political and economic activities.

Negotiated peripherality

Nesting the WST model within a framework of domination/subjugation, Kardulias (2007) addressed the issue of personal agency, as well as response to the core by the inhabitants of the periphery. Kardulias (2007) introduced the concept of "negotiated peripherality" to explore how inhabitants of the periphery expressly negotiate the terms of their interactions with and incorporations into the core. Because the core depends on the periphery as a source of material collection and labor production, under this model the core must respond to the needs and demands of the periphery. Rather than accepting subjugation, the inhabitants of the periphery have some degree of autonomy to receive or refuse the symbolic or material objects that the core presents to them. Morris (1999:63) argued that, "peripherality is not an automatic and passive status" meaning that non-elites on the margins of society were agents of their own culture to varying degrees.

Within this choice, the inhabitants of the periphery have the option to embrace particular goods or ideas and incorporate them into their own social program. As Kardulias (2007:76) wrote, what is "clear in the ethnohistoric and archaeological records is that people on both sides of a cultural divide manage their resources in ways that they believe will fit them best." For example, in the Maya world, inhabitants of the periphery may not have retained the large caches of luxury items that core agents consumed, but they may have adopted symbols of core status (e.g. ear spools). During the Late and Terminal Classic, the Maya experienced abandonment and re-location of site cores, and thus the periphery shifted as well. Zones that were formerly hinterlands may have been incorporated into newly developed site cores requiring negotiations of the terms of interaction between cores and peripheries. These interactions likely produced some degree of stress, both social and political, that resulted in a biological response. Perhaps the building of new cores benefited the peripheral zones by imbuing them with more resources and power to control the raw materials sought by the core. However, the construction of new cores in previously peripheral zones may have adversely affected the inhabitants of the hinterlands as their resources and land rights may have been usurped. It is conceivable that WST, with a focus on the particular version of the model that best suits the Maya case in conjunction with an archaeologically-informed NP perspective, will aid in interpreting health patterns and biological response to stressors in the Maya region.

Examples of agency in non-elite Maya populations

The NP concept is understood as an "agent-centered approach (Galaty 2010: 119). In order to set the framework for the application of NP to the study sample, a brief discussion of examples of agency of non-elites in Maya prehistory is warranted. The following summary is not exhaustive (nor is it intended to be); rather, these examples serve to illustrate how non-elites were not simply extensions of or handmaidens to the elite classes living in the urban centers.

Archaeological evidence for non-elite agency can be gleaned from the reconstruction of food production in the past. Lohse (2004) cited archaeological data from the site of Dos Hombres to underscore his contention that commoners managed food production systems in the absence of orders from a ruling polity. Local variability in markers of status, architectural structure, and group proximity to favorable soil were documented in the archaeological record, indicating that non-elites were making deliberate, beneficial decisions for themselves (Lohse 2004).

Yaeger and Robin (2004) presented another example of non-elite decision making in their examination of site composition in the settlements in the Xunantunich hinterland. Household size varied, making community size and composition disparate between sites. Heterogeneity between and among settlements was due to social, political, environmental, and economic factors that influenced and conditioned members of a society (Yaeger and Robin 2004). Communities were decisive in their participation within the larger polity and likely influenced and conditioned the demands of the rulers in part (Yaeger and Robin 2004). Until fairly recently, Mesoamericanists were predominantly concerned with urban center excavations, not small residential sites in peripheral zones. This “large-site bias” (King and Potter 1994:65) obscures the roles that rural individuals played within hinterland communities and in the greater regional landscape. While certain sites were more important than others in prehistory, the factors that determined significance were likely not scalar; rather, they were political, religious, or economic (King and Potter 1994).

Another theme that underscores non-elite agency is group mobility. Non-elites with greater flexibility of movement across the landscape were generally subject to less state control (Inomata 2004). Individual and group mobility is a means by which non-elites subverted oppression by rulers and remained somewhat autonomous on the landscape. Inomata (2004) related that, during the Contact period, indigenous groups subject to despotic Spanish rule even retained some degree of mobility allowing them to resist colonial power. The retainment of freedom, even during the most oppressive of conditions, leads to the reasonable assumption that before the Contact period perhaps non-elites living in aggregated settlement groups were not strictly beholden to rulers.

Negotiated peripherality and health experience

The agency-based approach of NP theory can be extended to health stress and management of individual health experience in prehistory. To the best of my knowledge, NP theory has not been employed in bioarchaeological studies of health. Kardulias’ work was primarily concerned with core-periphery interactions as they related to management of trade relations and agency. However, a bioarchaeological and biocultural view of NP theory can be extended from Kardulias in two ways: 1) the core-periphery interactions may influence the access to or restriction of resources that result in greater or poorer health experience, and 2) the agency of the peripheral communities may result in personal management of health exercised outside of the core that may have resulted in greater health experience.

I argue here that the principles of the theory are applicable to the sites in this study due to their clear elite (Pacbitun and Tikal) and non-elite (Caves Branch and Sapodilla Rockshelters) status that defined them as either core or peripheral zones. Caves, of course, remain somewhere in the middle of the spectrum, both outside of the core zone but possibly associated with the core. This study addresses biological variables not yet explored through NP theory; therefore, the application of NP to understanding these three site types and their burial samples is a novel approach to interpreting the main results of the study.

Ultimately, this dissertation seeks to provide biological data for a historically understudied segment of the Maya world: those individuals buried outside of urban centers. A trend of exceptionalism has often permeated bioarchaeological studies of the Maya dead, with a focus on tombs and elite individuals. This study takes a different approach by also focusing on persons buried in caves and rockshelters, both spaces geographically removed from urban centers. Though there is evidence for elite Maya use of caves, the majority of cave surveys have focused on areas of geographic proximity to elite centers (Moyes and Brady 2012). This bias permeates cave archaeology in Mesoamerica, such that Moyes and Brady (2012:164) suggested the following: "…what is needed are cave surveys carried out along a transect that would provide comparative data on both core-area and rural caves, and which would consciously sample both large and modest-sized caves." Fortunately, there are recent studies that trend toward this need (Morton 2015). The data presented in this dissertation adheres to at least part of Moyes and Brady's admonishment in that rural cave (and rockshelter) burials are incorporated.

CHAPTER 2: THE SIGNIFICANCE OF THE STUDY AREA IN CENTRAL BELIZE

This chapter first deals with the variable cultural and geographic definitions of Mesoamerica and the Maya area, including relevant time periods. A brief review of the history of archaeology in Belize follows, with a special emphasis on the study area in central Belize. The purpose, work to date, and future goals of the Central Belize Archaeological Survey (CBAS) are summarized before a discussion of the mortuary landscape of west-central Belize. In this final section, the history of cave and rockshelter excavation in the region is presented along with a discussion of the themes and patterns of cave and rockshelter use through time. The specific sites sampled in this study are discussed at length in the Materials chapter.

Defining Mesoamerica

First coined by Paul Kirchoff in 1943, the term “Mesoamerica” was used to refer to a region defined by geographical boundaries, religious concepts, settlement patterns, ceramic styles, ethnic groups, language, and cultural traits (Kirchoff 1952; Creamer 1987). The boundary of Mesoamerica reaches from northern Mexico south to the Gulf of Nicoya, though scholars have continuously reconsidered and adapted the definition of the region, as well as what it meant to be Mesoamerican in the years since the term was introduced (Creamer 1987). Specifically, anthropologists have recognized the variation present in prehistoric Mesoamerica due to cultural and environmental differences across the vast region, which led to the formation of sub-areas with different socio-political structures and ideological systems (Creamer 1987). Traditionally, the discussion of Mesoamerican archaeology is often framed through the incorporation and explication of diverse data sets such as ceramics, architecture, linguistics, or iconography; these data are used to explore what it means to *be* Mesoamerican. However, rather than defining past peoples through shared singular traits (e.g. religion, dress, economy), anthropologists now use the term Mesoamerica to refer to cultures which, “through extensive interaction, developed a common set of values and practices that continued to develop over a long period of time, some 3,500 years before European contact" (Joyce 2004:3). Religion and ritual, evidenced via ethnohistorical documents and archaeological research, have been used to trace Mesoamerican culture through time (Blanton 1993; Tozzer 1941; Webster 2002).

Defining the Maya region

The most studied of these Mesoamerican cultures is that of the Maya, who are defined by language, culture, architectural and ceramic styles, art, iconography, and geography. The Maya area reaches from the Isthmus of Tehuantepec through the Yucatán Peninsula, Guatemala, Belize, and portions of El Salvador and the west of Honduras (Morton 2015; see Figure 1). Geographically, the Maya area is divided into three zones: the Pacific Piedmont, the volcanic Highlands, and the Lowlands where nearly 30 languages were spoken by inhabitants (Sharer and Traxler 2006). A limestone shelf replete with caves, rockshelters, and sinkholes dominates the northern three-quarters of the Maya region (Woodfill et al. 2016:198), in which the archaeological remnants of impressive city centers and agricultural villages are still being discovered today. The Maya, ancient and modern, were not a "monolithic group" (Morton 2015:4). Today, Maya populations exist throughout the geographic locations occupied by the ancient Maya and their culture and language is still diverse owing to the relative isolation of certain groups by distance, conflict, migration, or sociopolitical change; these factors shape Maya culture today just as they did in the past. Approximately 11 million modern Maya inhabit Central America, again demonstrating the persistence of the culture through time (Scherer 2015).

Incorporating archaeological context, skeletal biology of individuals, epigraphy, art, language, and ethnohistorical data, anthropologists have been successful in formulating testable models for research questions concerning social interaction and individual experience in the pre-Hispanic Maya world. Initially, archaeologists believed that the Maya were descendants of the

Olmec culture based on similarities in writing and architecture, as well as in the practice of sacrificial rites (Ibarra-Rivera et al. 2008).

Figure 1. Map of Maya area (www.latinamericanstudies.org).

Olmec roots of the Maya are debated in the literature as much of the material evidence for the Olmec culture cannot be definitively interpreted, but it is now known that a Maya center, Ceibal, pre-dated La Venta, an Olmec center, by approximately 200 years (McKillop 2004) and that the earliest ceramics in the Maya area also pre-date the Olmec culture (Sullivan and Awe 2013). Most likely, the Olmec represent a distinct cultural and ethnic tradition that interacted to some degree with the Maya, as influence flowed both ways. The Maya did not descend from the Olmec, nor did the culture develop independently; rather, extensive interactions, cultural diffusion, and some flexible cultural shifts likely resulted in the rise and eventual dominance of Maya identity while Olmec traditions faded or were absorbed into the prevailing social schema of the region.

The archaeological signatures of the first Maya civilizations date to the Preclassic period (starting around 2000 - 1800 B.C.), while stratified societies structured as chiefdoms emerged in the Middle Preclassic (1000-400 B.C.) (McKillop 2004; Scherer 2015). From this shift of political power, ruling elite classes and city-states were born in the Late Preclassic (400 B.C. – A.D. 100). The Protoclassic period (A.D. 100 to A.D. 250-300) served as a transitory period; both architecture and ceramics from this period show distinctions in style and form (Pendergast 1993). Obsidian sourced from the region around Teotihuacan and ceramic vessels of Teotihuacan form have been found at Maya sites including Altun Ha, demonstrating that the Protoclassic Period Maya were in contact, in some capacity, with the extremely powerful city-state (Pendergast 1993). Ceramic data provide evidence for the sharing of knowledge about styles and the practice of trade, underscoring the notion that populations across space were in contact with one another early in the Preclassic (Pendergast 1993).

Rising social inequality led to political rivalries, increased warfare, and further differentiation of social classes; all of these characteristics would define the Classic period Maya. From small-scale beginnings of unincorporated villages and rural settlements, the Maya reached a cultural zenith during the Classic period with hallmarks of monumental architecture, writing systems, complex trade networks, and complex ideological belief systems (McKillop 2004). At the dawn of the Classic Period, Maya civilization was powerful and expansive, with ruling dynasties controlling vast amounts of land and people. However, by the Terminal Classic (A.D. 800-900), the complex sociopolitical and economic system started to disintegrate and population numbers dropped in many areas of the southern Lowlands (Ibarra-Rivera et al. 2008). Large-scale abandonment of major city centers caused the ruling elite to be forced out of power. Late in the Terminal Classic, some elites may have moved and attempted to rebuild their dynasty, and there is considerable evidence for powerful new centers in the northern Lowlands. There is also considerable evidence for the re-occupation of sites on a smaller scale after initial abandonment (Pendergast 1993). Several centers like Lamanai withstood the tumultuous end of the Classic and continued to prosper, in a more restricted and revised fashion, into the Postclassic (Pendergast 1993).

A combination of external and internal factors likely resulted in the eventual “collapse”; those causes commonly thought to have incited the sociopolitical reorganization of the Terminal Classic period include a combination of factors like famine, climate change, natural disasters, increasing political conflict, deforestation, and overexploitation of agricultural land (Ibarra-Rivera et al. 2008). A probable cause for the collapse is the interaction between population growth and the toll that density took on the environment. Degradation of the environment and an overtaxed agricultural system resulted in fewer subsistence yields. Over-cultivation of particular crops led to the adoption of high-yielding maize, thus shifting the focus of the popular diet and resulting in a loss of dietary diversity among some segments of society (Wright 1997). High population density brought on increased disease loads in populations.

Using paleodietary (stable isotope data) and paleopathological (presence of anemia, oral health, infectious disease, dental growth disruptions) analyses of a skeletal sample from the Pasion region, Wright (1997) showed that a purely environmental model was ineffectual for explaining the collapse. While maize was prominent in the diet, there was no isotopic evidence to show that the increase was significant or that consumption was attributed to poorer health. Paleopathological analyses showed that there was no detectable decline in overall health leading up to the collapse. The role of increased political violence and warfare, as well as social inequality and restriction of resources by class, should be examined as appreciable factors in the study of the Maya collapse (Wright 1997).

After the decentralization of power in the Terminal Classic, Maya society in the Post-Classic was restructured into a number of smaller, independent states though these new polities did not escape external pressure from the powerful contemporaneous cultures of the Aztec and Toltec in Mexico. By the Spanish invasion, Maya civilization was highly fragmented and was eventually forcefully colonized.

Time periods of relevance to the Maya

Table 1. Chronological periods associated with Mesoamerican cultures.

Culture	Dates
Olmec	1600 – 400 B.C.
Maya	
Early Preclassic	2000 – 1000 B.C.
Middle Preclassic	1000 – 400 B.C.
Late Preclassic	400 B.C. – A.D. 100
Terminal Preclassic	A.D. 100 - 250
Early Classic	A.D. 250 - 600
Late Classic	A.D. 600 - 800
Terminal Classic	A.D. 900/1000
Postclassic	A.D. 900/1000 - 1500
Teotihuacan	A.D. 100 - 500
Aztec	A.D. 1200 - 1521

Dates of chronological periods are contingent upon which author and book one is reviewing, but most scholars agree on approximate periods (Table 1, following Moyes and Brady 2012:152).

The cultural context of Belize: a review of the archaeology

The modern day country of Belize is located entirely within the Maya region. Many Maya sites have been excavated in the small country located in Central America and bordered to the north by Mexico, the east by the Caribbean Sea, and the south and west by Guatemala. Belize is a small country (22,800 km^2) with a long period of human occupation in prehistory before Spanish contact in the 16^{th} century. The Spanish chose not to colonize the area because of the lack of gold and the fierce opposition to contact by Maya groups living in the Yucatan Peninsula. By the 17^{th} and 18^{th} centuries, colonists from England and Scotland realized the resource potential of the region and the country, called British Honduras, became incorporated into the British Empire from 1862-1981. The logging of the mahogany and other hardwoods began in earnest during colonial times (17^{th} and 18^{th} centuries) and continues today (a beneficial byproduct of logging activity has been the access given to archaeologists to the more remote parts of central Belize, but the added increase in looting has been largely destructive). In 1981, Belize gained independence from the United Kingdom. Today the country is composed of a diverse population of indigenous ethnic groups and immigrants. Modern Maya populations in Belize are concentrated in the Stann Creek and Toledo districts, which are economically poorer than the remainder of the country (Morton 2015:7). Wet and dry seasons characterize the weather in the distinct topographical regions of Belize. The Maya Mountains, as well as the Mountain Pine Ridge, dominate portions of the country with seasonally swampy plains (0 – 100 meters above sea level) throughout (Miller 1981; Morton 2015:8-9). Rainfall throughout the country increases with elevation and southern direction with annual rainfall reaching 5000 mm in the south (Morton 2015:9).

History of archaeological research in Belize

The history of archaeological research in Belize is rich and archaeological teams, including CBAS, continue to add to the body of knowledge about pre-Hispanic Maya origins and lifeways. Initial archaeological research in Belize took the form of cursory site descriptions with little focus on interpretation of Maya cave use. Early explorers took note of the mounds and surface finds that were clues to the rich prehistoric past of the geographic area now known as Belize as far back as the early 1800s (Pendergast 1993). However, interest in the region was intermittent and tempered by a disconnect between the prehistoric past and the modern inhabitants of the area. Formerly known as the colony British Honduras (1862-1981), Belize was not initially recognized by scholars as a geographic region critical to the ancient Maya. Past views saw Belize as the latent peripheral zone in reaction to Guatemala's efficacious core (Pendergast 1993).

International institutions like the Carnegie Institution and the British Museum funded excavations at Baking Pot (1920s), Pusilha (1920s), and Lubaantun (1930s) (Gann 1930; Gruning 1929; Joyce 1929; Pendergast 1993). However, these field seasons were short in duration and decades would pass before archaeologists returned to these field sites. The only notable long-term field projects in the first part of the century, the excavation of San Jose and the preliminary investigation of Xunantunich, were led by Eric Thompson in the Cayo District (Pendergast 1993). The onset of World War II effectively ended these pilot investigations though by the 1960s anthropologists sought to perform large-scale, problem-oriented research in the country. By 1957, an official Department of Archaeology was established in the Belizean government, thereby allowing for identification and record keeping of sites and, unfortunately leading to increasing monument destruction and looting (Roberts 1990). Confluent with the general re-appearance of interest in surface site archaeology in the 1960s, was the newly emergent interests of cave use and treatment in prehistory, as well as costal and offshore archaeology (Pendergast 1993).

The 1970s saw a period of exponential growth of cave archaeology and geomorphology research, a pattern that continues today as demonstrated by the many U.S. and Canadian-led archaeological projects in Belize. Until the last few decades, human remains found at sites were largely treated as appendages to grave goods or, at best, recorded in association with interpretations of funerary practices, with the mention of burials at cave sites being exceedingly rare (Roberts 1990; Saul 1972; Welsh 1988). Increased interest in bioarchaeology and projects led by bioarchaeologists has turned this tide in recent years. Since the 1970s, a focus on interdisciplinary scholarship and interpretative models has shaped the field; researchers routinely include ethnography, iconography, ethnolinguistics, and epigraphy in their assessment of caves.

The current government of Belize is supportive of archaeological research, and there are many scholars working in the country today to uncover the past and provide linkages to modern Maya descendants. It is the archaeologists' duty to move past single-site studies and site descriptions to a more systematic, cooperative research paradigm that draws upon the work and opinions of international scholars, the government, and the modern Maya descendants living in the country today.

The river valleys of Belize

The northern, western, and central portions of Belize are host to a number of rivers that cut through the landscape and form the river valleys that are rich in archaeological sites. The

Roaring Creek and Caves Branch River Valleys are the areas from which the cave and rockshelter samples in this study originate, but a brief review of the other river valleys in Belize are noted here for regional perspective. The Belize River transects the center of the country, beginning east of San Ignacio and cutting along the northern face of the Maya Mountains before reaching the ocean via Belize City. Sites along the lower Belize River and its tributaries are the focus of most of the longest and most extensive work in the country. Among these projects, the Belize Valley Archaeological Reconnaissance Project (BVAR) has focused on the large prehistoric sites of Cahal Pech, Baking Pot, Lower Dover, and Xunantunich that flourished during the Classic period. Excavations at Cahal Pech have also revealed evidence for much earlier occupation during the Formative period which continued unabated until after 1000 AD (Awe 1992). The Sibun River originates in the Maya Mountains and flows through a floodplain riddled with caves before terminating south of Belize City where the river meets the sea. The Xibun Archaeological Research Project (XARP) has excavated a number of sites in the Sibun River Valley since 1997, investigating the settlement locations along the river and the prehistoric use of the cave systems in the area (McAnany 1998; 2002). Peterson's (2006) dissertation study examined the relationship between the domestic and ritual spheres using a sample of caves in the Sibun River Valley. Interestingly, Peterson argued that the Preclassic material culture found in the Sibun caves was indicative of more pragmatic use – a view in opposition to positions of Brady (1989) and Prufer (2002) who argued that the evidence for early use of caves in areas that have only later evidence of residential sites is verification that the Maya were embarking on cave pilgrimages before taking up residence near the caves.

The Roaring Creek River Valley is distinguished by its narrowness and steep limestone ranges (Awe 1998). Both BVAR and the Western Belize Regional Cave Project (WBRCP) have investigated residential sites, caves, and rockshelters, documenting temporal variation in use of the karstic spaces. As echoed by Brady and Prufer referenced above, Awe (1998:8) found that the evidence for cave use in the area predated the evidence for settlement, which dates predominantly to the Late to Terminal Classic periods. The large civic-ceremonial site of Cahal Uitz Na, proximal to Actun Tunichil Muknal, Actun Nak Beh, and Actun Uayazba Kab, has been well documented (Awe and Helmke 1998; Conlon and Ehret 1999; Halperin 2001). Actun Nak Beh, a large rockshelter containing a prepared plaster floor and human burials, was connected to Cahal Uitz Na via a raised road indicating the importance of access to the site in prehistory.

The prehistory of central Belize

Central Belize, defined generally as the Roaring Creek and Caves Branch river valleys, was largely left unstudied by archaeologists until the 1980s (Davis 1980; Graham et al. 1980; Miller 1981; Reents-Budet 1980). In the 1990s, Juan Luis Bonor of the Belize Department of Archaeology led salvage operations focused at and around the Caves Branch Rockshelter. Soon after, the Western Belize Regional Cave Project (WBRCP), which was an extension of the Belize Valley Archaeological Reconnaissance Project (BVAR), both led by Dr. Jaime Awe, began work in the Roaring Creek River Valleys on surface sites, caves, sinkholes and rockshelters (see Morton 2015:14 for exhaustive list).

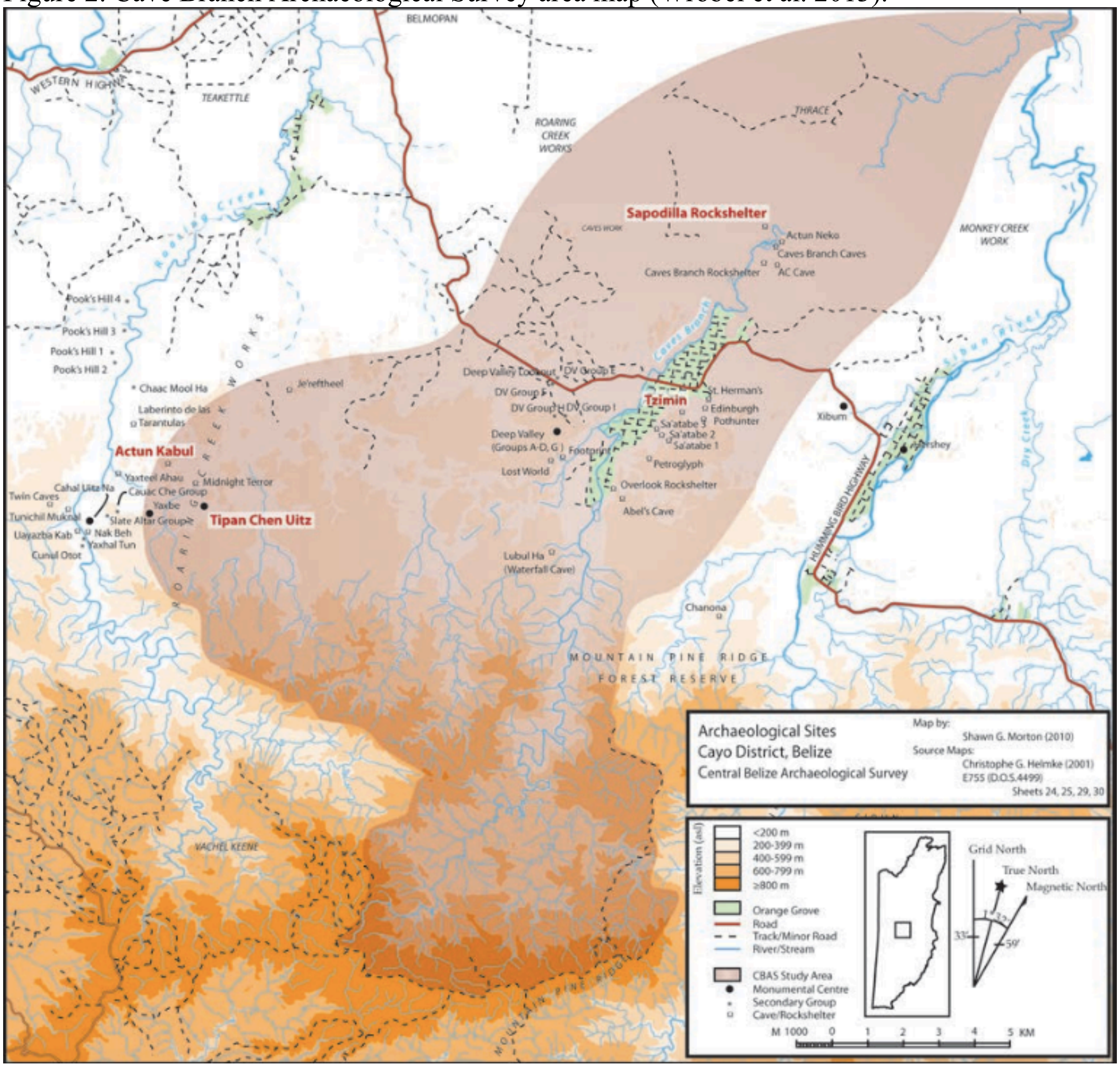
The prehistory of human occupation in central Belize certainly pre-dates the Maya, though archaeological evidence is largely ephemeral for the earliest time periods. Humans were in the area of Belize during Paleoindian period (pre-12,000 BC – 10,000 BC) and Archaic period (10,000 BC – 1200/900 BC). The pre-Maya inhabitants were present in central Belize during the Archaic period did not form aggregated groups and population numbers were low. These pre-ceramic inhabitants left behind lithics which have been discovered sporadically in Belize, including in the CBAS study area at the Caves Branch Rockshelter (Lohse et al. 2006; Rosenwig 2004; Stemp et al. 2016). Proto-Maya groups began to inhabit the region around 1100 BC (McKillop 2004). Ceramic sherds dating to the Middle Preclassic are found throughout central Belize, but in markedly lower frequency than materials from the Late Preclassic when small communities began to settle in the area. By the Classic period, aggregated settlements were established throughout central Belize though groups remained relatively small in size and were likely living for some time unfettered by dominant political powers (Andres et al. 2011; Morton et al. 2016; Wrobel et al. 2009). By the Middle Classic period (~6th century AD), population sizes increased dramatically in central Belize due to the fluorescence of relatively expeditious constructions of civic centers (Wrobel et al. 2009). From an ecological point of view, central Belize is an interesting and varied area. Many sites, while geographically proximal, exist in zones of geological and resource confluence making these locations quite desirable in prehistory.

Currently, according to the archaeological data, it appears that unincorporated rural settlements dotted both Caves Branch and Roaring Creek River Valleys with consistent human occupation not occurring until the Middle Formative period (ca. 600 BC – 300 BC) (Morton 2015). During this period, settlement groups of unknown density were participating in a long-distance economic trade network as evidenced by the incorporation of non-local materials in regional caves. The extent to which these economic networks were developed (or even how they were developed) is currently unclear from the archaeological data (Morton 2015:333). Using dated materials from primary cave contexts, Morton (2015:333) estimated that by the Late Formative (ca. 300 BC – AD 0) and Proto-Classic (ca. AD 0 – AD 280) periods, the caves and rockshelters of central Belize were being utilized as sites of ritual activity. Interestingly, during these periods the light zone rockshelters and associated shallow caves in the area were used as mortuary deposits by local groups interested in staking claims to territory in an increasingly populated landscape.

The Early Classic (AD 280 – AD 580) period saw escalating use of caves in the region. During this time, individuals were sourcing goods from areas of modern day Guatemala and Mexico for use in cave ritual; fine ware ceramics from the Petén, Pasión, and southern Yucatán regions have been recovered from central Belize cave contexts, though more pedestrian local ceramic wares are higher in frequency in the caves (Morton 2015:334). The frequent representation of utilitarian material assemblages in the caves indicates that inhabitants in the region were increasingly specializing in local production of goods. In his analysis of ceramics of the CBAS study area (see Figure 2), Morton (2015:338) suggests that during this period, "centres within the study region are finally coming into their own, not simply as frontier consumers of Classic Maya identity, but as important centres in their own right, tied predominantly into local economic networks over foreign, but still maintaining access and connections to the symbolic heartland."

Practices of restricted access and inclusion/exclusion in caves are still up for debate. During the Late Classic (AD 580 – AD 830/880) cave use increased exponentially in the Caves Branch and Roaring Creek River Valleys, as well as in the nearby Belize River Valley. This pattern is also found in the elevated Late Classic karstscape activity in the Pacbitun polity in the (modern day) Cayo district (Spenard 2014). Construction of civic-ceremonial centers with a distinctly regional style continued in earnest during the Late Classic, with the monumental sites of Deep Valley, Tipan Chen Uitz, Yaxbe, and Cahal Uitz Na all dominating the landscape. Morton (2015:336) noted that the architecture at these sites suggests that each locale, excluding Deep Valley, was independently operated for some time before becoming incorporated into a unified network of sites via causeways. Tipan Chen Uitz, positioned between the major drainages of Caves Branch and Roaring Creek river valleys, was a large civic-ceremonial center with complex architecture, multiple causeways and courtyards, a cistern, and monuments (Andres et al. 2010, 2014, 2015).

Figure 2. Cave Branch Archaeological Survey area map (Wrobel et al. 2013).



The site is a particularly strong example of the relationship between the karstic landscape and the built environment. The expansive size and features of the site indicate a clear energy investment that must have originated with leaders that were able to harness vast labor forces, a telling gauge of social hierarchy. Further, the emphasis on vertical architecture must have ensured the delineation of elite vs. non-elite residences and the incorporation of natural limestone cliff features on the northern site margin likely served defensive functions (Andres et al. 2010). Independence, power, and literacy at Tipan are further underscored by the carved monuments uncovered by CBAS that demonstrate the significant organization and influence of the site. Inter-site causeways also linked Tipan, the capital of the polity, to the smaller centers of Cahal Uitz Na (3.0 km west) and Yaxbe (1.5 km west) illustrating the integration and communication of sites in this region (Andres et al. 2014). Glyphic inscriptions on two monments found at Tipan Chen Uitz are associated with dates, both of which place their dedications in the early eight century AD; these inscriptions, as well as a variety of other epigraphic and architectural data, suggest ties with Naranjo and other powerful sites associated with the Snakehead dynasty at Calakmul (Andres et al. 2014, 2015, in press).

With both cave activity and civic-ceremonial center construction on the rise in central Belize and neighboring areas, Morton (2015:337) questioned the direction of the relationship between caves and urban settlements: “The ubiquity of cave use in this period may simply be a product of proximity and population growth. Alternatively, it may signal the acquisition of traditional (or ‘senior’) cave environments by an emerging elite class, and the consequent spread of ‘lower level’ cave use to secondary contexts.” This is an interesting point and one that is not easily examined in the archaeological record. Regardless of the nature of cave use by only elites or by all social classes, subterranean space was clearly reserved for ritual (mortuary or other).

Fluorescence in the area peaked and the affluence of the region could ultimately not be sustained. To illustrate, Tipan’s largest structures were composed of dry-laid boulder core, a cheap and time-efficient technique used to build an impressive center in little time. Pseudo glyphs found on ceramics at Tipan signal the last attempts by elites to hastily extend their power through the commission (and, likely, trade) of objects meant to connote status. The illiterate masses may not have been able to determine that the glyphs were meaningless, but by the Terminal Classic period (AD 900) the point was moot. During the Terminal Classic and Early Postclassic periods, Tipan Chen Uitz, Deep Valley, Yaxbe, and Cahal Uitz Na were abandoned, some abruptly, and cave activity all but ceased.

Integrating the study area with the larger archaeological context

CBAS efforts to provide regional data sets for cave and rockshelter use in central Belize have bolstered archaeological knowledge, but further excavations at the civic ceremonial centers in the region, as well as more systematic excavation of subterranean and rockshelter sites, will result in a broader understanding of *who* was buried at these sites and *why* they were selected for interment over other individuals. In a summary of the wider impact of CBAS' studies, Morton (2015:332-333) stated that, "by approaching the cave context as an integrated dataset, linked not only to other subterranean sites, but recognizing as well its broader significance and entanglements in activities occurring at surface sites, we are able to build up a remarkably complex, if still provisional, picture of the socio-political, economic, and ritual systems in process over the region's history, and with particular clarity during the Classic and Terminal Classic periods."

Social, political, and ritual meaning of caves in Belize

During the early years of the study of cave archaeology in the Maya region, subterranean spaces were interpreted as habitation areas following the Old World Paleolithic view of caves (Mercer 1896). In 1898, Gordon published on caves around Copan, Honduras and also conclused that they were used for habitation. When Thompson (1897; 1904; 1938) began to investigate caves in the Yucatan (including the Cenote of Sacrifice at Chichen Itza), the idea of the cave as a locus of residence started to lose favor. This was a turning point in Maya cave archaeology as subterranean spaces began to be understood as ritually charged ceremonial spaces. Generally, the intermittent nature of early excavations resulted in short descriptive reports leaving the field of Maya cave archaeology bereft of methodological and theoretical advances until the scholars of the 1970s and 1980s worked toward more theoretically grounded scholarship (Brady 1989; 1997). Though cave excavations in the region stretches back to the 1840s, consistent problem-oriented research did not routinely occur until the 1960s and 1970s (Scott 2012; Spenard 2014) with the contributions of A.H. Anderson, E. Wyllys Andrews, Barbara MacLeod, David Pendergast, Dennis Puleston, Doris Heyden, and Sir J. Eric Thompson. Thompson (1975) hypothesized that the Maya used caves for the following purposes: 1) places to collect drinking water; 2) places to conduct religious ceremonies; 3) burial sites; 4) places to showcase art; 5) repositories for broken artifacts; and 6) habitation sites or places of refuge. This list has formed the basis for hypothesis testing in cave archaeology today.

A synthetic view of cave archaeology is still being vetted in the anthropological literature (Brady and Prufer 2005; Heyden 2005; Prufer and Brady 2005). The ritual importance of caves to Mesoamerican peoples has been explored through many lenses, including art, ethnography, epigraphy, archaeology, and linguistic analysis (Bassie-Sweet 1991; Brady 1997; Helmke 2009; Grove 1973; Heyden 1975). Building upon concepts of the cave as a site of fertility, creation, and contact with the underworld (Bassie-Sweet 1991; Brady 1998; Brady and Ashmore 1999; Rissolo 2001; Stone 1995), current cave studies are concerned with the cave as a locus of community identity, mortuary tradition, and ritual performance.

While cave scholars often disagree over ritual and mortuary evidence for sacrifice or restricted elite usage of caves, there have been recent efforts to integrate regional studies and focus on models for cave use. Writing from a European perspective, Bergsvik and Skeates (2012) identified five areas of focus essential to contextualizing caves within a greater archaeological and anthropological framework: 1) natural and cultural formation processes of caves, 2) stratigraphic record of caves, 3) spatial setting within the landscape and between other landscape features, 4) temporal use of caves by humans, 5) placement of caves within broader socioeconomic contexts, and 6) placement of cave archaeology in historical terms in the anthropological canon. These criteria are generally incorporated into all current Maya cave studies, as there is a contemporary focus on regional perspectives and formation processes.

Because of these recent efforts by archaeologists to take broader, more contextualized perspectives, Kieffer and Scott (2012:19) questioned whether there is a "Mesoamerican cave paradigm." The authors stated that, following Geertz's notions of social paradigms, a Mesoamerican Cave Paradigm does exist based on the following attributes: 1) caves were primarily used for ritual, 2) caves must be understood from an indigenous perspective, 3) caves played a significant role in pre-Columbian society, and 4) cave archaeology can address wider theoretical issues. Focusing on the Maya region specifically, Spenard (2014:104) expanded on Kieffer and Scott's conclusions and described the current Maya cave paradigm as one that "stresses that karst features were socially significant places used by both elites and commoners for ritual interactions with the sacred animate earth and a variety of supernatural beings thought to inhabit those underground locations including ancestors and the rain god, Chahk."

Caves are integral to understanding sociopolitical organization and ritual activity in central Belize. Because there is evidence that the Maya utilized caves in the Roaring Creek, Caves Branch, and Sibun River Valleys for some time before these areas were occupied by large civic ceremonial and residential centers, caves have the potential to reveal changing social and cultural processes related to mortuary activity, political boundaries, and ritual behavior and the timing of these transitions. Fluctuating variables of economic, political, and environmental pressure articulate with archaeological evidence for site use by the pre-Hispanic Maya (Wrobel et al. 2010). The remainder of this chapter will discuss the various archaeological evidence for cave and rockshelter use in prehistory. Following that, a discussion of the temporality of caves and rockshelters precedes a summary of the sampling issues and biases in these spaces.

Caves as loci of cosmological beliefs

The natural topography of the ancient landscape was linked inextricably to the supernatural world in prehistoric Maya belief systems (Ashmore 2009; Brady and Ashmore 1999). Caves were associated with supernatural deities, fertility, and (re)birth, as the Maya considered the cave to be the site of creation and renewal (Brady and Veni 1992; McNatt 1996; Moyes and Brady 2012). Ethnographic accounts, coupled with archaeological data, reveal that the Maya considered mountains to be home to supernatural earth deities, while the mouths of caves were the entry to both the hollow mountain and the underworld (Bassie-Sweet 1991; Brady 1989; 1997; Brady and Ashmore 1999; Fitzsimmons 2009; McNatt 1996). A portal from the earthly world into the invisible realm of the underworld gods, the cave was the interim point from which one could shift worlds (Bassie-Sweet 1991; Scherer 2015). The cave was not simply a geologic feature, but a touchstone of the “living manifestations of spiritual power” (McNatt 1996:81). Referencing the modern Maya practice of episodic visitation of caves and cenotes to petition and make offerings to the supernatural gods inside, Scherer (2015) stated that visitation of caves has occurred in some form since the Preclassic period.

Caves as sources of sacred water and sites of water rituals

Water and caves are inextricably linked in Maya cosmology. Watery pools in caves were revered as portals to the underworld and the use of uncontaminated cave-sourced water (*zuhuy ha*) in rituals was widespread among the Maya (Thompson 1975). Water dripping from the upper reaches of a remote cave was particularly desired in these rituals since it had contacted neither the ground nor humans (Thompson 1975).

Aside from drawing sacred water from caves, the Maya also used caves as sites to petition for water from the underworld deities. Drawing on archaeological and epigraphic studies of the Maya, Moyes (2007) argued that caves were connected with ideas of control of water resources and agricultural yields. Using the site of Chechem Ha, Belize as an example, Moyes (2006; 2007) suggested that use of caves for ritual practices intensified in the Late Classic as part of a reaction to climatic stress. The drought cycle experienced by the Maya during the collapse correlates with changes in elaborateness and style of ritual cave use at Chechem Ha, indicating that there was a concerted effort to appeal to the deities that were associated with the caves (e.g. deposition of large jars in remote parts of the cave, emphasis on complete vessels, etc.). Subsequent abandonment of the area after the drought period suggests that this effort was a failure (Moyes 2007). Regardless of outcome, this active negotiation with landscape features shows that there was "a ritual response to the environmental stress." (Moyes 2007:51).

Caves as boundary markers

Scholars have explored ideas regarding the use of natural features like caves, rockshelters, and cenotes as boundary markers for different social or ethnic groups (Andres et al. 2011; McAnany 1995; Roys 1943; Wrobel et al. 2013b). Because these landscape features are associated with water or mountains (elements crucial to the Maya religious belief system), groups would have been highly motivated to stake landscape claims on caves. The continual maintenance and protection of these natural features would have required ritual circuit activity (McAnany 1995), or the repeated revisiting of spaces to leave offerings or otherwise confer ownership. In some cases, Maya political boundaries may have covered thousands of kilometers (Marcus 1993) and so maintenance of peripheral locations like caves and rockshelters could have been integral to the preservation of the community.

Caves incorporated into civic-ceremonial centers

Due to the spiritual importance of caves in Maya cosmology, it is not surprising that many settlement sites contain caves or were connected to local caves via causeways (Brady and Ashmore 1992; Scherer 2015; Slater 2014). Brady and Veni (1992) argue that the leaders of sites absorbed caves into their territory as a way of demonstrating their divine connection to the underworld. Caves are associated with a number of large settlement sites like Chichen Itza (Thompson 1938), Dos Pilas (Brady 1997), and Aquateca (Houston 1987). Often, these caves contain evidence for ritual activity that pre-dates residential occupation of the area which suggests that the cosmology and ideology influenced site construction, in effect determining where the architectural features would be placed. In building a site near caves, or by establishing pathways to peripheral caves, elites were ensuring claims on the ancient landscape. Mirro (2007:vi) called this practice the "political appropriation of caves" by groups that were motivated by political, economic, and ritual pressures to control these spaces. Brady and Veni (1992) argue that the leaders of sites absorbed caves into their territory as a way of demonstrating their divine connection to the underworld.

Central Belize offers an interesting case study through which to explore the relationship between caves and settlement sites as Tipan Chen Uitz ("Fortress Mountain Well" in Yucatek

Maya), a major urban center, is located near untold numbers of caves and rockshelters in the valley. Looters' activity has revealed that a significant feature of Tipan Chen Uitz is the presence of multiple cave chambers beneath constructions. Artifact assemblages in these chambers demonstrate that the subterranean spaces were used for ritual purposes (Andres et al. 2010).

Caves as repositories for sacrificial victims

Caves containing small numbers of individuals have been variably interpreted as spaces for the elite, for persons belonging to a specific lineage, or even locations of sacrificial deposits (Brady 1989; Gibbs 2000; Mercer 1895). The debate between scholars over evidence for the encavement of sacrificial victims continues in the literature currently. Osteological evidence for sacrifice is generally lacking in Maya skeletal assemblages (Gibbs 2000; Tiesler and Cucina 2007; Wrobel 2008; Wrobel et al. 2014), though the alternative case can be made that it is possible to kill an individual without scarring the skeleton. While there is glyphic text evidence for burial of individuals in caves after death, there is currently no glyphic record of human sacrifice in caves (Helmke 2009; Wrobel et al. 2014). Helmke's (2009) extraordinary study of the Maya epigraphic corpus described the written record as "relatively mute" (p. 521) on the subject of sacrifice in caves, noting that the bulk of the Classic Maya texts reference caves in the context of war and military exploits.

Certainly what can be agreed on is that interment of human remains in a cave is not unassailable proof of sacrifice, as caves served a variety of ritual functions through time. For example, the extremely large assemblage of human remains at the cave site of Actun Kabul shows no evidence of perimortem trauma, though all individuals do skew younger in age (a common trait of sacrificial victims). Researchers have often referenced the central Belize cave sites of Actun Tunichil Muknal and Midnight Terror cave in their claims of human sacrifice in caves due to the atypical positioning of the remains, the restricted demographics of the assemblages, and, on occasion, the pathological conditions of the remains (Awe and Helmke 2007; Buikstra 2007; Gibbs 2000; Kieffer 2015; Lucero and Gibbs 2007). Owen (2002; 2005) determined that based on body positioning, lack of grave goods, and restricted age distributions, the skeletal remains at Barton Creek Cave in west central Belize were sacrificial victims. Pronouncements of sacrificial victims are often made in association with an argument for the collapsing Maya world during the Terminal Classic period, wherein some researchers propose that sacrifice was used as an appeasement to the underworld spirits to restore order in the world. At present, it is irresponsible to conclude that all encaved individuals were sacrificial victims; future analysis of cave burials should proceed cautiously to avoid essentializing or dramatizing mortuary assemblages in caves.

Caves as restricted mortuary repositories

Cave burials never occurred at a large-scale in the Maya world, likely due to the difficulty in maintenance of these subterranean spaces outside of the immediate habitation zone (Scherer 2015). Disturbance of cave burials, by animals, water, or living persons, would have effectively limited the number of inhumations, thereby leading archaeologists to ask even more questions about the significance of these burials. Scholars who do not subscribe to the idea of encaved individuals as sacrifices understand the skeletal deposits found in these ritually charged spaces were deposited as primary or secondary inhumations and that the restricted nature of mortuary use likely reflects the control of each space by a socially defined group, such as a small community or an extended family group. Because skeletal remains in caves are often surface deposits, commingling and taphonomic activity obscures the reconstruction of mortuary formation processes. Currently, it is accepted that cave burials can represent non-sacrifices, but the social status of these individuals is still largely debated.

In her study of fifteen caves and two rockshelters in the Sibun River Valley, Peterson (2006) determined that, from the Middle Formative to the Colonial period (1000 BC – AD 1798), elites appropriated large caves for mortuary and ritual use while non-elites utilized smaller caves and rockshelters. This pattern certainly appears to be true of the Caves Branch and Sapodilla Rockshelters in the Caves Branch River Valley as well. The caves/elites and rockshelters/non-elites hypothesis is based on the belief that lower status Maya did not have the economic or social capital to be interred in tombs, so they were variably placed in rockshelters, shallow caves, and chultuns as part of a sacred ritual that was conducted in the same manner but at a different scale of that of the elite (Glassman and Bonor 2005). While elites may have been buried in caves as part of their privileged afterlife entry to the "creation cave," non-elites may have been interred in rockshelters to symbolize their placement at the threshold of the "creation cave" (Glassman and Bonor 2005).

Social and ritual meaning of rockshelters in Belize

Researchers have increasingly considered rockshelters (and the shallow caves often associated with the rockshelters) in their analyses of ancient Maya sacred landscape use (Dunham et al. 1998; Glassman and Bonor 2005; Goldstein and Prufer 1999; Hardy 2009; Saul et al. 2005; Scott and Brady 2005; Wrobel et al. 2007). These mortuary sites were regularly used as burial locales approximating what archaeologists believe were rural cemeteries for the non-elite agricultural communities. Linguistic studies of modern groups have revealed that the pre-Hispanic Maya may have understood caves, rockshelters, cenotes (formed after the collapse of the uppermost portion of a cave), sinkholes, grottoes, springs, and crevices in a cohesive framework with functional distinctions between each not sharply drawn in many cases (Brady 1997, Brady and Ashmore 1999; Rissolo 2005; Tiesler 2005; Vogt and Stuart 2001). Archaeological data recently emerging from rockshelter studies indicate that rockshelters appear to have been used in a fairly uniform manner, but ethnolinguistic studies to date have not revealed definitively if the ancient Maya conceptualized these spaces in the same manner as caves (Brady 1997; Rissolo 2005). While cultural material found at rockshelters generally differs from material recovered from dark zone caves, Dunham et al. (2009) contended that rockshelters were probably conceived of as entrances to the underworld as well.

In Central Belize, there is documented functional variation between rockshelters that have been subject to archaeological investigation. Ceramic data from both Caves Branch Rockshelter and Sapodilla Rockshelter in the Caves Branch River Valley indicates that these mortuary spaces were re-visited intermittently over extended periods of time likely as part of a ritual circuit that the Maya practiced as a mortuary activity (Wrobel et al. 2007). Hardy (2009) reported on six rockshelters in the Caves Branch River Valley, noting the differences between density of assemblages and artifact types at each rockshelter. The number of individuals interred at rockshelters varies greatly, though all individuals appear to be of a lower social class due to the modest grave goods recovered at these sites. Data from the rockshelters excavated by CBAS, as well as Rissolo's (2001; 2005) study of five rockshelters in Quintana Roo, Mexico, does seem to support the incorporation of rockshelters into a broad mortuary paradigm that included caves and cenotes as well (see also Slater 2014). Rockshelters, while once overlooked, have become important sources of information on the prehistoric ritual landscape probably denoting some formalized burial program for non-elites that were not afforded interment in civic-ceremonial centers.

Temporality of cave and rockshelter use

Cave use by the Maya in Belize spans an enormous time period, from the Early Middle Preclassic through the Terminal Classic (Awe et al. 1998; Brady 1989; Graham 1980; Hardy 2009; Mirro et al. 1999; Moyes 2007, 2008; Peterson 2006; Reents 1980) and into modern times. This use through time is a testament to how important subterranean spaces were though their meaning, function, and symbolism likely fluctuated through time. Surrounding caves in the Macal, Roaring Creek, and Sibun river valleys also produced ceramic assemblages that suggest Preclassic and Early Classic use, but remain incomparable to the extensive activity that characterized the Late Classic (A.D. 700-800) period (Griffith 1998; Helmke 2009; Moyes 2009; Peterson 2006; Wrobel et al. 2009, 2010).

In Central Belize, ceramic assemblages demonstrate continuity of use at Caves Branch Rockshelter and nearby Deep Valley Rockshelter, while smaller rockshelters and caves in the area are only used later. Wrobel et al. (2009) interpreted this pattern as a possible indication that ritual activity was being practiced by more inhabitants, or that the influx of migrants into the region resulted in cave appropriation and subsequent reconfiguration of site use according to social class. Before the establishment of the monumental center Tipan Chen Uitz, as well as minor centers Deep Valley and Yaxbe, in the Central Belize River Valley, local populations were utilizing rockshelters for burial. However, usage of cave spaces appears to follow the introduction of the centralized administrative cores.

The nature of cave use shifted through time as well, as the Maya increasingly utilized different parts of caves to perform ritual activities (Helmke 2009; Morton 2014; Wrobel et al. 2009). Perhaps due to increases in both social complexity and population size during the Late Classic, the Maya intensified their focus on cave ritual and pursued deeper segments of caves than before. Interestingly, small crevices and overhangs also become incorporated into the ritual program (Wrobel et al. 2013). During the Late Terminal Classic larger caves show evidence for increasingly complex ritual activities, a pattern that is reflected in the adjacent Roaring Creek and Sibun River Valleys (Awe et al. 1998; McAnany et al. 2003; Wrobel et al. 2009). These temporal trends are also reflected in the continuous, though intermittent, use of the rockshelters.

The Late Classic escalation of cave use

Use of caves and rockshelters as sites of mortuary and ritual activity accelerated in the Late Classic, with more diverse and expansive use of these spaces (Awe 1998; Halperin 2001; Helmke 2009). In current archaeological models of cave use, it is thought that cave access was governed by social status; that is, elites earmarked the large, impressive caves for themselves while non-elites were relegated to smaller caves and rockshelters (Peterson 2006; Scott and Brady 2005; Wrobel et al. 2009). Escalation in the ritual use of caves and rockshelters must have been linked to changing rules of mortuary behavior, possibly reflecting shifts in social complexity at the local level. A singular cause for changes to the existing social system is unlikely; rather, researchers have identified a number of possible explanations, all of which must be understood as interrelated elements. Moyes et al. (2009) have suggested that this boost in ritual cave usage correlates with serious droughts throughout the region. As tensions rose throughout the Late and Terminal Classic periods, the incumbent elites were facing increased challenges to their power and rule. Escalating ritual use of caves in this time period may have reflected efforts to "shore up deteriorating prestige and sacred authority" by the anxious elite population (Wrobel et al. 2010). Claim to, performance within, and maintenance of caves (and possibly rockshelters) may have served to strengthen territorial boundaries for the political hierarchies that surfaced during the Classic period (Wrobel et al. 2010).

The future of Maya cave and rockshelter archaeology

Further analysis of human skeletal deposits from caves and rockshelters examined in a contextualized regional approach will continue to reveal the relationship between burial space and social identity, but a greater understanding of cave and rockshelter interments cannot move forward based only on the study of skeletal remains. Synthesis with other previously under-studied datasets, such as zooarchaeological remains representing the ritual caching of animals and contemporary ceremonial hunting (Anderson 2009; Brown and Emery 2008) and paleoethnobotanical samples (Morehart 2002), must be undertaken to fully appreciate the breadth of prehistoric use of natural geologic features. Other sources, such as Helmke's (2009) analysis of the epigraphic corpus and the ethnographic observation of cave ceremonies by modern ritual specialists, such as the events detailed in Scott's (2009) dissertation, can also effectively help bioarchaeologists to contextualize the significance of prehistoric cave use. In current models, it is most likely that cave use and meaning changed through time according to social and cultural transitions that *may* have been linked to status.

A stronger conclusion can be made in the assessment of status in the rockshelter burials. Lack of elaborate grave goods, presence of utilitarian vessels, and dearth of cranial and dental modifications underscores the supposition that rockshelter interments are the deceased members of communities living nearby. In summary, the present study does assume that due to the archaeological evidence gathered thus far, the rockshelter burials are those of local, rural commoners. Conversely, the present study does not claim that all the cave burials examined here are the remains of elites. It is tempting to oversimplify the past at times by gravitating toward 1:1 correlations (e.g. caves = elites, rockshelters = commoners) because these binary divisions would greatly aid in data interpretation. It is unlikely that caves were used only by elites as these karstic spaces occurred throughout Mesoamerica and mortuary ritual in some form and capacity does, of course, belong to everyone.

The difficulty in determining the significance of caves and rockshelters in ancient Maya ritual and mortuary programs underscores the need for a dissertation study such as this one. By addressing one biological variable, dental health, through multiple means (e.g. caries, hypoplasias, and microdefects), a better understanding of *how* the burials at the site types differ leads to the more anthropological inquiry of *who* is buried in caves and rockshelters. Following the how and who questions, the central investigation, as referenced above, of *why* these spaces differ can be better understood.

CHAPTER 3: DENTAL GROWTH AND DEVELOPMENT

Micro- and macroscopic analyses of teeth allow bioarchaeologists to investigate subadult health since the permanent dentition is formed during early childhood. Unlike bones, which constantly remodel throughout life and can essentially erase evidence of stress or disease episodes in many cases, teeth do not remodel so dental developmental defects are permanently recorded. Enamel has the distinction of being the most highly mineralized structure in the human body and differs from other tissues (e.g. bone, cartilage, or dentine) because it is non-collagenous, originates from epithelium, and is not subject to remodeling or resorption (Fincham et al. 1999). Since dental development occurs over a period of multiple years from slightly before birth to adolescence, instances of episodic stress recorded in the enamel present bioarchaeologists with opportunities to develop a time-sensitive narrative of the overall health experience of individuals (at least in cases having well-represented dentitions). Determining the timing of stress episodes in population studies can be useful in identifying the causes of that stress, such as weaning or other cultural behaviors related to developmental ages (Cook 1981; Danforth 1989; Hillson 2014). However, while clinical and experimental research over the past couple of centuries has revealed much about the microscopic structure of teeth, the biological forces driving the development, timing, and significance of some microdefects are still being debated in the literature.

This chapter begins with a discussion of the composition, growth, and eruption of human teeth. An explanation and description of the microscopic anatomy of the teeth as it relates to histological research then precedes sections on the specifics of the micro- (Wilson bands) and macrodefects (enamel hypoplasias and caries) analyzed in this study. Finally, a review of the history of dental histology in anthropology concludes the chapter.

Composition, growth, and eruption of human teeth

Human teeth have a complex architecture that reflects their anatomical function for mastication. Two sets of teeth (deciduous and permanent), composed of tooth types of different forms (e.g. incisors, canines, premolars, molars), characterize the human dentition. The deciduous set is composed of 20 teeth, while the permanent set is composed of 32 teeth. Each tooth has an antimere located on the opposite side of the dental arcade. The crown, root, and pulp chamber form the tooth with the enamel-dentin junction separating the enamel from the internal dentin and the cement-enamel junction dividing the root from the enamel crown (Hillson 2005). The root is secured in the alveolar bone via the periodontal ligament, a group of semi-flexible specialized connective fibers. Dentin, another calcified tissue, is found in the root, inferior to the crown, and surrounding the pulp chamber (Hillson 2005). The pulp chamber houses the nerves and blood vessels that supply the teeth.

The stages of dental development

Dental growth and development is controlled both by genetic and environmental factors, beginning in utero and continuing until approximately 25 years of age (Aiello and Dean 1990). Genetics dictate the size and shape potential of the teeth, while the environment determines the extent to which the potential is fulfilled (Hillson 2005). Growth initiates at the cusp tip and continues lengthwise to the root apex (Dean 1989). Dental growth is generally understood as occurring in three stages: formation of crowns, formation of roots, and eruption of teeth (Smith 1991).

Approximately six weeks after fertilization, the fetus develops dental laminae, or bands of epithelial tissues, which extend into the jaw tissues (Hillson 1996). Epithelial cells grow and swell around the dental lamina producing tooth germs in which the enamel and dentin will be deposited (Hillson 2005). Development and growth of teeth progresses through three stages: bud stage, cap stage, and bell stage. During the bud stage, mesenchymal cells grow around the conglomeration of epithelial cells to form the dental papilla, which will aid in the formation of dentine and pulp (Hillson 2005). The enamel organ, derived from the epithelial cells, will eventually lay down enamel. The enamel organ grows and the tooth germ passes into the cap stage followed by the bell stage during which hard tissues are finally deposited. At this point, the tissues inside the tooth germ are differentiated and the epithelial cells form a number of layers (Hillson 2005). A series of infoldings characterize the enamel organ at this stage and indentations for cusps and ridges in the tooth crown start to materialize. The dental papilla and tooth germ are enclosed by the enamel organ, while the crypt develops outside the tooth germ in the jaw.

Dentine, produced by odontoblasts, is the first tissue to be deposited. Odontoblasts generate dentine along the enamel-dentine junction where the future tooth cusps will form (Fitzgerald and Rose 2000). Soon after, the epithelial cells that line the interior of the enamel organ began to differentiate into ameloblasts. These ameloblasts take the form of closely linked sheets of cells and each ameloblast acts to produce enamel matrix (Hillson 2005). The enamel matrix is laid down around 14 to 16 weeks after fertilization (Hillson 1996). Enamel cusps grow by apposition as the ameloblasts continue to add to the dome-shaped layers of enamel (Hillson 2005). Under microscopic view, enamel is made up of thousands of enamel prisms that are formed by ameloblasts, which secrete matrix toward their distal ends (Fitzgerald and Rose 2000). Post-secretion, the matrix mineralizes and the enamel reaches its final state of maturity (Fitzgerald and Rose 2000).

Once the crown is formed, the root begins to develop via odontoblasts and cementoblasts (Hillson 2005). Odontoblasts deposit pre-dentin while the cementoblasts begin to overlay it with cementum matrix, thus forming the root. In multi-rooted teeth, the band of active odontoblasts is divided so that each root has a separate band depositing conical layers of dentine until the root is completely formed (Hillson 2005). The pulp chamber of the tooth is formed when odontoblasts located in the apex of the tooth cone stop the production of predentine (Hillson 2005). Odontoblasts then form the top and lining of the pulp chamber. The tooth will start the eruption process before the root is complete. Dental cementum, a tissue that consists of organic collagen fibers, serves to anchor the periodontal ligament to the root (Hillson 1996).

Dental eruption

Dental eruption has long been studied by anatomists. By the late 1800s, researchers were producing dental age and eruption charts based on variable populations and samples. Often, the early charts, several of which are still used today, were developed on disparate populations (Moorrees et al. 1963; Schour and Massler 1940; Ubelaker 1978) demonstrating that while differences in dental eruption timing between groups or individuals can vary by weeks or months, in essence the teeth will erupt on a regular schedule.

Table 2. Dental eruption schedule (adapted from Logan and Kronfeld 1933).

Tooth	Age at First Evidence of Calcification	Age at Complete Enamel Formation	Age at Eruption
Deciduous mandibular canine	6 mos. in utero	9 mos.	16-20 mos.
Central maxillary incisor	3 – 4 mos.	4 – 5 years	7 – 8 years
Third maxillary molar	7 – 9 years	12 – 16 years	17 – 21 years
Third mandibular molar	8 – 10 years	12 – 16 years	17 – 21 years
Mandibular canine	4 – 5 mos.	6 – 7 years	9 – 10 years

Generally, the deciduous teeth erupt in order from anterior to posterior position (Hillson 2005). Permanent incisors and first molars often erupt around the same time (approx. 7 years), followed by the canines, premolars and second molars, which all generally erupt concurrently at around 9 years (Hillson 2005). Deciduous teeth erupt in order from the first incisors, second incisors, third premolar, canine, and fourth premolar (Hillson 2014).

Table 2 shows general eruption schedules for teeth pertinent to this study. While it has been documented that females develop on a faster schedule than males, this difference has not been shown to be statistically significant (Smith 1991). Thus, there is no reason to suspect that males and females in the Maya samples in this study experienced significantly different dental eruption processes or schedules.

Microscopic anatomy of the enamel

There are three main features that comprise the internal anatomy of enamel: prisms, prism cross striations, and brown striae of Retzius (Hillson 2014).

Enamel prisms

Prisms are the “main structural unit” of enamel (Antonova 2011:33). Prisms form as a result of ameloblasts depositing enamel. Enamel prisms grow appositionally, leading out from the enamel-dentin junction (EDJ) to extend to the surface of the tooth crown (Hillson 2014). During the process of mineralization, the organic matrix is replaced almost wholly by hydroxyapatite crystals (Antonova 2011). This process forms the basis of the enamel prisms. The first 5 µm of enamel adjacent to the dentin and to the external tooth crown are devoid of prisms due to the cessation of the last stages of amelogenesis (Marks 1993). Approximately 4 – 6 µm apart, the prism boundaries run parallel to each other and obliquely across the tooth section (Hillson 2014). The number of prisms within each tooth varies according to tooth type, ranging from 5 million prisms per mandibular lateral incisor to 12 million prisms per maxillary first molar (Marks 1993).

Prism cross striations

Prism cross striations are short-period markers variably expressed throughout the enamel. This irregular expression leads to difficulty in tracing the full length of a particular striation. The prism striations present microscopically as light and dark bands, evenly spaced cross-hatch marks that run across the lines of the enamel prisms and represent a developmental cycle of enamel matrix secretion that lasts about 24 hours (short period Circadian rhythm) (Hillson 2014). Cross striations were first noted by Leeuwenhoeck in 1674, though Massler and Schour (1946) discovered the micro-features were linked to circadian rhythms much later after an experimental study of terminally ill patients called for the injection of sodium fluoride at periodic intervals. The researchers were able to demonstrate that the days lapsed between injections was equal to the number of cross striations between artificial markers in the enamel. Through the view of a light transmitted microscope, the cross striations appear as alternating bands of light and dark that cross enamel prisms every 4 μm (Hillson 2005). Boyde (1979) hypothesized that the striations were the result of changes in carbonate levels in the apatite minerals that is regulated by the intake of carbon dioxide.

Intradian lines

Intradian lines, another type of short-period markers formed between the prism cross-striations, were originally thought to be an artifact of problematical microscope visualization (Boyde 1964). Because enamel is formed in layers and visualization of the layers is somewhat transparent, Boyde hypothesized that the intradian lines were simply cross striations of different enamel layers that overlapped each other. Subsequent studies (Gustafson and Gustafson 1967;

Boyde 1989) demonstrated that intradian lines did in fact exist, but the cause(s) of their exact timing is still the subject of ongoing research. Smith (2006) suggested that intradian lines represented 12 hour periods, while Fitzgerald (1995) argued that the lines form on a cycle of 8 or 12 hours. Because of this ongoing debate and the uncertainty of their meaning, intradian lines were not included in this study.

Striae of Retzius

Striae of Retzius, also known as Retzius lines or Brown striae of Retzius, are long-period markers first described by Retzius in 1837 (reviewed by Boyde 1964). Striae of Retzius run in a perpendicular orientation to the enamel prisms and under the microscopic appear variably thick and dark. The striae take on the appearance of “domes” in the cuspal enamel and “sleeves” in the lateral enamel when viewed in three dimensions (Hillson 1996).

In their most prominent state, striae can be viewed as lines extending from the dentino-enamel junction to the external surface of the tooth (Simpson 1999). Hillson (2014) and Risnes (1998) noted that striae of Retzius rarely continue as the clearly expressed form they take near the crown surface; if the striae are followed toward the enamel-dentin junction, their expression often becomes amorphous. Viewed in a transverse plane, striae in the cusp of the tooth are typically 30 – 45 μm apart, while the striae in the cervical portion of the tooth are about 15 – 20 μm apart (Fitzgerald and Rose 2008).

Striae of Retzius are deposited in a routine event that reflects a circaseptian (around 7 days) period of regular growth lasting 6-9 days (Hillson 2014; Simpson 1999). According to Marks (1993:51), “a striae is registered each time the ameloblast gradually slows for this temporary rest resulting from the pressure decrease in the cell.” The metabolic rhythms influence secretion of enamel matrix, thereby changing the rate and density over the circaseptan cycle in a regular manner (Fitzgerald and Rose 2000).

Due to the non-uniform mineralization process throughout the tooth, the daily secretion rate and the width of the prisms vary. Boyde (1964) found that prisms were, on average, 3 μm wide and formed at a rate of 3 μm per day in the cuspal part of the enamel. However, the lateral layers of enamel contained prisms that measure about 5 -6 μm wide with secretion rates of 5 – 6 μm per day (Boyde 1964).

Perikymata

Perikymata are slight grooves or undulations on the outer enamel surface seen mostly under microscopy that result from the termination of the striae of Retzius. Perikymata are formed when the ameloblasts cease secretion of the enamel matrix just before reaching the crown surface, thus creating the shallow grooves that circumnavigate the tooth (Hillson 2005).

Microscopic defects of the dentition

The significance of micro- vs. macroscopic dental defects is still debated in the anthropological literature. Generally, it is thought that the exhibition of a visually identifiable enamel surface defect is reflective of a chronic stress event, while microscopic defects are generally indicative of a rapid and acute stressor (Wright 1990). Enamel hypoplasias, which are macroscopic defects, result from prolonged stressors (weeks to months) that disrupt enamel matrix formation whereas microscopic defects called Wilson bands result from brief stress events (1-5 days) (Wilson 2014). While it may seem reasonable to conclude that every instance of enamel hypoplasia would be preceded by Wilson bands, this study and previous studies (most notably Simpson 1999) found that this was not the case. Reasons for this incongruity between dental defects are discussed further below, but first it is necessary to define and describe microscopic defects of the dentition viewed in human teeth.

Neonatal line

The neonatal line is the most common example of a microscopic defect in the teeth. Thought to result to the trauma and stress of birth, this darkened band has been used to age individuals since the line essentially acts as "day zero." Little much research has been dedicated to the study of Wilson band development that occurs prior to the neonatal line, though in theory such data could possibly be linked to maternal and fetal health stress in utero. By counting the cross striations that occur after the formation of the neonatal line, it is possible to date periods of stress events in childhood by counting the days between birth and the defect manifestation. However, this work is painstaking and tedious, requiring laborious time investment and very clear dental slides that are often not possible to create when working with archaeological samples. Certainly modern, freshly extracted teeth prepared in a variety of thicknesses would be more easily assessed for daily cross-striations than the archaeological dental materials in this study, which were cut at only one thickness and often not visually ideal due to age. The first molar, the only permanent tooth to retain the neonatal line, would have to be selected in all samples in as the zero point in order to count the cross-striations in an individual's dentition. Due to labor intensity, the friability of the archaeological teeth, and the lack of reliability in securing first molars from all individuals in a sample, the aging method involving counting cross-striations from the neonatal line is applicable to few studies.

Wilson bands

The type of striae of Retzius on which this dissertation project focuses is called a Wilson band. Wilson band formation can be understood as a disruption in amelogenesis, or the process of enamel formation. Amelogenesis is linked to the body's production of amino acids, which enable the body to make proteins necessary for enamel production. If the proteins are inhibited or not produced due to some stressor, the enamel formation process will suffer, potentially resulting in dental defects (e.g. hypoplasias, Wilson bands).

Most researchers identify Wilson bands (also known as accentuated striae of Retzius or pathological Retzius lines) by their morphological differences when compared with normal striae of Retzius; the pathological bands are generally wider and longer, and exhibit atypical prism structure (Fitzgerald and Saunders 2005). Thomson (2011:63) stated that "the intensity, type, and/or duration of stress do not determine the size and shape of the defect." Another idea that has been posited by Goodman and Rose (1990) and recently tested by Witzel et al. (2008) states that individual ameloblasts are variably susceptible to stress and this differential reaction causes Wilson bands to take on an array of appearances. A detailed discussion of Wilson bands can be found in the Methods chapter.

Macroscopic defects of the dentition

Two types of macroscopic defects, enamel hypoplasias and caries, were assessed for this study. In the anthropological literature, these macrodefects are considered non-specific indicators of stress; that is, there is no precise disease or disorder that initiates the manifestation of the defect. Rather, a generalized series of events or the combination of stressors results in the development of a carious lesion or an enamel hypoplasia (e.g. prolonged poor diet, dental trauma, chronic illness, etc.).

Enamel hypoplasias

Much has been written about enamel hypoplasias in the anthropological literature, as the defects are fairly easily observable and quantifiable. A chapter published in 1999 estimated that there were around 1000 clinical and bioarchaeological studies of enamel hypoplasias to retrospectively study individuals' health (Goodman and Song 1999). Hillson (1996:165) defined an enamel hypoplasia as, "a deficiency of enamel thickness, disrupting the contour of the crown surface, initiated during enamel matrix secretion." Enamel hypoplastic defects are essentially a thinning of the enamel that can traverse numerous perikymata with or without a disruption to the internal enamel prisms (Goodman and Rose 1990). They are observed macroscopically as a developmental defect in the formation of enamel on the tooth surface taking the form of pits, planes or furrows (Hillson 1996, 2014). Linear enamel hypoplasias (LEH), the most commonly observed manifestation of hypoplasias, form as a result of a disruption in ameloblast activity during the secretion of enamel matrix (Goodman and Song 1999) and "follow the trend of the perikymata" (Hillson 1996:165), meaning that they assume a linear trajectory around the tooth when viewed macroscopically. By recording the position of the LEH on the tooth, it may be possible to estimate the age of the individual at the time of the developmental insult. The physiological disruption that results in an enamel hypoplastic defect cannot be linked to a specific day. Rather, the defect is the biological result of the development, incubation, and manifestation of the stress (e.g. malnutrition, psychosocial, etc.) that takes time to evolve. It should be noted that defect size cannot be used as an indicator of duration or severity of stress (Hillson 2014).

Etiology of enamel hypoplasias

The appearance of an enamel hypoplasia cannot definitively reveal cause, duration, or intensity of the stress, but archaeological context, culture history, and skeletal analysis may aid in the interpretation of hypoplasia occurrence. While the observation and documentation of hypoplasias is well-cited in the literature, the etiologies of hypoplastic defects are varied and the assignment of cause to defect(s) is often difficult. Development of enamel defects have been attributed to a variety of external (trauma, lack of access to nutritional sources, cultural modification of teeth) and internal (genetics, chromosomal anomaly, congenital defects, metabolic disruptions, infectious disease, neonatal disturbances) factors (Buikstra and Ubelaker 1994). Early laboratory experiments using non-human models attempted to find cause(s) for developmental dental defects, but were largely unsuccessful in isolating relationships with a specific external stressor (see Marks 1993:56-57 for review).

Trauma and hereditary anomalies occur with much less frequency, presenting on either one tooth or adjacent teeth (trauma) or throughout the entire dental arcade (hereditary anomalies) (Buikstra and Ubelaker 1994; Cook 1980; Goodman and Rose 1990). Modern clinical studies have shown that developmental enamel defects co-occur with a wide range of disorders, syndromes, and diseases including: hypoparathyroidism, taurodontism, sclerotic bones, Ehlers-Danlos' syndrome, Down's syndrome, congenital heart defects, low birth weight, various metabolic disorders, premature birth, hypocalcemia, rubella, neurological conditions, diabetes mellitus, nephropathies, enteropathies, celiac disease, and more (Pindborg 1982; Waldron 2009).

Location of hypoplasias

The position of the defect on the tooth surface reflects the completeness of the crown at the time of insult (Goodman and Armelagos 1985). Hillson and Bond (1997) argued that the location of the defect on the tooth surface is related to the area of the crown under development when the stress event took place. Interestingly, researchers have reported that LEHs were most often exhibited in the middle third of the tooth, which has many implications for analysis and interpretation of results. In a study of location of enamel defects, Goodman and Armelagos (1985) found that, in the anterior dentition, hypoplasias most often occurred in the middle third (followed by cervical third and incisal third). Hypoplasias were most frequently noted on the middle thirds of both molars and premolars as well.

This finding could be due to specific tooth architecture that allows for greater areas of susceptibility in defect formation, or it could be the result of defects forming during age periods that are linked to the middle third of the tooth. For incisors and canines, peak periods of enamel hypoplasias do tend to occur around ages two to four years, coinciding with pre- and post-weaning periods in many cultures (Goodman and Song 1999) and the middle third of the tooth crown.

Co-occurrence of LEHs and Wilson bands

While Wilson bands and surface defects may be found within the same tooth, one defect can exist without the other (Simpson 1999; Wright 1990). Witzel et al. (2008) found that micro-defects often occurred in the absence of macro-defects on the crown surface. Simpson (1999) has suggested that since Wilson bands and enamel hypoplasias can occur independently of one another, the epidemiology of each defect could be distinctly different.

Dental caries

Frequencies of caries are widely tabulated in bioarchaeological investigations of prehistoric health, diet, and disease. Carious lesions are visualized as dark eroded areas on the tooth (Buikstra and Ubelaker 1994) and are usually easily observed by the naked eye. Larsen (1997:65) defined dental caries not as the observable lesions on the enamel surface, but rather as, "a disease process characterized by the focal demineralization of dental hard tissues by organic acids produced by bacterial fermentation of dietary carbohydrates, especially sugars." Generally, the posterior teeth are more susceptible to caries formation due to their broad crown morphology, pits and fissures on the occlusal surface, and chewing surface area. However, as age increases, interproximal, cervical, and root caries occur with greater frequency than in younger individuals (Buikstra and Ubelaker 1994).

Development of these enamel lesions is due to multiple interactive factors including, but not limited to: food preparation techniques, oral plaque, nutrition, periodontal disease, dental wear, composition of enamel, salivary composition, and more (Larsen 1997). Generally, once sugar (or carbohydrates) became widely available in prehistory, its consumption affected the occlusal surfaces of the teeth, most notably the fissures of the molars (Waldron 2009). Combining the caries data with the enamel defect data can result in a broader picture of health stress for particular individuals. For this project, caries data were collected for the purposes of future research studies as a comparative data point; however, the observation and quantification of caries in the samples reported here was not a main focus of this research.

History of dental histology in anthropology

The biological review of dental growth and development, as well as the discussion of enamel defects, outlined above can be used to understand the role of dental histology in anthropology. Anatomists first investigated the microstructure of the dentition as they did with all other tissues of the body, but dental researchers soon took up the mantle of describing and defining dental micro-features. Early studies of dental histology were descriptive in nature, noting that enamel disruption was caused by environmental factors and metabolic disturbances (Schour 1936; Massler et al. 1941; Schour and Massler 1940). Early researchers contributed greatly to the identification and description of the striae and cross striations in studies that were able to demonstrate that amelogenesis took place in a predictable manner (Massler and Schour 1946; Schour and Massler 1937; 1941). It was these investigators who first noted the neonatal line in deciduous teeth and the first permanent molar. This particular accentuated stria of Retzius would later factor into aging studies of prehistoric and modern dental samples.

In 1970, Wilson and Schroff recorded their observations of irregular prisms viewed microscopically, terming these irregularities, "Wilson bands." This irregularity in prism appearance was attributed to some external force that caused a disruption in normal ameloblastic activity. One of the first and most well-known applications of dental histology to anthropology was a paper by Bromage and Dean (1985) in which the authors argued that early hominid dental growth mimicked dental formation rates in modern apes rather than the lengthier enamel development times of modern humans (Fitzgerald and Rose 2008).

Though now over 25 years old, one of the most thorough anthropological literature reviews of physiological disruptions in the dentition is a paper by Goodman and Rose (1990). The authors summarized many decades of histological research and proposed three factors necessary to create a disturbance in the enamel, either macroscopically or microscopically, which formed the basis for later bioarchaeological studies. These conditions are: 1) the unknown susceptibility of the individual, mostly due to genetics; 2) deficiencies in nutrition; and 3) illness. These factors, especially when combined, will lead to disruption of normal cellular activity and result in the cessation of ameloblastic activity. These observations have continued to be referenced in the anthropological literature as researchers attempt to sort out the complex biological and social processes underlying defect formation.

Dental histology as an investigative method in anthropology is not readily used by researchers. During the 1980s and 1990s, anthropologists sought to further their studies of health stress by incorporating microscopic research into their traditional methods (Danforth 1989; Goodman and Rose 1990; Rose et al. 1978; Rudney 1983; Wright 1990). Some minor interest in the 2000s followed (Fitzgerald and Rose 2000; Fitzgerald and Saunders 2005; Fitzgerald et al. 2006), but dental histology largely came under the purview of case study or small-scale research endeavors with occasional use in forensic anthropology (Skinner and Anderson 1991; Walker et al. 1997). At the time of this dissertation, a search of the ProQuest database of theses and dissertations revealed that relatively few anthropological projects have been carried out using dental histology as a primary or secondary method of inquiry since the 1980s (Antonova 2011; Condon 1981; Danforth 1989; Garland 2014; Karhu 1991; Marks 1993; Reeves 2013; Reilly 1986; Thomson 2011; Wilson 2014).

Despite the important and sensitive data derived from histological methods, use of dental histology in bioarchaeology and forensic anthropology is likely constrained due to a number of reasons: 1) the preparation of friable archaeological samples is time consuming and not always successful as enamel shatters during the preparation process, 2) there is a lack of a single, established protocol for defining, identifying, and measuring Wilson bands, 3) there is disagreement in tooth selection, thin sectioning/embedding procedures, and microscope technique in the literature, and 4) the method is inherently destructive. In the past five years, there has been some resurgence in the use of dental histology for investigating health in bioarchaeological contexts, as multiple theses and dissertations have been recently completed using the method with varying degrees of success (Antonova 2011; Garland 2014; Reeves 2013; Thomson 2011; Wilson 2014). Furthermore, Hillson (2014) recently highlighted dental histology in his newest book, Tooth Development in Human Evolution and Bioarchaeology, discussing its application to archaeological samples and addressing key methodological problems.

The sub-field of dental histology is, in reality, still somewhat nascent. Marks (1993) provided an honest and detailed discussion of the difficulties of histological research given the constraints of both the method and our limited knowledge of the etiology of defects. Many of his concerns remain unresolved today, though researchers have been working to better understand the timing and appearance of internal dental anatomy structures (Dean and Beynon 2005; Fitzgerald 1998; Reid and Dean 2006; Risnes 1998) in the fields of oral biology and primatology. Thomson (2011) succinctly outlined what is required in order to successfully complete a dental histological study: "…microscopic studies of enamel require a clear definition of what constitutes a stress event, the selection of an appropriate sample, the employment of the correct aging methods, and a realization of the non-specific nature of the data" (p. 48). This quote summarizes several issues endemic to bioarchaeological study of dental microstructure, namely the disagreement in the literature over what criteria are necessary to indicate a stress event and the lack of population-specific aging methods in archaeological samples.

Results from dental histopathology studies are varied, but a general conclusion found by most authors is that dental microdefects are caused by early childhood stress linked to environmental and cultural factors like poor nutrition, disease, maternal stress, and weaning, and thus may be of use in studying the biological effects of a variety of social processes and institutions, including sociopolitical change, residential migration, and social age. Anthropologists can (and should) continue to pursue research on enamel formation tempos to address inter- and intra-specific variation of past and present populations. Unfortunately, perhaps due to restrictions in journal article length, many researchers do not fully detail their methods, leading to difficulty in replicating studies and using comparative samples. With continuing research into dental microstructure at genetic and developmental levels, as well as in methodological and technological advances, the field of dental histology is poised to address important anthropological, biological, and clinical questions in the future.

CHAPTER 4: MEASURING AND INTERPRETING ANCIENT MAYA HEALTH

By studying the dental and skeletal manifestations of systemic stress, bioarchaeologists may begin to interpret a portion of the complex social, emotional, and physical experiences of individuals in prehistory. Paleopathological analyses of the human skeleton and dentition have long dominated the attention of physical anthropologists, with many texts detailing the numerous diseases, traumas, and health stressors that can be identified in bones and teeth (Buikstra and Ubelaker 1994; Ortner and Putschar 1981; Waldron 2009, for example). Historically, physical anthropologists have examined a variety of specific and non-specific indicators of disease or stress such as porotic hyperostosis, osteoarthritis, cribra orbitalia, carious lesions, linear enamel hypoplasias, Wilson bands, Harris lines, and periostitis in order to reconstruct disease prevalence and health experience in burial populations (Armelagos 1990; Larsen and Walker 2010; Pinhasi and Stock 2011).

The body is a nexus of biology and culture (Sofaer 2006; 2011), so rather than calculating the presence of a disease in an individual or the frequency of pathological features in a given population during a particular time, modern bioarchaeological questions seek to address patterns of health and infirmities that reflect social and ecological interaction processes. Re-framing traditional bioarchaeological investigations of population health by infusing skeletal and dental research with social theory allows researchers to understand why and how a particular disease or health stressor is distributed throughout a population, why certain individuals might be more susceptible to health stress, and how disease experiences and pathogen loads might be related to or influenced by larger social mechanisms and culture change.

Clinical research outside of the field of anthropology has aided bioarchaeologists in differential diagnoses of pathological conditions present in archaeological samples (Gowland

2015). However, while bones and teeth react to stress in somewhat predictable ways, many observable pathologies are indicative of generalized systemic stress responses (the etiologies of which are still debated). Rather than seeking to link skeletal or dental pathologies to a specific stressor, health in bioarchaeological research is studied as a complex interaction between biology, environment, and culture. Steckel and Rose (2002:3) described the far-reaching effects of health studies, noting that "historians and political scientists have identified inequality, not only in income or wealth, but also in the form of disparities in health and nutrition, as a driving force in social, political, and economic change." Social inequality in the past, as interpreted through skeletal biology, can shape our understanding of ancient cultures and lived experience. Stress, chronic and acute, had tangible impacts on ancient Maya individuals and populations who managed their health against a backdrop of changing environmental and cultural factors.

In this chapter, remarks on the definition and measurement of stress in human populations precede a discussion on the interpretations and limitations of health studies in bioarchaeology. A review of Maya literature on health follows, highlighting the topical themes that most health studies in this region cover. Finally, due to the formation of the adult teeth during childhood, a brief summary of the importance of childhood studies in archaeology is presented. The difficulties of "seeing" children in the material record and the main factors affecting childhood health are outlined and the most relevant literature on ancient Maya concepts of childhood health is discussed.

Defining and measuring stress in human populations

The study of stress in human populations can encompass dietary, social, psychological, economical, political, and environmental factors that result in some physiological disturbance(s) (Goodman et al. 1988). Pressures of these types on an individual can create a stress event or a kind of generalized stress, both of which often have biological consequences (though these are not always observable or quantifiable). Stress can be defined as, "a physiological response that serves as a mechanism of mediation linking any given stressor to its target-organ effect" (Everly and Lating 2002:15).

Selye (1974, 1976) pioneered studies of the adverse effects of stress on the human body, introducing the concept of "general adaptation syndrome" (GAS) to explore how the body reacts to stressors. GAS serves as a model through which stress was defined as a response and the stimulus was defined as a stressor (Everly and Lating 2002). Selye's model can be succinctly understood as a series of progressions in which, 1) a stress event occurs, 2) the bodily system is disturbed, and 3) the body responds to the stress event. External environmental stimuli, like malnutrition, disease, or psychosocial stress, disrupt the equilibrium of the body. This disruption removes the body from its homeostatic state, setting off a biological chain of events geared to make the body return to equilibrium. At first, the body may initiate a behavioral response to the stimuli/stressor, which may or may not be successful. Following this, a physiological response to the stimuli/stressor can manifest in the bones or teeth. Karhu (1991:10) stated, "physiological/developmental responses to stressors are dependent on the duration, frequency and intensity of the stimuli." Girdano et al. (2009) determined that stressors can be psychosocial or biogenic, the former being either real or imagined. Researchers who study the human stress response in living populations acknowledge that psychosocial stressors do not cause the stress response, but rather set the body up for the evocation of the response (Everly and Lating 2002). Alternatively, biogenic stressors cause stress responses due to biochemistry.

Bioarchaeologists have adapted the Selyean stress model to reflect archaeological constraints and nuances (Hillson 2014; Larsen 1997). This model has been used by researchers in many studies that address the cultural and social constraints placed on individuals' bodies that negatively affect their health. These psychosocial stressors are rarely conspicuous events in prehistoric populations, but archaeological evidence can help to fill in gaps. Goodman et al. (1988) described the utility of stress research in bioarchaeology using methodology and examples that underscored the complex interplay between culture and biology. The authors presented a well-reasoned plea for bioarchaeologists to incorporate stress models that map the relationship between health and adaptation to internal and external factors. Clearly, both the threat and reality of psychosocial stress must be considered in archaeological populations known to have undergone intensive cultural change or disruption (e.g. movement of new ethnic groups into a region, abandonment of civic centers, etc.).

Even in cases where individuals have the benefits of elevated social status, external stimuli can still negatively impact health experience. Status and resource access may not always be buffers against stress, but rather contributors to the cause of stress (see Maya-specific examples later in this chapter). For instance, in his discussion of stress events represented by enamel defect formation, Hillson (2014:203) commented on the difficulty faced by bioarchaeologists considering psychological causes: "It has not been possible to find any clinical study in which psychosocial factors alone are implicated in enamel defects, even though it seems reasonable enough to suppose that this might be the case." As is the case with so much in clinical and bioarchaeological studies, absence of evidence of psychosocial stress linked to observable defects does not mean that the correlation does not exist – only that it is difficult to measure or has not yet been addressed.

Interpretations and limitations in bioarchaeological health studies

It is possible that anthropologists, using multiple lines of evidence, such as ethnohistoric accounts or iconographic images, can comment on the mental and social well-being of individuals in the past, but only physical well-being can be identified to a degree in the bones and teeth. Mental and social dysfunction may contribute to a physiological disruption in the body, but these causes are ephemeral at best in the archaeological record. For bioarchaeologists, Goodman and Martin (2002:12) provide a definition of stress as, “a measurable physiological disruption or perturbation that has consequence for individuals and populations.” As Hillson (2014:199) stated regarding archaeological samples, “health is essentially measured through ‘unhealth.’” That is, for bioarchaeological study, the presence and prevalence of observable defects are used to estimate health experience in mortuary assemblages.

Because bioarchaeological studies of prehistoric health rely on the manifestation of observable pathologies in the bones and teeth, all studies are rendered unavoidably incomplete since not all stressors have a physical presentation (and not all skeletons are complete). These limitations on bioarchaeological data (e.g. skeletal and dental remains) result in an appreciably limited view of stress in this past. Non-specific indicators of health stress, such as the dental defects discussed in this dissertation study, do not usually correlate with specific types of stress or particular diseases, so detailed recreations of individual or population health are necessarily generalized. Micro- and macrodefects are thought to develop when the body undergoes a stress event that surpasses the threshold necessary for enamel defect formation. It is only through multi-factorial analyses, incorporating archaeological, cultural, and biological data, that useful anthropological interpretations can be made regarding these systemic markers.

Bioarchaeologists have recently cautioned against over-interpretation of pathological states (Walker et al. 2009). Currently, there are very few direct correlations between skeletal and dental lesions and specific diseases. Goodman and Martin (2002:16) advocated for the analysis of pathologies without belief that the cause(s) may be uncovered: "Excessive focus on specific etiology may be unproductive because infirmities are usually the result of multiplicative and interactive forces, and the skeleton typically responds in nonspecific ways. Fortunately, what may be of greatest anthropological interest is not the specific agent that caused infirmity, but the severity, duration, and temporal cause of physiological perturbation."

Combinations of biological models and social theory, as well as the use of ethnographic and ethnohistoric data, can successfully augment bioarchaeological health studies of prehistoric peoples. Clinical analogies drawn from literature on modern populations, as well as experimental studies addressing the links between disease, diet, and ecology, can also help bioarchaeologists to interpret past health experience. Temple and Goodman (2014) recently argued for the incorporation of methodological approaches and theoretical models from primatology, epidemiology, and human biology into bioarchaeological study in order to enhance the relevance and comparability of bioarchaeological research to other sub-fields.

Any bioarchaeological study of health would be incomplete without the consideration of the osteological paradox, or the general notion that adult skeletal remains with lesions could actually be the healthier individuals in a population because these individuals weathered the stressor(s) and survived past initiation and completion of the disturbance. Citing considerations of heterogeneous frailty and selective mortality in skeletal populations, Wood et al. (1992) cautioned bioarchaeologists that the most unhealthy individuals may have died before observable pathologies were impressed on the skeleton, whereas those individuals exhibiting pathological features may have been healthy enough to survive the disease or stress and continue living. The publication of this paper caused many thoughtful debates in the literature (see Cohen et al. 1994; DeWitte and Stojanowski 2015; Wright and Yoder 2003) as researchers attempted to work out what this information meant for their particular samples and the field at large. Recently, Dewitte and Stojanowski (2015:397) admonished anthropologists for not engaging with the osteological paradox in more sophisticated ways, arguing that research should be directed toward subadults and intra-site studies, as well as exploring the relationship between stress markers and demographics and the biological process of skeletal lesion formation. Ultimately, researchers agree that the osteological paradox should be seriously considered when making interpretations in bioarchaeological studies of health.

Review of health studies of the ancient Maya

Archaeological, epigraphic, and iconographic evidence indicates that the Maya were a stratified society, consisting of polities of varying size and power led by a dynastic elite that controlled access to and management of resources (Coe 2005; Marcus 1993; McKillop 2004). Past research endeavors have focused on the identity and influence of the elite class, those thought to have controlled and directed the Maya world. However, the role of the non-elites in the processes of creating, influencing, rejecting, and manipulating the history of polities and the structure of communities needs to be critically examined in the archaeological record. The efforts of the non-elite classes in the shaping and maintenance of Maya society cannot be underestimated as these are the masses responsible for specialized labor, construction of public works, movement and trade of goods, and food production (Marcus 2004). Non-elites directly affected the political economy of ruling civic centers and were likely innovators during the process of production (Marcus 2004). As kingships splintered, an untold number of rural Maya withstood the Classic Period collapse (Webster and Gonlin 1988). It is worth investigating, then, the behaviors, rituals, and mortuary patterns of the largest (yet arguably least visible) segment of the prehistoric Maya population.

Critical examinations of the variable of health, seen through the lens of diet and disease, as part of the package of lived experiences has dominated the bioarchaeological literature on the ancient Maya. Cucina and Tiesler (2005) asserted that traditional bioarchaeological itineraries have focused primarily on identifying biological correlates of ecological collapse and social status, with a marked focus on elites buried in tombs or ceremonial centers. This near singular emphasis on elites has resulted in much archaeological excavation being performed at site cores and within public buildings (Cucina and Tiesler 2005). Because large skeletal assemblages representative of populations (non-elite or otherwise) have not been recovered due to preservation issues and other factors, bioarchaeological studies of small or mid-size burial populations are still needed. In terms of Maya studies of health and stress, research often deals with the "collapse" and Contact periods though the data sets vary across studies.

Dietary studies of health and nutrition accessibility can also be used as part of a multifaceted approach to interpreting status when analyzed in conjunction with mortuary data like grave goods and burial locale. Similar to modern populations, the consumption of and access to food sources was likely an indicator of social privilege in prehistory. In Mesoamerica, status could be (but was not always) expressed through differential access to food resources and by consumption of foods with ideological and ritual significance (Danforth 1999; White 2005; White and Schwarcz 1989).

Cucina and Tiesler (2003) argued that lifestyle differences could be reflected in the dental health of past individuals, even within social classes. An analysis of antemortem tooth loss, dental calculus, and frequency of caries showed that while there were significant differences in dental health among male and female elites, there was no discernible difference in dental health among commoners (Cucina and Tiesler 2003). Interestingly, these data suggest that the Classic Period Maya may have practiced differential access to food resources at the elite level; perhaps only males were benefitting from their elevated social status.

Aside from the macroscopic indicators of poor health like calculus, caries, and tooth loss, isotopic analyses have also played a role in assessing paleodietary practices that may have resulted in stress events (Gerry 1997; White et al. 2001). White et al. (1993) related a study of isotopic ratios in 33 individuals buried in either residential or site core contexts at Pacbitun, Belize. An analysis of isotopic signatures showed that there were differences between males and females, though the extent to which this distinction related to status was unclear. Because males were more often interred in the site core as compared to females (2:1 ratio), the authors hypothesized that status (reflected in deposition in the site core) was linked to resource access (White et al. 1993). This means that members of the upper class were consuming more protein, suggesting that they were selected to receive better food resources. However, it must be noted that dietary studies should consider the impacts of cultural and subsistence activities that could be linked to age and sex rather than status (White et al. 1993). Divisions of labor and social attitudes toward individuals of particular ages or sexes could contribute to resource access. To explore the association between diet and social status, White et al. (1993) analyzed burial context, distance of grave from the site core, and presence and quantity of grave goods. To this end, the authors were able to frame the interplay between diet and status in a more sophisticated manner and not assume a direct correlation. In a review of paleodietary studies of ancient Maya mortuary samples, Wright and White (1996) investigated the interaction between skeletal biology, diet, and the presumed ecological basis for the Classic Maya sociopolitical "collapse." After a re-examination of the data, the authors demonstrated that skeletal pathologies and isotopic data did not consistently support changes in Preclassic and Early Classic periods when compared with the Terminal Classic. Rather than a wide dietary shift, Wright and White (1996) postulated that local environmental and sociopolitical factors likely influenced diet (and, to an extent, disease).

Utilizing a modern population to explore pathologies of the past, Wright and Chew (1998) compared forensic samples of the crania of rural children from Guatemala to ancient Maya crania to re-address questions of porotic hyperostosis and anemia in prehistoric populations. Modern children with known conditions of anemia had far fewer skeletal lesions than the individuals from archaeological sites. Interestingly, Wright and Chew were able to demonstrate using forensic data that anemic children were more likely to reach adulthood in ancient populations than in modern populations.

All of these studies center on the themes of diet and resultant pathologies from poor nutrition, but the breadth of samples and methodological toolkits used to study the samples demonstrate that bioarchaeologists need multiple strategies to evaluate an incomplete archaeological record.

Traditionally, studies of the Classic Maya collapse (800-900 AD), as well as the Contact period (post-1511 AD), focus on ecological or political variables hypothesized to contribute to social disintegration or the stresses of colonization. These periods are disparate in time (separated by ~600 years), but are similar in that they are times of rapid cultural change. Therefore, it is expected that increased disease, shortage of resources, and sociopolitical upset may have affected the lives of the Maya during these periods.

These studies utilize different data sets (e.g. climate, material culture, etc.) to address the cause(s) and/or transitions associated with these periods during which the Maya were re-organizing their political alliances, social structure, and cultural interactions. Bioarchaeological research has focused on health experience leading up to (or at the time of) collapse (Cucina and Tiesler 2003, 2005; Danforth 1989, 1997, 1999; Gerry 1997; Storey 1997; White et al. 2001; White 1997, 2005; Wright 1997; 2006), or during the Contact period when the Maya were introduced to new biological and social stresses brought on by the arrival of the Spanish (Danforth 1989; Wright 1990).

Interestingly, a number of these health-based studies have shown discordance with hypotheses derived from archaeological data in that a decrease in health status is generally not associated with sociopolitical stress and social status. While a tempting correlation may be made between social wealth and health status, bioarchaeological studies have shown that elites were not always protected against physiological disruptions or disease due to their class (and, presumably, access to resources). For instance, in her analysis of dental defects at Late Classic Copan, Storey (1997) found that residence in the site core did not protect against childhood health stress. Social capital did not translate to greater health experience during the Late Classic, possibly due to a variety of issues related to restricted consumption of status-specific foods, political upheaval during the Late Classic, or urban living conditions (Storey 1997). During the Late and Terminal Classic periods, skeletal indicators of stress affected the entirety of the social stratum regardless of status (Storey 1999). Wright (2006) was able to identify health stress patterns in the Pasión Maya of varying social statuses, which was likely related to a combination of environmental, social, and political issues at the time of the collapse. Danforth (1997) used bioarchaeological evidence in her dental defect study to demonstrate that individuals living in the periphery experienced fewer dental pathologies than those living at site cores in the Late Classic, a result that may not have been expected from the material record and speculations about the political and social dynamics of the Late Classic.

In a study of dental remains from burials at urban and semi-rural sites of different sizes from the Late Classic and Contact periods, Danforth (1989) found that there was a low correlation between Wilson bands and linear enamel hypoplasias in Maya populations, most likely due to different etiologies for each type of defect as well as the structure of each tooth class. Danforth was able to conclude that differences in status, as related to residence at urban vs. more peripheral sites, did not dramatically affect childhood health. Interestingly, Danforth discovered that while there were few differences in defect formation between sexes and ages, individuals with deciduous hypoplasias were significantly less likely to live past four years of age. Because three Late Classic sites of varying political clout were examined, Danforth also was able to state that sociopolitical organization was not a factor in the development of dental defects, as all three sites experienced similar childhood health patterns. That is, there was no health distinction by class in the Late Classic and Contact groups, even though there was likely socioeconomic differentiation between individuals during life. It can be assumed, then, that "the general consistency in defect patterns, especially in the timing of growth disruptions during childhood, suggests considerable continuity in Maya culture over time" (Danforth 1989:ix).

The only significant difference in Danforth's study was that the Late Classic Maya populations experienced significantly more health stress during the ages of 4 – 5 years than the Contact Period Maya. While Danforth (1989) compared Contact and Classic period populations, other researchers have examined Maya skeletal and dental remains from the Colonial period in isolation to address questions about the biological consequences of the arrival of foreign persons and ideas to the Maya world. White (1997), using isotopic analyses of diet, was able to demonstrate that the arrival of the Spanish had an inconstant biological impact on the Maya with some amount of increased stress but not to the degree that may be reasonably hypothesized given what is known of the cultural impact of contact.

Similarly, the site of Tipu, a colonial era cemetery in western Belize, has been studied by multiple researchers interested in the interaction between colonization and health stress (Danforth et al. 1997; Harvey 2011; Jacobi 2000). Again, there appears to be no skeletal or dental evidence for significantly increased health stress following contact with the Spanish, despite the obvious introduction of disadvantageous cultural changes brought about by the forced interaction. While environmental and social disturbances certainly affected the lives and culture of the Maya at both the end of the Classic Period and the duration of the Contact Period, a number of researchers have posited that since contact or collapse cannot fully explain health disruptions or disparities there must be much more complex social reasons for the deleterious conditions observed in mortuary samples (Danforth 1989, 1999; Wright 2006). Similarly, there are likely multifaceted explanations for the relationship between health and social status, as well as the processes of achieving, attaining, maintaining, and negotiating that status during life. The results of the studies discussed here indicate that the Maya life experience cannot be easily reduced to interpretations that rely on singular events to explain health.

Health experience during childhood

A review of childhood health studies on Maya mortuary populations is warranted in this chapter due to the shift away from description and tabulation of physiological disturbances (e.g. enamel hypoplasias, Wilson bands, Harris lines, etc.) and turn toward a more interpretive focus on how these defects would have affected individuals during their formative years. Physiological disturbances due to restriction of resources, malnutrition, disease, and psychosomatic stress can result in pathological alterations that are inscribed on the teeth and persist indelibly through adulthood since the permanent dentition develops during childhood and adolescence. Even though this dissertation study attempted to access a wide range of ages by examining different tooth classes, the ages of interest are still confined to childhood (incisor and canine) or adolescence (third molar).

Childhood is a time of significant cultural and biological change as the developing body reacts to cultural, environmental, and nutritional influences (Bogin 1997). Due to the traits of dependence and socialization that are associated with it, childhood is a "universal life history stage" (Thompson et al. 2014:1) and therefore research done on other populations in other geographic locales has some bearing on the Maya sample presented here. The archaeology of childhood as a research area has gained considerable ground in the literature since the 1990s as an extension of gender theory exploring "invisible" populations (Ardren 2006; Lewis 2007; Perry 2006).

Because the time period before the attainment of adulthood is a formative social period, the study of children can inform on the relationship between age and gender, identity, agency, and personhood as individuals engage with and manage new social personas (Baxter 2008). Previously, the active and agency-filled lives of children were not critically considered in archaeological inquiry; that is, children were viewed as a passive audience to the culture-creating adults around them. The care for and training of children to develop into social actors versed in the prevalent political and economical attitudes of a particular culture is critically important in understanding prehistoric societies (Baxter 2008).

The importance of bioarchaeology in childhood health studies

Since childhood is "both a biological and cultural phenomenon" (Halcrow and Tayles 2008:190), bioarchaeologists who work from a biocultural perspective are uniquely positioned to answer questions about the earlier years of life in the past. However, previous analyses of sub-adult skeletal remains have often lapsed into biological *or* cultural approaches, rarely integrating both perspectives (and social theory) until relatively recently (Baxter 2008; Halcrow and Tayles 2008; Kamp 2001; Lewis 2007; Perry 2006; Sofaer 2011; Thompson et al. 2014). Children comprised significant percentages of ancient populations (Chamberlain 1997), so their exclusion from bioarchaeological analyses is unwarranted. Dental health, especially the study of enamel hypoplasias and Wilson bands, can illuminate early childhood and adolescence as the adult dentition is formed at this time.

Typically, bioarchaeologists consider three concepts of age: 1) physiological or biological, identified through the sequential physical changes associated with maturation; 2) chronological, identified by the passage of time since birth; and 3) social, characterized by cultural constructions of age periods (Sofaer 2011). There is a difference between the umbrella term "childhood" and the chronological age of the non-adult. Whereas "childhood" is culturally prescribed and can be described as the multi-year period before adulthood, the chronological age of the individual is based in biology. Markers of biological maturity (e.g. puberty, secondary sex characteristics) associated with biological and chronological ages may or may not coincide with social age indicating the transition to adulthood (Lewis 2007). None of these age concepts should be considered in isolation; rather, each concept informs the others in an anthropological investigation of childhood. Just as chronological age cannot offer information about social position, social age cannot offer conclusions about biological processes (Sofaer 2011). An analysis that considers the relationship between all age concepts, when possible, is critical to an informed bioarchaeological study.

Archaeological (in)visibility of children in the past

Children are generally underrepresented in bioarchaeological studies due to a variety of cultural and taphonomic reasons (Jackes 2011). Certain societies may restrict children from being buried at sites with other community members, or may call for the interment of children in mortuary contexts that are not privy to bioarchaeologists. Additionally, children's remains can be more susceptible to post-mortem disintegration due to thinner cortical structures and smaller size. The underrepresentation of children in mortuary contexts either through taphonomy or researchers' disinterest, coupled with the assumption that sub-adults did not have political or social agency, has led to a mischaracterization of children in archaeological interpretations of past social structures (Baxter 2008). Finding similarities between the treatment of women in the archaeological record in decades prior, Baxter (2008:162) wrote of the "shared history of disempowerment, marginalization, and invisibility" between women and children.

More recently, researchers have worked to find children in the material record, as well as to source ethnographic information that explains societies' views of childhood. Recovery and analysis of ancient toys, small fingerprints in clay pots and trial-and-error lithics and ceramics have all been used as evidence that children actively and consistently contributed to the society (and thus to the archaeological record) (Ardren 2006; Kamp 1999; Lopiparo 2006). Ethnohistorical and ethnographic accounts of childhood (and the social parameters dictating it) can help to explain an archaeological record that has traditionally overlooked non-adults. Ardren (2006:7) stated, "…the rituals of childhood were also key rituals of the state and, as such, windows to the cultural values anthropologists strive to illuminate."

Factors affecting childhood health

Developmental disruptions and health stress during childhood is likely linked to a variety of biological and cultural factors. Many bioarchaeologists have argued that early childhood is a time of susceptibility not only to disease, but also to the cultural factors that may inhibit adequate access to resources and nutrition (Bogin 1997; Lewis 2007). Unique to the mammalian experience, human children undergo a period of dependence after breastfeeding that is not observed by other mammals. Demographic studies of pre-industrial societies consistently illustrate the precarious position of subadults from birth to around the age of five years (Corrucini et al. 1985). Before the age of five years, children experience the process of weaning off mothers' milk as their diets are supplemented by cereal foods and meats. Stress, of some degree, during this time period is expected across all cultures and time periods as children develop the antibodies needed to protect against exposure to pathogens and infection (Perry 2006). The weaning process is not the stressor; rather, it is the reduced consumption of breast milk, which lowers immunological aid, that can result in a stress event (Wright 2006). Reilly (1986) also cited the psychological effects that the weaning period has on the child as she separates from the mother and begins to, in part, figure out self-feeding. Generally, the weaning period lasts from the ages of 1 – 2 years, with a period of stress following into the 3rd to 5th years as the child adjusts to new diet supplemented by cereals and/or meats (Corrucini et al. 1985; Perry 2006).

Because young children are initially dependent on parents or community members for food and protection, they are often the most vulnerable members of a given society. Though incorporation into more adult roles varies by culture, children of age ten or older may begin to perform work that puts them at greater risk for injury or disease (Lewis 2007). The transition from childhood to early adulthood is also fraught as the individual's mobility restrictions are released and s/he may come into more contact with stressors as workload and societal contributions are increasingly expected.

Ancient Maya concepts of childhood

Studies of children in the skeletal assemblage, as well as the assessment and attainment of personhood, have appeared with more regularity in the Maya literature in the past several decades. Ardren (2006), in the opening chapter to her co-edited volume about the social experience of children in ancient Mesoamerica, began with a reminder that the Western concept of a blithe childhood untouched by the responsibility of adult life is specific to a particular Western culture/time period and cannot be imposed on the past. Ardren (2006) viewed the development of an archaeology of childhood along two lines of inquiry: 1) the identification of Maya children in the archaeological record as a means to uncover the ignored voices of prehistory and 2) the examination of the process of cultural information diffusion through children as a means to uncover the cultural mores of the pre-Hispanic Maya.

In Mesoamerica, differences in nutritional stress between children and adults, apparent occasional sacrifice of children, and labor demands of children have been used as examples of poor treatment of children. However, translations of hieroglyphics have demonstrated that a sub-adult ascended to a royal position at the age of twelve (Ardren 2006). Nutritional stress disparities may be explained by susceptibility factors not related to cultural food restriction or exclusion practices. Labor demands, while not appropriate by modern Western standards, may be skewed by our modern insistence of childhood as a "carefree" period (Ardren 2006). These disparate accounts illustrate that childhood in Mesoamerica was perhaps not broadly defined or experienced in the same way across regions and time. Joyce (2000) identified discrete periods of childhood in Aztec populations wherein different social rituals were performed and transitional ceremonies marked movement from one stage to the next. Vogt's (1970) ethnographic account of modern Maya demonstrated that children were segregated by biological sex around age nine and expected to perform different labor tasks. Around thirteen years of age, the transition to adulthood and personal identity began, and Gellar (2011) stated that the Maya conceptualized individuals as adults around the ages of 15 – 19 years. Adolescents were even accepted into political roles (Ardren 2006).

There has been some effort by Mesoamerican archaeologists to address chronological age categories as they relate to social age and cultural rites (Storey and McAnany 2006; Trachman and Valdez 2006). Most applicable to this dissertation study, McAnany and Storey posited that childhood age periods were most meaningfully divided in experiential categories: ages 1-3 (before walking, a period of total dependence), ages 4-9 (after weaning, transition to different diet), and 10-13 (approaching puberty, incorporation into social adulthood). These social and biological age categories are generally found in other studies of Mesoamerican cultures, as related by Joyce (1994, 2001) in her studies of Central Mexico and Yucatan ethnohistoric documents from the 16th century. In the Mexica culture, children were treated as homogenous beings with no attention paid to individualism. However, by ages 4-8 years, the Mexica began to train for their eventual adult roles (Joyce 2006). Toward the end of this second phase of childhood, Mexica received ear piercings that would eventually become the bodily site for the important ear spools and were introduced to ceremonial drinking. Upon puberty around age 13, males and females were dressed in sexually dimorphic clothing and received ear spools and adult haircuts (Joyce 2006). Clearly the ethnohistoric documents that exist for the Mexica do not exist for the Classic period Maya, but Landa's (1941) descriptions of the Maya of the Yucatan suggest that these social rites were not isolated to the Mexica but rather experienced by a wider circle of Mesoamerican cultures (Joyce 2006).

Ultimately, the specifics of childhood experience in the Maya are still being explored though researchers have demonstrated this period was likely a dynamic interval of each individuals' development both biologically and socially. This dissertation study adds but one layer of information, health experience as interpreted through the dentition, to the canon. Through iconographic interpretations, further archaeological excavation, and a more conscious and deliberate attempt to (re)evaluate sub-adults in the material record, bioarchaeologists may begin to more fully address childhood in the past. Current anthropological thought places children as social agents responding to a host of cultural and social factors that may be restricted by age, however Joyce (1994, 2006) cautioned against conflating direct evidence that children existed (i.e. the presence of juvenile skeletal remains) with cultural concepts of childhood. While the experience of childhood can be viewed, in part, through the biology of the skeleton as it reacts to the natural and cultural environment, anthropologists must avoid essentializing the significant distinctions between individuals' childhood experiences. Children, like adults, were distinguished by their own idiosyncracies and personalities. The focus should be on importance of understanding the social experience of childhood and not simply dismissing it for lack of archaeological evidence or assumptions about the passive role of children in prehistory (Baxter 2008; Halcrow and Tayles 2008). After all, Maya children were not simply "small copies of adults" (Joyce 2006:284).

CHAPTER 5: MATERIALS

The primary sample for this study is composed of teeth of individuals buried at three cave sites and two rockshelter sites in central Belize. Additional teeth from two surface sites, Tikal in western Guatemala and Pacbitun in central Belize, were used as comparative samples. The Pacbitun sample, curated at Trent University, were included with permission from Dr. Paul Healy, former director of the Pacbitun Regional Archaeological Project (PRAP), and Dr. Terry Powis, PRAP's current director. The dental slides from the Tikal sample were originally created by Dr. Marie Danforth for her 1989 dissertation. With the exception of the Pacbitun, Tikal, and Actun Uayzaba Kab materials, all dental remains were excavated during field projects led by the Central Belize Archaeological Survey (CBAS). The Caves Branch Rockshelter material was excavated by both the Belize Valley Archaeological Reconnaissance (BVAR) project and CBAS over the course of the multiple field seasons at the site.

Comparative analyses of individuals from these three distinct mortuary contexts – cave, rockshelter, and surface sites – revealed dental health trends of individuals buried at different site types. The burial sites, especially the cave and rockshelter sites, were characterized by commingling, secondary movement of burials, and taphonomic disturbance. Therefore, the completeness of each burial in the sample was highly variable, resulting in a mixed data set where the complete sample (maxillary central incisor, mandibular canine, and mandibular third molar) was rarely attained.

In total, there are 176 teeth in this study (Table 3). These teeth represent 110 individuals from 7 sites. In addition to the site descriptions below, the total number of teeth sampled (commingled or isolated vs. primary burials), the minimum number of individuals represented by the teeth, age distributions (number of adults and subadults), and number of individuals with multiple teeth available for defect sequencing are noted.

Table 3. Summary of teeth and individuals by site.

Site type (number of sites)	Total teeth in sample	Minimum number of individuals
Cave (3)	64 total AKB: 37 JRH 18 AUK: 9	31 total AKB: 14 JRH: 12 AUK: 5
Rockshelter (2)	39 total CBR: 23 SDR: 16	32 total CBR: 19 SDR: 13
Surface (2)	73 total PB: 40 TK: 33	47 total PB: 20 TK: 27

Actun Kabul (AKB)

Actun Kabul is a large, dark zone cave located on the east side of the Roaring River Valley in central Belize situated within one kilometer of the regional capitol of Tipan Chen Uitz and Midnight Terror Cave, a large mortuary cave (Andres et al. 2014; Brady and Kieffer 2012; Gibbs and Weinberg 2002; Morton and Wrobel 2011; Wrobel 2013). Following reports of looting, Gibbs and Weinberg (2002) first investigated the cave, producing a brief descriptive report focusing primarily on a large chamber near the back of the cave containing highly disturbed skeletal remains. Later investigations by CBAS in 2011, 2013, and 2015 included mapping, as well as documentation and sampling of human remains, ceramics, and other artifacts from a variety of surface features in different parts of the cave.

AKB is a complex space containing multiple chambers, and can be roughly divided into front, middle, and back portions, each characterized by different types of deposits. The front burial chambers were notably devoid of human remains, though ceramic deposits have been described in detail (Shelton et al. 2015). There is a constructed wall of dry-laid stone wall that marks the transition from the front to middle chambers. While this ancient architecture may have been erected as a way to seal off the middle and terminal chambers, portions of the wall were removed in modern times making it impossible to determine if there was a doorway built into the wall or if it was meant to seal the passageway between Chambers 2 and 3 (Morton et al. 2015).

Investigations thus far have focused on the terminal and middle chambers, both of which have yielded human remains albeit in dramatically different concentrations. While ceramic assemblages were noted throughout most chambers, it was initially hypothesized that human remains would only be found in the terminal chamber due to minimal evidence of bone in the preceding chambers. However, upon analysis of the ceramic assemblages in the middle chambers, it was noted that small fragments of human bone and teeth mixed into the large ceramic scatters (Shelton et al. 2015).

The terminal burial chamber

The terminal chamber was systematically excavated and skeletal material was re-associated and removed by CBAS in 2011, 2013, and 2015 field seasons. The terminal chamber (approximately 10m x 3m) served as a large burial repository and is characterized by commingled, disarticulated skeletal elements comprising approximately 150-200 individuals (Wrobel 2013; 2015). The highly fragmentary and commingled state of the burials complicated the recovery of skeletal material from the southern portion of the chamber where bone was so reduced in size that the remains in effect "carpeted" this space. Directly preceding the area are several rimstone dams with scattered human remains throughout. Due to small work teams and a limited number of field days at the site, the 2011 excavations focused on the sampling and recovery of data-rich cranial and dental material, while the other areas of the chamber were documented in situ and mapped. Further excavations in subsequent field seasons focused on detailed photomapping and careful field documentation, but the extensive disturbance of the assemblage necessitated the collection of skeletal and dental remains for laboratory analysis (Wrobel 2015). The terminal chamber areas of interest were divided into a grid of 50 cm by 50 cm subunits that were organized by an x and y coordinate system so that elements could be reasonably re-associated during the laboratory analysis phase (e.g. teeth to alveolar bone) based on proximity of remains, non-repeating elements, and condition of remains. The remains were generally of subadult or young adult age with similar numbers of males and female adults. Bones and teeth were extremely commingled and laboratory analysis showed that there was no perimortem trauma indicating that the bodies had not undergone defleshing procedures (Wrobel 2015). The equal representation of males and females, coupled with the lack of trauma, suggest that the burials were not sacrifices as Maya sacrificial sites trended toward overrepresentation of males and/or subadults (Domenici 2014; Tiesler 2007).

In the upper reaches of AKB, another area called the Chandelier Chamber housed the remains of one primary burial (so called due to articulations of the feet, the right hand, and the right knee) (Wrobel 2015). Beyond this one instance of articulation, the terminal chamber was characterized by commingling with little representation of smaller bones suggesting that remains in the back chamber may have decomposed elsewhere first before transport into the upper reaches of AKB. However, the articulated burial in the Chandelier Chamber does demonstrate that primary burials did occur in the cave in some capacity (Wrobel 2015).

Identification of individual burials in the terminal chamber was nearly impossible. Firstly, the remains were all placed on the surface and, due to lack of articulations observed, it is possible that bodies were processed elsewhere before placement in the cave. Secondly, the mortuary ritual at AKB was predicated on the transfer of remains from a rimstone dam area to a low ceiling area in the furthest reaches of the chamber, a movement that additionally commingled burials and obscured individuality of decedents. Finally, the terminal chamber was looted in modern times, contributing to disturbance and disarticulation.

Ceramic analyses of sherds from the terminal chamber indicate a usage date within the Late-Terminal Classic period, similar to Je'reftheel and nearby Actun Tunichil Muknal (Wrobel 2015). While AMS dating is needed to further refine dates in the terminal chamber and to test the middle chambers, the Late-Terminal Classic date for the upper chambers does seem to fit with the archaeological hypothesis that cave burials/sacrifices increased during this time period as a reaction to droughts (Moyes et al. 2009). An alternative hypothesis by Wrobel et al. (2014) linked the influx of migrants (and social hierarchy) into the area with an increase in mortuary use of caves.

The middle chambers

The middle chambers of AKB are distinctly different from the front and terminal chambers in several ways. The ceramic assemblages in the largest middle chamber, Chamber 3, yielded many diagnostic sherds concentrated beneath a large ledge that follows most of the perimeter of the chamber (Shelton et al. 2015). The sunken and collapsed chamber floor gives the appearance of an amphitheater (Morton et al. 2015). A sizable flowstone formation commands the central portion of the chamber and the ceramic deposits cease in concentration around the flowstone. A pot with a kill hole was also found in this chamber. Moving from Chamber 3 into Chamber 4, there is evidence for vandalism, either in antiquity or by modern looters, on a sloping inactive flowstone feature (Morton et al. 2015). Against the wall marking the transition from Chamber 3 into Chamber 4 an intentionally modified flowstone feature composed of a "curtain wall" and "several thin columns" showed evidence for the removal of part of the flowstone to form a small window that complemented the small pathway (Morton et al. 2015:11).

The entryway from Chamber 4 to Chamber 5 is divided by a large flowstone formation that bisects the entryway to form two paths. These pathways had no surface artifacts and further probing yielded no evidence that these spaces had ever contained material culture deposits as there were no artifacts found in an otherwise artifact-rich space. Two scatters (8 and 10) existed on either side of the flowstone in Chamber 5, both of which were mounded against the cave walls opposite one another. The third scatter (9) was mounded directly in front of the flowstone, centered between Scatters 8 and 10. In total, Shelton identified four scatters of human bones and teeth mixed with thousands of ceramic sherds in the middle chambers (Shelton et al. 2015).

During the 2013 field season, two 1x1 meter excavation units in Scatters 8 and 9 yielded a restricted assemblage of human remains with a concentration of teeth, vertebral fragments, and bones of the hands and feet. Dentition and phalanges, both adult and subadult, were overwhelmingly represented, indicating that there was preferential selection for these elements over others. In the 2015 field season, Scatter 10 was excavated. Flowstone prohibited the setting of a 1x1 meter unit and the boundaries of the deposit were fairly visible, so the borders of the scatter were photographed and mapped. The area of interest was approximately 150 cm in length and 80 cm in width. All skeletal and ceramic material in this area was excavated. Beyond these borders, the cultural material was no longer visible on the surface. Abundant looter activity in this chamber was observed, with a screen, shovel, pair of pants, graffiti, and food debris all noted in the small area, none of which were present during the 2013 season. Looters surely disturbed Scatter 10; additionally, there was gibnut activity visible in the chamber.

Near the front of the cave entrance an adult humerus and 19 loose teeth were found out of context, likely from looters picking up human remains, carrying them through the cave, and re-depositing them at the cave's entrance before exiting into the jungle. It is possible that these teeth came from Scatter 10, as there were teeth clearly visible on the surface in 2013 that were not collected during that field season due to time constraints. Upon a brief return to the cave in the 2015 field season, the middle chamber was found to be highly disturbed by looters who had been digging in the cave floor disturbing the scatters.

The meaning of the deposits in the middle chamber is still unclear, though some hypotheses can be made about the significance of the human remains when the rest of the archaeological context is considered. A large assemblage of broken water vessels was found against one cave wall in Chamber 5. Because the human remains in this chamber are not burials, it is likely that their presence is tied in some meaningful way to the broken water jars possibly reflecting some petition or ritual activity (Moyes et al. 2009). In each scatter, the human remains were mixed with ceramic sherds of varying sizes, though the majority was "buckshot" (i.e. smaller than a U.S. quarter). To date, no detailed ceramic analysis has been done on these deposits but a cursory observation of the materials did not reveal any re-fits in the large amount of body sherds. Many of the sherds were exfoliated, perhaps indicating their use elsewhere as fill for construction episodes. The uniting feature of the ceramics, like the bones and teeth, is their size. That is, all scatters were composed of small, portable elements that could be easily transported and deposited in the cave for some ritual function (Burbank et al. 2014).

The dental remains from the middle and terminal chambers appear to represent different mortuary rituals, perhaps suggesting that the individuals deposited in each area are from different sources. While the terminal chamber appears to have received complete (or nearly complete) burials, the middle chambers are characterized by only physically small human remains (e.g. teeth, phalanges, fragmented vertebrae). The integration of these small elements with non-refitting ceramic sherds in discrete piles in the middle chamber suggests that, though these are human remains, the deposits do not represent burials of individuals. Rather, it is likely that some other ritual requiring human elements occurred in the middle chamber while the terminal chamber was dedicated to placement of the individual decedents.

Description of the sample

Dental samples from AKB were collected from both the terminal and middle chambers. In some instances, presence of calculus, modifications, or postmortem taphonomic conditions helped to identify different teeth to the same individuals. The MNI (n=10) for the terminal chamber was calculated based on the presence of nine left mandibular canines and one right deciduous mandibular canine. The MNI (n=6) for the combined middle chamber scatters was calculated based on the presence of four left central incisors and four right mandibular canines, as well as two right deciduous central incisors.

There are a number of biases that may be at work in the recovery of these teeth, including the differential preservation of more taphonomically resistant adult teeth and the perhaps random selection of teeth for deposition in the scatters. Hundreds of teeth were recovered from AKB, but this study only culled those that matched the selection criteria and were un-modified and free of calculus. There were 12 incisors and 6 canines that were not analyzed due to modifications. One incisor and one canine were removed from the sample because the teeth were still in the crypt and could not be removed without damaging the alveolar bone. One canine was excluded due to severe calculus obscuring the enamel surface. Two canines were not analyzed due to taphonomic alteration from cave burial. Only one instance of defect sequencing was possible, further illustrating the difficulty in re-associating teeth in this excessively disturbed cave context.

Table 4. Summary of AKB sample from terminal and middle chambers.

Chamber	Commingled Teeth	MNI	Age Distribution	Total Teeth From Terminal
Terminal	33	12	10 adults 2 subadults	33
Middle	4	2	2 adults	4

Table 5. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
Scatter GG (terminal chamber)	RM^3 LC_
Scatter A (terminal chamber)	RC_ RM_3

Table 6. Distribution of teeth in the sample from AKB.

Tooth Type	Right	Left
Maxillary central incisor	9	5
Mandibular canine	7	10
Maxillary third molar	1	1
Mandibular third molar	1	2
Deciduous mandibular canine	1	0
Total teeth in sample: 37	19	18

Je'reftheel (JRH)

Je'reftheel, ("Skeleton Cave" in Plautdietsch, also known as Franz Harder Cave), is a dry cave in the Roaring Creek Works, an area of karst outcrops located between the Caves Branch and Roaring Creek river valleys in Central Belize (Helmke and Wrobel 2012; Wrobel et al. 2014). Helmke (2009) identified twelve features in the cave, with seven features associated with human remains. He focused on the ceramic assemblage in the cave, finding that most features were characterized by the deposition of whole vessels (some smashed) consistent in form and dating to the Late Classic.

Recent settlement activities by Mennonites in the area have resulted in the destruction of some ancient housemound structures; as such, it is difficult to determine the association of the cave to prehistoric communities (Helmke and Wrobel 2012). However, investigations by the CBAS project (Andres et al. 2014) and the Western Belize Regional Cave Project (Awe 1998) identified housemounds and a minor civic ceremonial center in the immediate vicinity of the cave. Helmke and Wrobel (2012:80) report three distinct types of activity areas in JRH: "1) entrance areas for ingress and egress, 2) chambers for gatherings and the deposition of the bulk of artifactual materials, and 3) termini that were the preferred areas for the deposition of human remains."

Initial skeletal excavations at JRH began in 2007 as Helmke and Wrobel (under the auspices of the Belize Valley Archaeological Reconnaissance project) collected loose bones from the surface of Features 6 and 7, stopping when articulated burials were noted beneath the matrix (Helmke 2009). Subsequent investigations carried out by CBAS focused on Features 3, 6, 7, and 11 where heavy concentrations of bat guano threatened further deterioration of skeletal remains (Wrobel and Ebeling 2010). During these excavations, it was noted that approximately 5 – 8 individuals of different ages were buried in Feature 7. Interestingly, the pattern of the burials suggested that as individuals were placed in the feature, older interments were swept aside into Feature 6 (a solution funnel) (Wrobel 2011). The final excavations at JRH were performed by CBAS in 2010 when Feature 5, an area containing the well-preserved and generally articulated remains of multiple individuals, was explored. Similar in mortuary nature to Feature 7, Feature 5 also presented a pattern of primary interment with secondary movement of some skeletal elements after decomposition of remains (Wrobel 2011).

Human remains representing individuals of various ages and sexes were dispersed throughout the multiple cave features (MNI = 24). Two areas of the cave appear to have been repositories for whole bodies while other smaller cave features received interments of loose bone and incomplete bodies (Wrobel et al. 2014). Shell tinklers, likely part of a belt or bracelet decoration, as well as a chert biface and possible ear adornments were found with remains in some clusters. No intentional trauma was noted on the skeletal remains, and observable breaks in the bone were ascribed to damage sustained while visitors repositioned the dead and added subsequent bodies. At least in Feature 7, mortuary space appears to have been at a premium as there is evidence that primary burials were later swept down an adjacent hole (Feature 6) following decomposition to create room for subsequent interments (Wrobel et al. 2010). This type of "cleaning" of burial space was also noted in Actun Kabul as described previously. The area was likely used continuously by groups over time; Wrobel et al. (2014) draws parallels with the mortuary use of JRH and a tomb.

All diagnostic ceramics found within JRH dated to the Late Classic period, a time of intensified cave use in the region that coincided with increased sociopolitical complexity in the region (Andres et al. 2011). It has been postulated that JRH may have been used as a burial ground for a selected corporate group, effectively marking territory and establishing boundaries on the newly contested landscape (Andres et al. 2011). Evidence for reuse of burial space, in addition to the presence of grave goods, reinforces the conjecture that the burials do not represent sacrifices (Wrobel et al 2014). Akin to the distribution of burials at AKB, the human remains at JRH were not found in the entrance but in the terminal chambers of the cave (Helmke and Wrobel 2012). The relatively high frequency of congenitally absent third molars among the JRH individuals further supports biological relatedness between the individuals, as does isotopic analysis that revealed most individuals were of local origin (Wrobel et al. 2014). Since the remains of infants and older adults were not present in the burial sample, it is hypothesized that these individuals were purposefully excluded and interment at JRH was guided by a particular social identity (Wrobel et al. 2014).

Description of the sample

The JRH sample consists of 20 teeth representing 12 individuals. The actual number of teeth meeting the criteria for the study was higher, but modified anterior teeth were not included in the study which likely biased the sample to some degree. Nearly all adults interred at JRH had dental modifications, but it was determined that modified teeth should be kept intact for future analyses.

Although the burials at JRH were commingled, sample selection from the site was notably easier than at AKB because the teeth were generally retained in skulls to a greater degree than at other sites with commingled remains, and there were fewer individuals making the re-association of dentitions easier. Skulls A, C, D, E, and H from Feature 5, as well as commingled remains from Feature 7 produced six modified incisors and one modified canine, resulting in seven teeth that were not included in the analysis.

Four individuals possessed multiple teeth used in the sample, allowing sequenced data collection in these cases. The MNI was calculated by counting the number of skulls (n=8) with teeth present for the study and adding the most represented element (mandibular canines; n=2 adult, n=2 subadult) from the commingled teeth. All adults at the site were young, mirroring an age pattern of young adults and subadults in the cave similar to the age distribution at AKB.

Table 7. Summary of JRH sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From JRH
7	11	12	12 young adults	18

Table 8. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
Skull A (2010)	LC_ RM^3
Skull B (2010)	LI^1 LC_
Skull C (2010)	LM_3 RC_
Skull E (2010)	LC_ LM_3
JRH07-6-5 Chamber 2	RC_ LC_ LM^3

Table 9. Distribution of teeth in the sample from JRH.

Tooth Type	Right	Left
Maxillary central incisor	0	2
Mandibular canine	4	5
Maxillary third molar	2	2
Mandibular third molar	1	2
Deciduous mandibular canine	0	0
Total teeth in sample: 18	7	11

Actun Uayazba Kab (AUK)

Actun Uayazba Kab, or "Handprint Cave," is located in the Roaring Creek valley of western-central Belize in close proximity to other ritual caves, including Actun Tunichil Muknal, as well the large civic-ceremonial site of Cahal Uitz Na (Gibbs 1998; Ferguson and Gibbs 1999; Helmke and Awe 1998; Wrobel 2014, in press). Featuring paintings of triangles and handprints in negative relief, a schematic drawing of two figures, charcoal smudges, carved faces, and an elaborate "Petroglyph Panel", AUK represents a unique and complex ritual space (Helmke and Awe 1998). The focus of most activity appears to have been beneath the associated rockshelter overhang entrance to the cave. In addition to the extensive petroglyphs in this area, excavations revealed dense concentrations of artifacts and scattered human bones, architectural elements, and primary human burials (Gibbs 2000). Jacks (2004) performed isotopic analysis on the bones from primary burials at AUK, finding that isotopic values clustered and individuals were local.

Dates derived from ceramics deposited in the cave indicates that ritual use of the site began during the Late Preclassic and continued through the Late to Terminal Classic (Gibbs 1998; Helmke and Awe 1998, Wrobel et. al in press). Similar to other caves throughout the Maya area, activity at AUK increased significantly during the Late Classic period (Andres et al. 2011). The cave was heavily looted before the first excavation by the Western Belize Regional Cave Project in 1997 (Gibbs 1998).

The primary burials were interred in pits, some of which intruded through plaster floors (Ferguson and Gibbs 1999). Gibbs (1998) argued that the simple nature of the burials at AUK indicated that the site's mortuary use was funerary in nature. There was some evidence that rocks were used to demarcate grave boundaries and the graves may have been associated with funerary objects including shell, quartz, ceramics, and more (Ferguson and Gibbs 1999; Gibbs 1998). However, these may have been simply elements recovered in the grave fill and not intentional artifacts. All burials were found in pits of similar depth, indicating that the individuals were likely interred within a relatively discrete period of time (Wrobel et al. in press). AMS dating of two burials at AUK place the mortuary use of the site in the Protoclassic (0 - AD 300) and Early Classic (AD 300 – 600) periods (Wrobel 2014). In this early period, the Roaring Creek was comprised of small peripheral farming communities with no evidence of centralized urban centers or social hierarchy (Andres et al. 2014). Isotopic analysis suggests that the primary burials were local individuals who spent their subadult years in the area surrounding the rockshelter (Wrobel et al. 2012; in press).

Description of the sample

Despite the looting, commingling was less of a factor when dealing with the AUK burials as it was in JRH and AKB because graves were distinct and individual remains often could be identified even when there was evidence that the bones were mixed. All of the individuals sampled were adults. Four of the five burials were females, with the fifth being of indeterminate sex.

Table 10. Summary of AUK sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From AUK
0	9	5	5 adults	9

Table 11. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
UAK98-B4-009 Burial 4	LC_ RI^{1} LM^{3}
UAK98-BA-438 Burial 98-2	LI^{1} RM^{3}
UAK98-BA-396 Burial 98-1	RI^{1} RC_

Table 12. Distribution of teeth in the sample from AUK.

Tooth Type	Right	Left
Maxillary central incisor	2	2
Mandibular canine	2	1
Maxillary third molar	1	1
Mandibular third molar	0	0
Deciduous mandibular canine	0	0
Total teeth in sample: 9	5	4

Caves Branch Rockshelter (CBR)

Caves Branch Rockshelter, situated in the Caves Branch River Valley east of the present-day Belizean capital of Belmopan, was first excavated by Juan Luis Bonor in the mid-1990s after reports of looting (Glassman and Bonor 2005). This salvage operation yielded 32 primary burials and countless bone fragments scattered throughout the matrix. Following Bonor's work, Wrobel continued excavations at CBR during 2005-2007 with the Belize Valley Archaeological Reconnaissance (BVAR) Project and again in 2015 with CBAS. Excavations at CBR have produced more burials than at any other site in the region.

All excavations demonstrated that the rockshelter received burials of all ages and sexes, suggesting that the mortuary rules that governed interment here were inclusive. Infants and children accounted for approximately 1/3 of the individuals, a statistical feature consistent with pre-industrial societies (Wrobel et al. 2007). Overall health of the burial population was generally good, with no instances of infection or trauma and very few occurrences of anemia and dental caries (Wrobel et al. 2009). Attendant grave artifacts, such as chert flakes, jute shells, and net weights, were utilitarian, reflecting use consistent with a rural non-elite population (Wrobel et al. 2007). Based on excavations to date, an estimated 400-500 individuals may be interred at the site (Wrobel et al. 2009). Wrobel and Tyler (2006) noted that the consistent use of CBR as a cemetery site, suggesting mortuary use for nearly a millennium, resulted in extensive grave disturbance. This resulted in disturbance and mixing of burials and, in combination with a matrix that is relatively consistent in its color, texture, and inclusion of scattered bones and artifacts, acts to obscure stratigraphic features.

CBR is distinguished by the extremely long usage of the site. Beginning during the Late Preclassic when there was no social hierarchy in the area and persisting through the major social transitions in the region during the Classic period, mortuary behavior took place at the rockshelter over the course of 1000 years. Ceramic analysis placed the range of site use from the Late Preclassic to Terminal Classic periods (Hardy 2009), and while permanent residents were present in the area by the Late Preclassic, sociopolitical complexity did not arise in the river valley until the Late Classic (Bonor 2002; Wrobel et al. 2009). Though, cumulatively, ceramics were recovered from a wide temporal range, the diagnostic ceramics interred as grave goods are largely from the Late Preclassic, indicating that the most intensive use of the rockshelter likely occurred during this period (Wrobel 2008a). AMS dates taken from bone returned dates spanning the Late Preclassic through Late Classic periods, suggesting that use may not have been punctuated, but rather persistent (to varying degrees). The relatively unchanged nature of the mortuary ritual suggest that the site was used by local agrarian communities even during sociopolitical change (Hardy 2009; Wrobel 2008a).

Description of the sample

Due to the widespread commingling activity in prehistory, as well as recent looting in some areas, teeth were selected only from primary burials. Loose teeth were often found in the burial matrix during excavation, but re-association of dental remains to bone is inhibited by poor preservation of alveolar bone and multiple episodes of grave disturbance in the past. Although CBAS returned in 2015 to continue excavations of the rockshelter, the remains from this field season were not included in the sample, though certainly will be a focus of continuing research. Overall, preservation of dental remains at CBR is good with few instances of extreme taphonomic alteration or dental pathologies. Age and sex estimates were previously performed and not rescored for this study.

Table 13. Summary of CBR sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From CBR
0	23	19	15 adults 4 subadults	23

Table 14. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
CBR05-076-954 Burial 38	LI^1 RC_{-}
CBRS-U6-L4 Burial 9	RC_{-} LI^1
CBRS-U6 Burial 10	RI^1 LC_{-}
CBR06-109-3679 Burial 51	RC_{-} LI^1

Table 15. Distribution of teeth in the sample from CBR.

Tooth Type	Right	Left
Maxillary central incisor	4	5
Mandibular canine	4	6
Maxillary third molar	0	0
Mandibular third molar	0	0
Deciduous mandibular canine	3	1
Total teeth in sample: 23	11	12

Sapodilla Rockshelter (SDR)

Sapodilla Rockshelter is situated near a small tributary of the Caves Branch River system within the northern portion of the Caves Branch River Valley. Ancient housemounds are still visible along the trail cut to the rockshelter, though these have not been explored in detail. The rockshelter has a small cave component, the furthest reaches of which require a headlamp for visibility. The site had been intensively looted and multiple spoil areas were located in the light zone of the rockshelter and the liminal zone in the entryway to the associated cave. In 2010, CBAS conducted salvage operations at SDR during which preliminary surface collection and excavation of looters' pits confirmed the presence of complex deposits that included primary burials, scattered human and faunal bones, ceramics, and lithics. Overall, the context at SDR appears similar to nearby Caves Branch Rockshelter, which is situated approximately 1 kilometer away (Glassman and Bonor 2005; Wrobel et al. 2007).

Though the rockshelter and associated cave are small, there is evidence that there were specialized activity areas for different mortuary or social purposes at SDR. While the dark zone area of the cave did not produce any human remains and only one rough-hewn artifact, a pendant, on the surface during test excavations, it can be reasonably concluded that the mortuary activity was restricted to the light and liminal zones. Whether this is due to a pan-Maya (or at least regional) social restriction on dark-zone cave use by non-elites is unclear. Specifically, in the adjacent Sibun Valley, Peterson (2006) noted that smaller caves and rockshelters were exploited by non-elites, while the upper class laid claim to larger karstic structures for their ritual purposes.

One high density special use area in front of a solution hole in the cave wall in the light zone was found to contain three 1x1m test units yielded high frequencies of ceramics, including two molded-carved fragments and six notched, carved re-worked ceramic pieces, quartz, and jute shell, but only one burial (an unassociated cranium in very poor condition). Because burials were found in high yields throughout the light zone other than this particular place suggests that the rockshelter was conceptualized as a space that functioned for some purpose other than just the deposition of human burials (Michael and Burbank 2013).

Following the preliminary work at SDR in 2010, members of the CBAS project returned to SDR in 2011 to perform systematic excavations of the rockshelter and to map and excavate the small dark zone cave. During the elapsed time between field seasons, the site had been looted again with new looters' pits noted in the cave and the light zone. The largest looters' pit in the light zone, which was highly disturbed, was excavated to sterile soil (approximately 85-90 cm) and produced only one articulation (acetabulum to head of femur) during the 2011 field season. Other operations during the field season focused on undisturbed areas, yielding 18 primary burials with more exposed but not removed due to time constraints. It is estimated that 40 – 50 individuals are buried within the light and liminal zones of the rockshelter. Test pits placed in the dark zone cave revealed that this space was not used for burials.

Most of the burials appear to be primary, though some graves infringed on earlier ones resulting in disturbed contexts or absence of particular elements. Additionally, there was some evidence for post-mortem secondary manipulation of remains. One burial (Burial 13) was complete with the exception of the skull and two skulls were found un-associated with any postcranial elements. As at CBR, attendant grave goods at SDR were utilitarian and all ages and sexes were represented in the skeletal assemblage. While similar in function, the temporal use of CBR and SDR overlap only to some degree. Ceramics at SDR demonstrate that the use of the site was predominantly limited to the Protoclassic and Early Classic periods in contrast to the more expansive use of CBR, where ceramics included a few examples of Middle Preclassic period types, and a large number of Late and Terminal Classic period types (Andres et al. 2011).

A number of patterns emerged during the analysis of the burials and grave goods in different operations across the site. Of the 17 burials excavated in 2011, only seven were interred with grave goods. Although the percentage of associated grave goods recovered from SDR is markedly higher than at CBR (Hardy 2009; Wrobel 2008b), this difference is not necessarily significant given the comparatively small sample size of SDR. In contrast with CBR, none of the burials excavated at SDR were interred with complete vessels, but instead with obsidian, jadeite, carved bone and various types of drilled shell beads and pendants. However, whole vessels were found in the looter's backfill that are similar to those found at CBR within burials, and thus it is likely these originated from graves prior to the looting.

Local groups were utilizing SDR in a very similar manner to CBR, demonstrating a need for mortuary space outside of immediate habitation areas. Aside from disposal of the dead, the discovery of several intentionally re-deposited skulls and crania suggests the presence of extended mortuary rituals. Corporate groups likely revisited and maintained this important mortuary site, placing SDR in the larger mortuary program that characterizes the region. SDR was not fully excavated, but there is no reason to believe it contains a burial population as large as Caves Branch Rockshelter; however, SDR was clearly a dedicated mortuary space unlike other rockshelters in the area. Deep Valley and Overlook Rockshelters, also in the Caves Branch

River Valley, are notably devoid of large burial assemblages, suggesting that there was not one singular conception of rockshelter use in prehistory (Hardy and Wrobel 2007; Wrobel et al. 2013).

Description of the sample

Re-associating the teeth from the looters' pits was difficult due to the commingling, so only the most repeating element, left central maxillary incisors, were selected from these areas (n=4; MNI = 4). For the primary burials, the three desired teeth were selected whenever available (n=13; MNI = 10). The age distribution was wider than the cave sites, with young, middle, and older ages represented in addition to subadults.

Table 16. Summary of SDR sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From SDR
4	13	14	13 adults 1 subadult	17

Table 17. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
SDR11-34-262 Burial 7	RI^1 RC_
SDR11-41-553 Burial 10	RM^3 RC_
SDR11-61-677 Burial 13	LM_3 LC_

Table 18. Distribution of teeth in the sample from SDR.

Tooth Type	Right	Left
Maxillary central incisor	2	6
Mandibular canine	5	1
Maxillary third molar	1	0
Mandibular third molar	0	1
Deciduous mandibular canine	0	0
Total teeth in sample: 16	8	8

Pacbitun (PB)

Originating as a farming village in the foothills of the Maya Mountains during the Middle Preclassic and eventually expanding into a mid-sized civic-ceremonial center, Pacbitun was at its cultural height during the Late and Terminal Classic period (Healy 1990; Healy et al. 2007; White et al. 1993). After the fluorescence of the site, Pacbitun was abandoned in the Terminal Classic. Early excavations led by Dr. Paul Healy through Trent University focused on mapping the core, epicenter, and peripheral zones. Former projects at Pacbitun included the Belize Valley Preclassic Maya Project (BVPMP) led by Dr. Paul Healy and Dr. Jaime Awe whose focus was on the development of the Classic period Maya traits in the region. Some years earlier, the Trent University-Pacbitun Archaeological Project (TUPAP) explored the history of Pacbitun, in addition to the terraces throughout the site.

These projects, as well as the ongoing Pacbitun Regional Archaeology Project (PRAP) led by Dr. Terry Powis, have revealed much about the site. Like many other Maya urban centers, Pacbitun boasted an acropolis center with multiple major plazas and temples, many stone monuments, range structures, ballcourts, and causeways radiating out from the core (Healy 1990). Prior to abandonment, it is estimated that 200 elite individuals lived in the epicenter along with additional 950 inhabitants per square km in the core zone and an additional 550 residents per square km located in the periphery (Healy et al. 2007). At the height of occupation, approximately 9000 Maya resided at the 9 square km site (Healy et al. 2007). The relationship of the urbanized site to the karstscape is explored in Spenard's (2014) recent dissertation. The caves in the Pacbitun region do contain human remains, but these materials were not used in this dissertation study. Rather, the individuals sampled here were buried in the core of the civic-ceremonial center.

Initial excavations in the core and epicenter zones of Pacbitun led to the discovery of 20 burials (containing 26 individuals as some graves were multiples) in a variety of burial styles (simple, crypt, cist, and tomb) (Healy 1990). The range of grave types suggests some division in social status at the site. All burials were found in temple structures or below monuments. Most individuals were placed in an extended supine position with the head to the south and the legs crossed at the ankles, which is common in the Belize Valley (Healy 1990). Additionally, three burials were found in urns and one burial was flexed in a simple grave. Healy (pers. comm.) noted that all individuals within the site core can be considered elites, while those burials outside of the core were commoners with some relationship to the urban center. The Pacbitun sample, therefore, represents members of an elite urban population since all burials in this study were excavated from the site core. All burials were dated to Late and Terminal Classic periods with the exception of one Middle Preclassic burial. The majority of burials were located in the epicenter during the Late Classic and the core zone during the Terminal Classic. The following table represents the number of graves (not individuals, as most graves contain multiple persons) from each time period and site location.

Table 19. Location of burials by time period at Pacbitun.

Location	Middle Preclassic	Late Classic	Terminal Classic
Epicenter	1	9	3
Core zone	0	0	8
Periphery	0	0	1

Further evidence for social stratification at Pacbitun has been documented by researchers through the investigation of isotopic studies of diet and mortuary formation processes (Robertson 2011; White et al. 1993). White et al. (1993) performed dietary studies on 33 of the individuals buried at Pacbitun from the Late Preclassic to the Terminal Classic, finding that food consumption may have been socially restricted by sex. Robertson (2011) found that single male burials were overwhelmingly represented in the epicenter. Although Pacbitun originated as an egalitarian farming community, site expansion and social change in the Late and Terminal Classic resulted in significant sociopolitical complexity and hierarchy.

In 2009, the Pacbitun Preclassic Project (PPP) began investigating the caves, rockshelters, and sinkholes in the periphery surround Pacbitun. More than fifteen caves were noted in just one section of a 3km survey area in the initial field season, some of which were connected to the main site via causeways (Powis 2010; Weber and Powis 2011). Perhaps future collaborations could focus on the histological dental analysis of the human burials found in the peripheral caves for comparison to the Pacbitun sample analyzed in this study as well as the other regional cave burials presented here.

Description of the sample

The dental remains at Pacbitun were variably preserved. Some teeth were unable to be scored or analyzed due to extensive taphonomic damage to the enamel. Estimated sex and burial type/position were recorded by the original excavators and the skeletal remains were not re-scored for this dissertation. Problematically, for the burials containing multiple individuals, the original excavation bags do not specify if the teeth belonged to one or more individuals in the graves (e.g. multiple teeth are included in a bag for one burial which may contain three individuals), and thus the total number of persons represented by the teeth is unknown in many cases. Perhaps there are detailed records in archaeological field notes, but these were not available for this study.

The MNI was calculated by considering both the number of persons of identified sex in a grave and the minimum number of repeating tooth classes/numbers (e.g. if two individuals were noted in a grave with two right maxillary central incisors and one left mandibular canine, the

MNI was 2 due to the minimum number of repeating elements). Even though multiple teeth were present in these graves, these teeth could not be considered for defect sequencing because it was impossible to determine if they came from the same individual. Only those individuals with more than one tooth from a primary burial were considered for defect sequencing.

Table 20. Summary of PB sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From PB
28	12	20	Cannot determine from commingled remains	40

Table 21. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
Burial 4-1, Lot 179	RI^1 RM^3
Burial 2-5, Lot 62	LI^1 RM^3
Burial 95-1, Plaza C	LM^3 LC_
Burial 2-3, Ind 2, Lot 34	LI^1 LC_

Table 22. Distribution of teeth in the sample from PB.

Tooth Type	Right	Left
Maxillary central incisor	4	9
Mandibular canine	5	11
Maxillary third molar	5	2
Mandibular third molar	3	1
Deciduous mandibular canine	0	0
Total teeth in sample: 40	17	23

Tikal (TK)

A major ceremonial center located on the eastern edge of the Peten in Guatemala and occupied from the Middle Preclassic through the Terminal Classic, Tikal was one of the most powerful civic-ceremonial cores in the Maya lowlands. Early excavations in the late 1800s heralded a long period of archaeological interest in the site, which continues today. The fertile land of the Peten was efficiently exploited by the first residents of Tikal and within 100 years, the site was a major political center and the social structure had become stratified (Haviland 1977). The monumental architecture, tombs, and careful planning of the site confirm the presence of elites, with evidence for a middle class and non-elites living in domestic groups at the site (Danforth 1989). The presence of non-local goods throughout the site indicated that Tikal was a powerful trading center (Culbert 1973).

During the most intense phases of excavation at Tikal, approximately 200 recovered individuals were associated with time periods from the Preclassic to the Terminal Classic (Danforth 1989). Of these burials, 55 were removed from elite tombs, often with attendant subadult remains of individuals aged 6-11 years at the time of death (Danforth 1989). Lower status burials were thought to be those individuals residing in smaller domestic groups related to the site, while the rest of the burials likely belonged to a middle class that received grave goods but not tomb burials (Haviland 1972). Haviland (1967, 1972) noted that the individuals in the elite tombs were taller, more robust, and generally lived longer than their contemporaries buried in other locales.

After a lull in construction and expansion between the Early and Late Classic, Tikal was revived and reached its highest levels of occupation (Haviland 1970). The much discussed decline of Tikal may have been due to unsustainable conditions, both environmental and social (Culbert 1973). By the Terminal Classic, the once dominant city was mostly abandoned.

Description of the sample

The secondary sample used for comparison comes from Tikal (TK) and was originally prepared by Danforth (1989) for her dissertation on dental microdefects in burials from the variably urbanized centers of Barton Ramie, Seibal, and Tikal. Initially, I intended to re-analyze all of these dental thin section slides for comparative study against the cave and rockshelter sites outlined above. Currently, I have access only to the Tikal sample, as the other slides are in the permanent collections at the Peabody Museum and cannot be removed for analysis outside of the premises.

There is likely considerable bias in the Tikal burial sample as there were significantly more males recovered than females in the sample Danforth used. In her dissertation, she explains that this unequal sex ratio is likely an archaeological bias; that is, archaeologists gravitated toward tomb and elite grave excavation, which were more frequently associated with males. Time period, social status, age, and sex were all determined for the sample previously, so these data were employed in this dissertation. Interestingly, the individuals were fairly evenly split along social status lines with middle class individuals (n=9) and lower class individuals (n=11) comprising the majority of the sample. Servant class (n=6) and indeterminate class (n=2) were also included. All samples were dated to the Late Classic period (550-870 AD).

From the examination of the original slides, it is clear that the nearly 30 years that have passed since the creation of the slides has affected the samples. The resin is yellowed and the dental structures are sometimes obscured under the microscope. The condition of these slides was particularly poor most likely due to their age, the resins used in the preparation process, and the glue used to affix the teeth to the slides. In some cases, the resin block of the thin section has started to yellow and peel away from the glass slide. These teeth appear to be cut in thicker sections, but overall there is a “cloudiness” to the slides which may be a result of the taphonomic processes at the site. As with the other samples, the subadult teeth are particularly difficult to analyze with microstructures often difficult to view clearly. I do not have a lot of confidence that my results will match Danforth’s data as the microstructures are unclear even when magnification levels are changed. The original teeth, of course, were not able to be analyzed so enamel hypoplasia and caries data was not recorded. A more thorough description of the preservation of the slides (and the resultant issues in analysis) is provided in the Results chapter.

Table 23. Summary of Tikal sample.

Commingled Teeth	Teeth From Primary Burials	MNI	Age Distribution	Total Teeth From Tikal
0	33	27	23 adults 4 subadults	33

Table 24. Individuals with multiple teeth present for defect sequencing.

Provenience	Teeth Present
Burial 45	LC_ LM_3
Burial 109	LC_ LM_3
Burial 151	LC_ LM_3
Burial 161	LC_ lc_
Burial 182	LC_ LM_3
Burial 201	LC_ LM_3
Burial 210	LC_ lc_

Table 25. Distribution of teeth in the sample from Tikal.

Tooth Type	Right	Left
Maxillary central incisor[1]	0	0
Mandibular canine	0	21
Maxillary third molar[1]	0	0
Mandibular third molar	0	8
Deciduous mandibular canine	0	4
Total teeth in sample: 33	0	33

[1]=not sampled in Danforth's (1989) original study

Sampling issues in the study

Bioarchaeologists must be cognizant that, often, their samples do not constitute a population. However, the analysis of human remains from a particular site or group of sites does constitute a meaningful sample. Addressing the relationship between classification, terminology, and nomenclature, Simpson (1963:1) wrote the following regarding the process of analyzing biological data: “The specimens studied and believed to be related in some biologically relevant way are a *sample*.” Clearly, by virtue of their genetic composition, a group of individuals buried in the same locale may then be considered a sample (they are the same species and deposited in the same manner, therefore it is reasonable that they may be studied in accord with one another). Simpson (1963) further explained that, regardless of number, specimens become significant only when they are representative of a larger group (the population). Populations are defined by a common principle or relationship between specimens (Simpson 1963). The sample is not the population per se, but a sub-set drawn from the population. Larsen (1997:334) stated that human remains recovered from archaeological sites are “cumulative aggregates usually containing multiple generations of individuals and not biological populations.” Biological profiles reveal that this characterization is largely true of the sites included in this research study. None of the samples are wholly representative of the burial population at each site; however, the incorporation of a multi-tooth selection protocol, including both adult and subadult dentition, greatly enhanced the sample sizes at all sites, reflecting a broader approach than previous studies which have focused on only one or two tooth classes.

This study did not aim to generate conclusions about the health experiences of all Maya, or even a regional group of Maya, at a particular time. Rather, individuals buried at different site types were compared to understand mortuary variability. The dental remains described in this dissertation must be understood within a framework of small, biased samples. Death assemblages are typically shaped by cultural factors, but Maya remains are also subject to post-depositional changes associated with tropical and/or subterranean environments, ancient and modern looting.

Because of the poor preservation of skeletal and dental remains in the Maya region, sample sizes are small and fragmentary; additionally, ritual behavior of the Maya results in complicated and "problematical" mortuary deposits (Cucina and Tiesler 2007; Webster 1997; Weiss-Krejci 2011; Wrobel 2015). Nearly all bioarchaeological studies suffer from the same critiques of non-random samples, non-random distribution of samples, and small sample sizes (Jackes 2011; Pinhasi and Bourbou 2008; Wrobel 2015), but these issues are intractable byproducts of an imperfect archaeological record which is constrained by cultural and environmental erasure of burials. Additionally, despite the multi-century habitation of many sites, it has proven a difficult task to excavate a skeletal sample large enough to provide evidence for patterns of temporal change (Webster 1997).

Fortunately, recent bioarchaeological research has focused on small and biased samples, as well as problematical deposits, in answering questions about the ancient Maya (Cook 1999; Weiss-Krejci 2011; Tiesler 2004, 2007; Wrobel 2015). Wrobel (2015) summarized the major issues inherent in Maya bioarchaeological research: taphonomic alteration, social restrictions in mortuary deposition, archaeological bias in excavation, physical access to sites, and secondary manipulation of bone.

Certainly all of these problems can be applied to this dissertation sample. Taphonomic processes biased the sample as some teeth were too damaged for enamel analysis. Cave burials may have been placed on the surface, thereby being subject to specific postmortem damage associated with exposed burials. Rockshelter interments are generally sub-surface burials, though groundwater and other postmortem decay can affect the preservation of the remains.

There were most likely social rules governing interment at caves and rockshelters, further biasing the death assemblages from which these samples were drawn. Aside from the natural and social issues that complicate sampling, there is an overall bias in cave burials. Caves, by all current archaeological evidence, are restricted mortuary locales so even complete excavation of a burial sample from a cave cannot be understood to represent a population. The general demographic pattern found in caves skews to younger individuals. Rockshelters fare better in representing an unrestricted burial population with equal access for individuals of all ages and sexes.

Excavations at caves and rockshelters defy the traditional archaeological bias toward elite surface sites, so perhaps these samples and this project can be understood as part of the push toward identification and analysis of non-elite or problematical deposits by bioarchaeologists. CBAS continues to work towards the excavation of more sites each field season, but physical access to sites must dictate the field work in part. Secondary manipulation of bone is evident at most all of the sites in the study, especially at AKB where small skeletal and dental remains were deposited in the middle chamber some unknown distance from their original deposition.

The main caveat for this study is that, although the samples were increased by analyzing three tooth classes rather than one or two as in previous studies, the samples are still small and biased. In many cases explained in the Results chapter, tooth classes or sites were pooled in order to generate statistically meaningful conclusions. Descriptive statistics at the individual level reveal some mortuary population "outliers" at each site, but the absence of additional bioarchaeological variables such as attendant grave goods, burial position, and secure time periods often precludes more sophisticated analysis. Further research and excavation in Central Belize, as well as at sites that could be used for temporal comparison would strengthen future analyses.

CHAPTER 6: METHODS

This study seeks to investigate health experiences of individuals distinguished by their burial placement through the analysis of dental macro- and micro-defects, as well as caries. Historically, bioarchaeologists have used the dentition to estimate health stress because the teeth record physiological insults during formation. The continuous remodeling of bones cannot provide evidence for early experiences of health and disease, but the teeth record developmental insults during formation that cannot be erased as enamel is never regenerated. These developmental insults can be seen macroscopically on the enamel crown as hypoplasias, taking furrow or pit forms. When the enamel is viewed in cross-section, defects present microscopically as Wilson bands, which are dark lines representing disrupted enamel production. Hypoplasias, seen superficially, and Wilson bands, viewed internally, are indelible markers indicating generalized systemic responses to stress. These defects are the result of a disruption in the production of enamel, though the etiology of each is not specifically understood.

As the teeth were assessed for enamel hypoplasias, the presence and type of carious lesions were also recorded. A combined study of hypoplasias, caries, and Wilson bands allows for more nuanced conclusions about health experience to be drawn from a particular sample. If only macroscopic indicators of health stress were observed, the burial populations may appear to have a more positive health experience than was their reality. However, by analyzing the teeth for three defect types, it is possible to observe more defects at more age ranges, resulting in a more complete picture of episodic health stress in the individual.

Justification for use of histological methods in anthropology

First, a justification for why the destructive method of histology is useful for archaeological samples is reviewed here. Many studies have traditionally focused on the identification and quantification of hypoplasias, which correlate with chronic stress events, likely due to the relative ease in locating these macroscopic defects on the dental crown surface. However, a histological approach can augment traditional hypoplasia studies because microscopic defects reflect acute stress events. Bioarchaeologists can explore early childhood health beyond the traditional caries and hypoplasia frequency tabulations by using dental histology which, unlike bone, provides “a more appropriate disease measure than pathological lesions and growth arrest lines that are subjected to remodeling” (Marks 1993:151).

Dental histologists use transmitted light microscopy, sometimes with polarizing filters, to observe thin sections of teeth that reveal the microstructures of enamel and dentin. Histological methods are undoubtedly destructive, as examination of internal dental microstructure always requires each sample to be cut. While non-destructive analysis in the form of scanning electron microscopy (SEM) (called “phase contrast X-ray synchotron microtomography”) has been used with some success (Tafforeau et al. 2006; Tafforeau and Smith 2008), currently this type of imaging is cost- and time-prohibitive when analyzing mid-size to large samples. Dental histology, then, must be undertaken after a researcher is confident that the attainment of microscopic data will outweigh the cost of destructive analysis.

Pfeiffer (2000) urged anthropologists to consider histology a “transformative” method rather than a destructive process. Though the sample is cut during thin-sectioning, it is not completely destroyed (as in isotopic sampling procedures). Furthermore, photographs, measurements, casts, and digital scans taken of the complete tooth can each provide a record of data potentially lost as a result of thin sectioning. The usual process of embedding teeth also results in two “blocks” (excluding the thin section) that can still be used for future analyses.

These blocks reveal the internal anatomy of the tooth, exposing the dentin and allowing for crown height measurements and scanning electron microscopy of the interior tooth.

Setting the issue of destruction vs. transformation aside, the area of microarchaeology is rife with potential for different types of data collection. The role of dental microscopy should be more seriously and consistently addressed in bioarchaeological study, but few studies employ the method. Interestingly, a recent text called Microarchaeology: Beyond the Visible Archaeological Record (Weiner 2010) makes mention of the utility of teeth in assessing incremental growth lines (14) and bone collagen in understanding weaning age (15), but there is no reference to the contribution dental micropathology. This dissertation study seeks to further fulfill that space.

Sampling issues in dental histology

Sampling procedures in dental histology (as in bone histology) vary significantly between research projects and there is no general consensus regarding which teeth and how many individuals constitute an appropriate sample for a histopathology study. Goodman and Rose (1990) allowed that a focus on the most studied teeth, incisors and canines, only was permissible. Most researchers agree that the use of two or more teeth per individual is necessary to make any significant conclusions, since analyzing multiple teeth per dental arcade/ individual enables the sequencing of defects between teeth. Because teeth form at different chronological ages and rates, sequencing defects between teeth allows bioarchaeologists to reconstruct multiple episodes of stress over an individual's life. While the use of two or more dental samples per individual is most desirable for dental histology research, studies (including dissertations) often utilize only one tooth per individual.

Sample sizes used in dental histology projects also vary widely. Hillson et al. (1999) and Witzel et al. (2008) each sampled fewer than 10 individuals in their studies. Masters theses on dental histology have sampled few individuals as well, often 15 or less per site (Antonova 2011) or per study (Thomson 2011). Even in large-scale study cases like that of Reeves (2013), 400+ teeth were examined for external defects while only 63 teeth were thin sectioned and analyzed microscopically. Few studies Simpson (1999), Fitzgerald and Saunders (2005), Wright (1990), Marks (1993), Danforth (1989) all sampled 30 or more individuals with some studies reaching samples of 100+ individuals, though most of these sampled only one or two teeth per individual.

Inconsistent definitions and variable identification techniques result in the incomparability of samples, highlighting the need for standardized methodologies in dental microscopy. Beyond disagreement in defining and identifying Wilson bands, there is no current standard in preparation, cutting thickness, microscope selection, or optics (Goodman and Rose 1990). In some cases, perhaps due to restrictions in journal article length, authors do not describe their methods in enough detail for others to replicate. Archaeological samples present a further challenge in their variable preservation. There is still a sense that each researcher must undergo a trial and error process on a tooth by tooth or site by site basis.

Definitions of Wilson bands in the literature

Under the view of a light transmitted microscope, normal striae will appear light in color and semi-transparent owing to the regular orientation of the enamel prisms. Wilson bands, or pathological striae, will appear dark and semi-opaque as light from the microscope cannot pass through the bands due to their irregular prism structure (Wilson 2014). Before undertaking data collection for this project, it was necessary to review the literature on pathological striae in an attempt to develop a "best practice" protocol for identifying Wilson bands. This process was markedly more difficult than initially imagined, and so a discussion of the variables (e.g. prism orientation, color, length and width) and issues (e.g. timing of ameloblastic activity) most cited in the literature is warranted below.

Prism orientation

Researchers have consistently disagreed over the criteria needed for the development of defects and the diagnosis of micro-pathology in enamel structures. Some researchers suggest that abnormal prism structure, in addition to a change in prism direction, result in atypical enamel (Wilson and Shroff 1970; Wright 1990). Other researchers (Condon 1981; Rudney 1983) contended that simply an observable change in prism direction was sufficient to diagnose microdefects. Witzel et al. (2008) argued that during amelogenesis, each ameloblast acts independently of others, resulting in Wilson bands with extremely variable prism structure. If this is true, then the formation of the Wilson band will depend on the ameloblasts that are currently active during the stress event (Witzel et al. 2008).

Color and width

Color and width of disrupted prism structures have been used by some researchers as criteria for Wilson bands. Simpson (1999) identified Wilson bands based on darker color and more narrow width, in addition to the altered prism structure. After calculating an average daily enamel secretion rate and measuring the width of the dark brown zones of disrupted prisms, Antonova (2011) determined that a period of three to five days was necessary to produce Wilson bands in a sample of Neolithic hunter-gatherers. In contrast, Wright (1990) found that Wilson bands in a Maya sample were formed over a 10-day period, which suggests possible populational differences in defect formation rates and widths. Danforth (1989) collected data on color of microdefects but concluded that this variable was not difficult to control during intraobserver error tests and was significantly related to the appearance, frequency, or timing of the Wilson bands. A more recent discussion from Thomson (2011:63) asserted that, “the idea that a larger, deeper or darker Wilson band is indicative of longer, more intense stress is not consistent with what is known about how these bands are formed. Wilson bands indicate only that a stress event occurred; they do not provide any additional information" (Thomson 2011:63). Color and width data was not collected for this dissertation study.

Length

Fitzgerald and Saunders (2005) argued that the etiology of both normal and abnormal striae were similar, and thus could not be distinguished from one another by prism structure. Rather, they stated (following a criterion outlined by Goodman and Rose 1990) that a Wilson band could be identified if the pathological stria was visibly disrupted for for 75% or more of its length from the enamel-dentino junction to the surface of the tooth crown. This percentage was estimated by visual assessment which introduces some amount of intra- and inter-observer subjective error into identification and quantification of Wilson bands.

Timing of ameloblastic activity

Adding to the complexity of the identification of pathological striae, Witzel et al. (2008) discovered that, when faced with a stress event, younger ameloblasts continue to secrete matrix to some extent (forming fine, thin Wilson bands) while older ameloblasts cease secretion completely (forming dark, deep Wilson bands) (Antonova 2014). Fitzgerald and Saunders (2005) also caution that timing of striae rhythm must be considered. These authors hypothesized that if a developmental disruption occurred simultaneously with the regular stria rhythm, the outcome would be a Wilson band that terminated in a hypoplastic defect on the external surface of the tooth. However, if the disruption occurred between normal stria rhythm, the effect would be less conspicuous and may not be recognizable as a Wilson band. Fitzgerald and Saunders (2005) contended that normal striae of Retzius and Wilson bands are similar in etiology, though the pathological nature of Wilson bands is due to the force of an external stressor on the regular developmental rhythm. That is, the biological mechanisms that form both normal and abnormal striae are the same, but depending on the timing of the stress event in the developmental cycle and the intensity of the stressor, an enamel defect can occur.

Variation in ameloblast secretion and striae rhythm may lead to disparities in Wilson band formation within and between individuals. More research is needed to determine if there is a threshold level for formation of Wilson bands, as well as if secretion rates affect the structures visualized under the microscope and identified as Wilson bands.

Definition of Wilson bands in this study

The parameters advocated by Hillson (2014:174-175) that were adapted from Rose et al. (1978:513) and Goodman and Rose (1990:93), were first considered as the standard observation and identification method for this project. Rose et al. (1973:513) defined Wilson bands as, "any striae of Retzius exhibiting abnormal prism bending and absence or distortion of prism structure." Three subsequent conditions were defined by Goodman and Rose (1990:93): 1) Wilson bands should be continuous through at least three-quarters of the enamel thickness from the dentin-enamel junction (DEJ) to the crown surface; 2) Wilson bands should be observed in matching portions of the enamel on both labial and lingual sides of the crown; and 3) Wilson bands should appear with oblique illumination as a trough or ridge, representing the sharp deviation of prism boundaries.

These criteria were then considered in combination with a more recent literature search. After reading all theses and dissertations listed on ProQuest under the search terms "dental histology" plus "anthropology" over the past 30 years, it became clear that nearly every researcher followed different protocols and named different criteria for identifying pathological striae. As such, a decision had to be made to blend several researchers' methods in order to strike a balance between over- and under-estimation of microdefects. Because there is largely no congruent definition, it was determined that enamel disruptions would be recorded as Wilson bands if two of the three criteria were met, following Reeves (2013:42) (who presumably took Goodman and Rose 1990 into account): 1) the stria appears darker and wider than surrounding striae, extending clearly from the dento-enamel junction to the enamel surface; 2) the stria exhibits rod disorganization on examination at 400x magnification; 3) a stria visible in the labial/buccal enamel has a corresponding darkened stria in the lingual enamel.

I believe that Reeves' criteria are most easily followed while still being consistent with the important criteria of previous literature. The first criterion is repeated in nearly all the anthropological research on dental microstructure, though the length of the stria is still debated. The second criterion is essential to the identification of Wilson bands as pathological striae must be understood by their chaotic prism structure. The only change I made to Reeves's protocol was in the second criterion, in which she suggested a magnification of 1000x, while I believe magnification at 400-600x is sufficient after some exploration with the features of the microscope and imaging software; all relevant microstructures could be seen at this magnification range. The third criterion is included because if Wilson bands are alleged to be the result of systemic stress, then pathological striae should be expressed on both the lingual and labial aspects of the tooth. Although there are discrepancies in definitions throughout the literature, the requirements of enamel prism disorganization, darkened striae, and expression on both sides of the dento-enamel junction are continually referenced as indicators of pathological striae.

Discussion of collected data points

The data collected for the study are summarized here before in general before the specifics of each site are addressed in the Results chapter. The Wilson band data is listed first (points 1-5), followed by the summary of data on LEHs (points 6-8), and caries (point 9).

Explanation of microdefects summary

1) The total number of teeth affected by Wilson bands versus the total number of teeth in the sample is offered. The number of individuals with Wilson bands and the range of instances of bands in the sample is reported. These data reflect the frequency of defects at each site.

2) The summary of Wilson band instances per tooth class and point estimates of average affected age per tooth class is documented via the tables. The point estimate of average age was calculated by summing the individual point estimates for each tooth class and dividing by the total (e.g. add the point estimates for 4 canines, then divide by 4 for a site-wide average). Only those teeth with defects were used to determine average age at defect formation. When there were no microdefects present, the tooth was not included in the average. These tables show which tooth classes are most affected by microdefects, as well as the average age of defect formation per tooth class.

3) The maximum and minimum ages of defect formation are reported in order to show the range of ages affected by microdefects.

4) When individuals had two or more teeth available for analysis, defect sequencing was attempted. Each overlapping age range between tooth classes are described to isolate those ages at which the most stress events likely occurred.

5) The hyper-events tables represent the number of times a cluster (3 or more Wilson bands within 0.5mm of each other) occurred at each archaeological site. Throughout the entire sample,

clusters were observed in groups of three, four, and five bands. Clusters of three bands were most common, followed by clusters of four and five bands. These tables demonstrate how many times cluster events happened, indicating a series of stress events that occurred in rapid succession.

Explanation of macrodefects summary

6) The total number of teeth affected by LEH versus the total number of teeth in the sample is offered. The number of individuals with LEH is reported. Because no other types of enamel hypoplasias were noted during analysis, all the defects in this study can be considered linear enamel hypoplasias. These data reflect the frequency of defects at each site.

7) The number of LEHs associated with Wilson bands was examined to determine the extent of the relationship between these macro- and microdefects. Previous researchers have questioned the strength of this relationship, if any, stating that there are likely distinct etiologies at work in the formation of the defects. Under microscopic observation, each Wilson band that terminated in a LEH was noted.

8) The number of LEHs viewed only microscopically was recorded. Traditionally, LEH data is collected macroscopically and it is possible that slight expressions of hypoplasias are not visible to the eye. In contrast, the depressions, however slight, are readily visible under the microscope. This data was recorded in order to show how many LEHs would not have been counted if the teeth were not also viewed in microscopic cross-section.

9) The total number of teeth affected by caries VS. the total number of teeth in the sample is offered. The number of individuals with caries is reported. Due to the low numbers of caries throughout all sites, the frequency of caries types is reported in one table for all sites in the Results chapter.

Appendix 1 summarizes the number of Wilson bands, clusters, and associated LEH by site. These tables are organized by individual and tooth class. The number of microdefects for each tooth is recorded along with the range of the hyper-event clusters (measured in mm from the CEJ). In parentheses following the range, the number of bands per cluster is listed. The final column represents the number of associated LEH; these are hypoplasias that are distinguished by their connection to Wilson bands. If a Wilson band(s) terminated in an LEH, the number of instances was recorded. In parenthesis following the number of instances, the exact associated band(s) was listed. Appendix 2 summarizes the ages at formation for individuals with Wilson bands by site. These tables are also organized by individual and tooth class. The point of origin for each Wilson band was matched to the age at formation tables discussed in the Methods chapter. The age ranges at which defects were noted are listed in the tables and age ranges with hyper-events are in bold type.

Protocol for data collection

Once the definition issues were resolved, the dental samples available for study were analyzed from primary burials and commingled remains at each site. All provenience information was for each the teeth. Tooth number and class were identified. Crown measurements (e.g. maximum bucco-lingual diameter, maximum mesio-distal diameter, maximum crown height) were taken using sliding digital vernier calipers in the event of future bio-distance analysis. Whenever an enamel hypoplasia was noted on the enamel surface, a distance measurement from the cemento-enamel junction to the defect was recorded in millimeters using the calipers to the nearest .05mm reading. Caries and enamel hypoplasias were identified and documented according to standard bioarchaeological methods (Buikstra and Ubelaker 1994).

Table 26. Caries scoring system (after Buikstra and Ubelaker 1994:54).

Score	Description
0	No lesion present
1	Occlusal surface
2	Interproximal surfaces
3	Smooth surfaces
4	Cervical caries
5	Root caries
6	Large caries
7	Noncarious pulp exposure

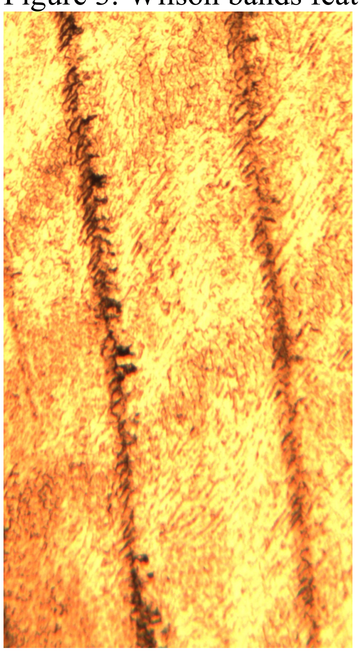
Table 27. Enamel defects scoring system (after Buikstra and Ubelaker 1994:56).

Score	Description
0	Absence
1	Linear horizontal grooves
2	Linear vertical grooves
3	Linear horizontal pits
4	Nonlinear arrays of pits
5	Single pits

Enamel hypoplasias were scored using a combination of the "thumbnail" test and taking an impression in putty. The thumbnail test was done by running a thumbnail over the surface of the crown to feel for linear horizontal grooves (the most prevalent type of defect). Following the thumbnail test, the tooth surface was pressed into putty and the resultant impression was inspected. The putty helps identify slighter expressions of horizontal grooves, as well as pit defects that may not be as immediately visible during the thumbnail test. Color and width of the hypoplasias were not recorded, as these data have not been demonstrated to provide any useful biological information (Buikstra and Ubelaker 1994). Fitzgerald and Saunders (2005) stated that variables other than defect presence do not factor into the threshold level or denote severity of the defect.

Ideally, the thin sectioning of each tooth through the midline should provide a sort of check and balance as true linear enamel hypoplasias seen in cross-section should be readily apparent by their concave presentation under the microscope. If a hypoplasia was recorded macroscopically, but microscopic appearance was not confirmed, then it was considered a false hypoplasia and removed from the records. Additionally, if a faint hypoplasia was not documented during macroscopic analysis but was confirmed during microscopic observation, the records were changed to reflect the observation. If viewed only microscopically, the linear enamel hypoplasia was measured from the CEJ to one point in the center of the defect using the imaging software in tandem with the microscope. This protocol mirrored how the enamel hypoplasia was measured macroscopically; in both cases, the defect was measured from the CEJ to a center point. While it may seem valueless to do the thumbnail and putty analysis if microscopic observation confirms hypoplasia presence, collecting the macroscopic data according to published standards allows for any future comparative studies focused on linear enamel hypoplasias.

Figure 3. Wilson bands featuring “stuttered” enamel at 400x.



Thin sectioning procedure

After the hypoplastic defects and carious lesions were recorded, the teeth were thin sectioned for examination of the internal surface. During a previous pilot study of dental remains from Actun Uayzaba Kab and Caves Branch Rockshelter (Michael and Wrobel 2011), it was determined that the Buehler ISOMET thin sectioning saw at Michigan State University's Forensic Anthropology Laboratory was not sufficient for cutting these archaeological samples. Because the teeth from the cave and rockshelter sites were variably preserved, the enamel was friable and easily flaked off during thin sectioning even though each tooth was embedded. I suspect that the resin did not bind to the enamel surface (either because the enamel was slick and/or covered with soil or cave residues even after cleaning), and so the teeth were not held securely in place by the resin block during the cutting process.

After consulting with a geologist, Dr. Tyrone Rooney (Michigan State University, Department of Geology), about these issues I was directed to a professional company that could create the thin sections using different resins and machinery. Spectrum Petrographics, a company specializing in creating thin sections of organic and inorganic materials, created the dental slides for this project. Spectrum utilizes a saw blade that greatly reduces the amount of enamel lost in the cut, or kerf, of the blade. Additionally, the company uses equipment for grinding and polishing samples that was not available to me at Michigan State University. The polishing, or lapping, step is critical in reducing the thin section to the desired thickness once the initial cut has been made.

At Spectrum Petrographics, each sample was impregnated with a resin/hardener mixture that surrounded the tooth making a hard block that can be cut with a rotating saw blade. Each block was cut in midline resulting in two thick sections. One thin section slide was created from a thick section block and the provenience information, tooth class, and side was etched into the slide glass. Per the literature, each thin section was ground to approximately 80-100µm (Fitzgerald and Rose 2000; Hillson 2014); however, even this thickness is up for debate as other publications advise a thickness of 150 μm for low magnification. Differences in opinion over appropriate thickness for dental sections further complicates comparability across samples prepared separately.

Age at defect formation

Following the recording of presence/absence, type, frequency, and location documentation for each sample, the age at defect formation for each Wilson band was estimated. The evaluation of age at defect formation was the most challenging aspect of this study. Researchers have tried to solve the issue of how to best match microdefects to age ranges in a variety of ways. Marks (1993:97) necessarily pointed out that, "assigning age to Wilson bands is, therefore, only as appropriate as the confidence in dental maturation standards." Dental maturation charts are readily available in the literature and many bioarchaeologists use developmental schedules developed for specific populations to age dissimilar samples, but Marks' critique remains appropriate.

Before the assignment of age at defect formation for each tooth in the sample, a decision had to be made about the best method for the Maya sample. Danforth's (1989) age charts for the adult canine and third molar, as well as the deciduous canine, were most appropriate because they represented the closest population-specific chart for this dissertation sample. However, since Danforth did not include central incisors in her study, a search for the most appropriate age standards for the enamel surface was done. Both methods used in age at formation studies, crown formation time and equal divisions methods are reviewed below, but only the equal divisions method was used in this dissertation study.

Equal divisions method

Traditionally, most studies have followed standards issued by Schour and Massler (1941) and Massler et al. (1941) that have divided the enamel of the anterior teeth into equal half-year segments associated with age ranges (Danforth 1989; Jablonski 1983; Rose et al. 1978; Wright 1990). These standards have been modified by subsequent researchers (Goodman et al. 1980; Marks 1993; Swardstedt 1966).

In the 1980s, a number of scholars tried to improve data collection methods by calculating the mean crown heights for each tooth in a sample and creating a population mean for the sample (Cook 1981; Condon 1981; Rudney 1981). The crown length from the cemento-enamel junction was then divided into 1 millimeter increments; each increment was associated with approximately 6 months of chronological age. While these divisions were generally useful, Reilly (1986) reported that she had to collapse the divisions into three millimeter segments in order to perform meaningful statistics on her sample as the numbers of pathological striae in each one millimeter segment were not significantly different from one another. Collapsing the millimeter segments allowed for the exploration of a longer biological period.

The main critique of the equal divisions technique is that this methodology does not take into account that enamel formation is not uniform over the course of tooth development (Reid et al. 1998; Ritzman et al. 2008). The problem lies in the variations in crown formation rates in a single tooth, as well as between teeth. Thomson (2011:58) noted that, "while 12 μm of enamel near the EDJ indicates approximately four days of formation, at the external surface of the tooth 12 μm takes only three days to form."

A second critique lies in the difference in tooth size between individuals being compared in a study. Because of interpersonal variation in size, some bigger teeth would have more enamel per section than smaller teeth which would skew the comparison of Wilson band chronologies across dentitions to some degree (Cook 1981).

Further complicating analyses dependent on crown length is the issue of dental attrition. In archaeological samples where the tooth crown is worn down from dietary or use wear, the earliest Wilson bands and hypoplasias are lost. Beyond noting wear and issuing a caveat in interpretation, there is nothing bioarchaeologists can do to reconstruct the data lost by attrition.

Crown formation times method

As discussed previously, teeth grow at different rates according to both tooth class and location on the crown (e.g. cervical growth is slower than cuspal growth). To combat this problem some researchers have instead calculated an individual-specific crown formation rate histologically for each person included in the sample using the neonatal line. More recent projects have focused on developing individual-specific crown formation times using the neonatal line as a starting point.

Recently, anthropologists working with smaller samples have advocated the estimation of specific crown formation times for individuals and biological groups. This method requires the identification of the neonatal line, a pathological stria formed during birth, and then counting of cross striations formed after the line, each of which corresponds to a day. Proponents of this method argue that the problem of non-linear growth of enamel is resolved because age is known instead of estimated by somewhat arbitrarily assigning half-year increments (Reid 1998). Unfortunately, the method is extremely time consuming and challenging as the researcher has to first identify the neonatal line (age zero) in the first permanent molar (the only adult tooth with a neonatal line because it is the only one in which the crown begins to calcify before birth), and then calculate the number of days that lapse between the development of each stria of Retzius by carefully counting the number of cross striations that occur between each stria. Once these days are added, a crown formation time is computed and enamel defects in other teeth are then able to be matched against the first permanent molar.

Antonova (2011) points out that since within populations there is individual variability in the numbers of cross striations between striae of Retzius, it is necessary to establish Retzius line periodicity *for each individual* in a given study. Anywhere from six to eleven cross striations between Retzius lines have been reported in the literature (Beynon 1992; Gysi 1931; Kajiyama 1965; Newman and Poole 1974; Risnes 1998). Researchers who have performed this type of analysis have had very small sample sizes owing to the technical difficulty and time consuming nature of the work (Hillson et al. 1999; Reid et al. 1998), as the crown formation method is tedious nearly to the point of impossibility if large samples are to be used. Indeed, after employing this method on a small sample, Antonova (2011) noted that "the method is destructive, time-consuming and technically demanding. Dental histology is most suitable for inferring age at the individual, rather than population, level" (p. 75).

Finally, the crown formation times method is often not feasible due to the incomplete dentitions, which is a common occurrence in archaeological contexts, including those of the current study. Because the first permanent molar (the only adult tooth with a neonatal line) is required to calculate crown formation rate, many archaeological samples would not be able to be analyzed due to the partial presence of this tooth.

Enamel divisions in the study

The current study focuses on a relatively large sample, which includes incomplete dentitions and commingled teeth. The variably commingled and looted contexts sometimes make it difficult to re-associate teeth when alveolar bone is absent. For these reasons, the equal divisions method was the preferred choice, as it is the best method for generating data about large and incomplete samples in a reasonable time frame. If the protocol for crown formation rate were followed, the sample would have been rendered far too small as the first molar would have been required of all individuals in the sample. However, perhaps the most important reason for using the equal divisions method is that it allows for comparability and replicability across samples, since this technique is most frequently used in the literature. In particular, the two largest Maya dental histology studies (Danforth 1989; Wright 1990) employed this method, and so the data presented here is in congruence with the previous (and limited) Maya histology samples to date.

While the equal divisions of enamel approach may be slightly less accurate in formulating age ranges, it is not *in*accurate. That is, the age ranges may be skewed by a few months at maximum, thus resulting in still usable and informative comparative data. Martin et al. (2008) compared the individual-specific crown formation method to the traditional division approach and found that all estimated ages were less than four months apart, with an average difference of 2.63 months. This difference is minimal and likely has no appreciable affect on the anthropological interpretations that can be made from dental defect data. As Martin et al. (2008) pointed out, bioarchaeologists use dental defects to understand periods of time in childhood rather than punctuated events. That is, the specific day or week of the stress event is not relevant. Rather, the rates of defect prevalence in a population or the timing of defects within a population provides more information about the life history and health experience of individuals in the past.

Microscopic analysis of the sample

Following the decision to use the equal divisions method, the thin sections were ready to be viewed under microscopic analysis. The process of identifying Wilson bands and creating a digital image is one of trial and error in which the focus, light, filter, and stage need to be experimented with in order to best visualize the Wilson bands. Unfortunately, there is no standard technique for analyzing Wilson bands using light transmitted microscopes, creating discordance between researchers' methods and complicating comparability of samples. Some researchers recommend a polarizing filter that will allow the pathological striae to stand out from the normal striae of Retzius but, because the condition of the samples vary and polarizing light is needed only in some cases. Under polarization, enamel and dentine will appear in a range of yellow and grey shades (Hillson 2014). In this study, the enamel microstructures were mostly visible without the aid of a polarizer.

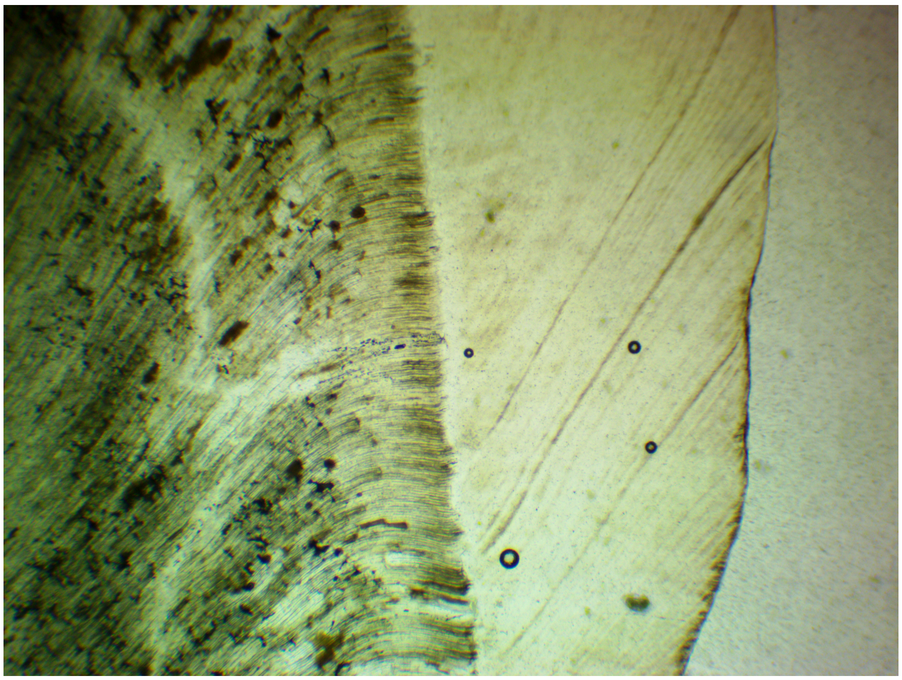
Specifics of the microscope and software

A standard light transmitted, binocular, LED digital compound microscope with 3D stage and 9MP camera attachment was purchased specifically for this project from United Scope. The AmScope 3.7 software included with the microscope was loaded onto a Lenovo laptop computer. The digital camera attachment provided a live feed to the computer, as well as an image capture feature. Measurements were taken from the live feed or the image capture so that each thin section was equally divided and individual sections analyzed.

Thin sections were magnified between 400 - 600x, the power range at which enamel microdefects are best observed (Hillson 2014). After initial identification of Wilson bands, the thin sections were viewed at 40x – 100x in order to note where along the DEJ the defect originated. The frequency of defects per tooth was noted in an Excel spreadsheet along with the measurement of each defect from the CEJ to the origin point along the DEJ. During data collection, it was observed that microdefects often occurred in clusters. When three or more bands appeared in a cluster of 0.5mm or less following the DEJ, it was termed a "hyper-event."

Manual adjustment of the stage platform and the focusing apparatus proved time consuming, as each slide required slight readjustment. The integrity of each thin section slide was variable resulting in some thin sections that were difficult to analyze due to poor preservation. Deciduous teeth were cut at the same thickness as adult teeth, but the microstructures were appreciably more difficult to view in sub-adult teeth. In the future, it is recommended that deciduous teeth be cut slightly thicker than adult teeth.

Figure 4. Image of tooth at 40x showing hyper-event (three black lines) and slight LEH in cross-section.



Because the field of view does not permit an image of the entire tooth, several photomicrographs of teeth would have to be stitched together in order to create a composite image of a whole tooth. Initially, it was thought that a digital photo of each tooth would be created for analysis and for future comparative studies, but this process proved far too time consuming. Dental histology researchers do not image all of their specimens in this way, rather they tend to create a few composite images as examples and collect the rest of the data according to traditional methods (e.g. viewing through the eyepiece or manually moving the slide on the stage platform and recording the data concurrently). In the future, it would be worthwhile to undertake a large-scale project in which photomicrograph composite images were created for all the teeth in the sample. These images could be used as a comparative data set that could be shared with researchers electronically.

Age at defect formation analysis

Age at defect formation was assessed using a combination of previous literature. Following Cook (1981), Danforth (1989) developed a population-specific age at defect formation schedule for Maya dental remains (deciduous canines, permanent canines, third molars). Danforth (pers. comm. 2011) stated that it would be reasonable to use these standards for this dissertation study. Because Danforth did not include central incisors in her study, another set of standards had to be used. Reid and Dean (2000) created age at formation tables for central and lateral incisors, which was judged to be the best age schedule to use for this sample. Reid and Dean divided the incisor crown into deciles with associated ages, so the process of enamel divisions is similar to Danforth (1989) even though it was developed on a disparate sample of 115 modern teeth extracted during oral surgery procedures. Reid and Dean (2000) readily admitted that standards developed on a modern sample cannot account for all human variation in the past and present, but they also stressed that there were few histological studies available that might provide useful models for future research.

Reid and Dean (2000) divided the maxillary central incisor into ten equal percentiles based on total crown height. This method does not exactly mirror the equal divisions method (e.g. divisions into 1mm increments) that Danforth employed, but is likely the best option for estimating age at defect formation. In order to check the Maya sample for comparability, a random selection of fifteen fairly unworn teeth were chosen for measurement.

If the Maya teeth were similar in overall crown size to the total crown heights published in the Reid and Dean study, the Reid and Dean dental standards could be applied (discounting, of course, the fact that the standards were developed on a disparate population group). All fifteen unworn teeth were between 9.5 – 10.1 mm in crown height, meaning that an application of the 1mm increments to the Reid and Dean charts would be reasonable. Again, this is the best case scenario for an incomplete sample on which no previous population-specific enamel development charts have been published.

Measurements of the location of the Wilson bands were taken along the DEJ with the CEJ acting as the zero point. For instance, if a Wilson band was recorded at 1.14mm, that means that the defect began 1.14mm from the CEJ. These measurements were matched to the appropriate increment for each tooth class (e.g. if a defect in a third molar of a female was noted at 2.5mm from the CEJ, the associated increment would be in Danforth's DEJ zone 5 and the associated age range would be 11.3 – 11.8 years; see Table 28 below).

Table 28. Age at development for mandibular third molars[1] (adapted from Danforth 1989).

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Years (Males)	Age in Years (Females)	Age in Years (Combined Sexes)
1	6.01 – 7.0	9.0 – 9.6	9.1 – 9.6	9.0 – 9.6
2	5.01 – 6.0	9.6 – 10.3	9.6 – 10.2	9.6 – 10.2
3	4.01 – 5.0	10.3 – 10.9	10.2 – 10.7	10.2 – 10.8
4	3.01 – 4.0	10.9 – 11.6	10.7 – 11.3	10.9 – 11.4
5	2.01 – 3.0	11.6 – 12.3	11.3 – 11.8	11.4 – 12.0
6	1.01 – 2.0	12.3 – 13.0	11.8 – 12.3	12.0 – 12.7
7	0.0 – 1.0	13.0 – 13.6		13.0 – 13.6

[1]The same chart was used for maxillary third molars based on the very similar development times (Logan and Kronfield 1933).

In instances where the sex of the individual was estimated, then the male or female age range was used. The majority of the individuals were not sexed, so the combined age ranges were employed. Tables 29-31 were developed in the same manner as the example listed above for the remainder of the tooth classes in the study.

Table 29. Age at development for mandibular canines (adapted from Danforth 1989).

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Years (Males)	Age in Years (Females)	Age in Years (Combined Sexes)
1	11.01 – 12.0	0.7 – 1.1	0.5 – 0.9	0.6 – 1.0
2	10.01 – 11.0	1.1 – 1.5	0.9 – 1.3	1.0 – 1.4
3	9.01 – 10.0	1.5 – 1.8	1.3 – 1.7	1.4 – 1.8
4	8.01 – 9.0	1.8 – 2.2	1.7 – 2.1	1.8 – 2.1
5	7.01 – 8.0	2.2 – 2.6	2.1 – 2.5	2.1 – 2.5
6	6.01 – 7.0	2.6 – 3.0	2.5 – 2.9	2.5 – 2.9
7	5.01 – 6.0	3.0 – 3.4	2.9 – 3.3	2.9 – 3.3
8	4.01 – 5.0	3.4 – 3.8	3.3 – 3.7	3.3 – 3.7
9	3.01 – 4.0	3.8 – 4.1	3.7 – 4.0	3.7 – 4.1
10	2.01 – 3.0	4.1 – 4.5	4.0 – 4.4	4.1 – 4.5
11	1.01 – 2.0	4.5 – 4.9	4.4 – 4.8	4.5 – 4.9
12	0.0 – 1.0	4.9 – 5.3		4.9 – 5.3

Table 30. Age at development for deciduous mandibular canines (adapted from Danforth 1989).

DEJ Zone	AmScope Measurement (mm from CEJ)	Age in Months (Combined Sexes)
1	7.01 – 8.0	5 – 6 (in utero)
2	6.01 – 7.0	7 - 8 (in utero)
3	5.01 – 6.0	9 (in utero) – 1 (post-birth)
4	4.01 – 5.0	2 – 3
5	3.01 – 4.0	4 – 5
6	2.01 – 3.0	6 – 7
7	1.01 – 2.0	8 – 9
8	0.0 – 1.0	10 – 11

Table 31. Age at development for maxillary central incisors (adapted from Reid and Dean 2000).

Zone	AmScope Measurement (mm from CEJ)	Age in Years (Combined Sexes)
1	9.01 – 10.0	1.1 – 1.3
2	8.01 – 9.0	1.3 – 1.6
3	7.01 – 8.0	1.6 – 1.8
4	6.01 – 7.0	1.8 – 2.0
5	5.01 – 6.0	2.0 – 2.4
6	4.01 – 5.0	2.4 – 2.9
7	3.01 – 4.0	2.9 – 3.4
8	2.01 – 3.0	3.4 – 3.9

Table 31 (cont'd).

9	1.01 – 2.0	3.9 – 4.4
10	0.0 -1.0	4.4 – 5.0

Coding variables for statistical analysis

Before statistical analysis, variables were coded when needed. While the raw data collection sheets list both the minimum and maximum ages at defect formation, the mean age of defect expression was used for most statistical analyses in order to meaningfully compare burials across sites. What follows is a description of the coded variables and values in the raw data spreadsheets (in order by column):

1: Individual – provenience given by original excavator

2: Tooth – each tooth was given a unique number (1-176)

3: Site Type – Cave (0); Rockshelter (1); Surface (2)

4: Tooth Class – Central maxillary incisor (0); Mandibular canine (1); maxillary or mandibular third molar (2); Mandibular deciduous canine (3)

5: Minimum Age at Defect Formation – earliest age at which the individual exhibited a microdefect

6. Maximum Age at Defect Formation – latest age at which the individual exhibited a microdefect

7. Point Estimate of Mean Age at Defect Formation – average of minimum and maximum ages at which the individual exhibited a microdefect

8. Sex – Male (0); Female (1); Indeterminate (2)

9. Caries Frequency – number of instances of caries

10. Caries – absence (0); presence (1)

11. Linear Enamel Hypoplasias – number of instances of LEHs

12. Linear Enamel Hypoplasias - absence (0); presence (1)

13. Wilson bands – number of instances of WBs

14. Wilson bands - absence (0); presence (1)

15. Hyper-events – number of instances of hyper-events

16. Hyper-events - absence (0); presence (1)

17. Age at death – If the original excavators estimated age at death, this information was entered into each site-specific data sheet. For the purposes of statistical analysis, age periods were pooled into juvenile (<14; represented by 0), young (15-25; represented by 1), and adult (over 25; represented by 2). Because field notes show that different researchers used variable age ranges to describe the same periods (e.g. 15-18 VS. young VS. young adult), the decision was made to use broad age categories to represent the burials.

Potential problems with the methodology

Underscoring the difficulty in execution of dental histology methods is the fact that Wilson bands take on considerably varied appearances within, and especially between, teeth (Thomson 2011). Therefore, identifying the same stress event in different teeth may be problematic or even impossible at times. Thomson (2011) necessarily stated that a clear definition of a Wilson band would mitigate this issue in part.

Beyond observation issues, the process of thin sectioning is still under review by researchers. Thin sectioning is a highly technical procedure that demands skill and replicability in order to create sections that are cut at a 90-degree angle through the midline of the tooth. Deviation from this angle can result in oblique sections in which Wilson bands are not visible or, at minimum, less observable under microscopic analysis. Thomson (2011) noted that it is difficult to view both cross striations and brown striae of Retzius (i.e., Wilson bands) in the same thin section. This is because cross striations are best viewed in thin sections ground to 100 μm or less, while striae of Retzius are better seen in slightly thicker sections. However, there is still no standard in the field and researchers consistently create thin sections between 80 μm and 150 μm depending on their own experience and their sample.

Finally, and perhaps most importantly, Fitzgerald and Saunders (2005) stated two problems that exist when pursuing dental histological studies: 1) not all stress events will be identified in the dentition where researchers can easily observe them (e.g. in the case of cuspal enamel where Wilson bands are difficult to observe); and 2) not every stress event will result in a Wilson band. Frequency counts of Wilson bands will then always be underestimates of stress episodes. These issues, in addition to the subjectivity of the definitions and methods used in the identification of Wilson bands, have resulted in a promising field of study that is still somewhat encumbered by the lack of standards and knowledge about the biology behind the appearance of these defects.

CHAPTER 7: RESULTS

The results of this dental defect study demonstrate that microdefects in the samples are the norm rather than the exception. Most individuals, regardless of site type, experienced microdefects at some point in time during their dental development. The number of defects per tooth varied widely, from one Wilson band to over 25 bands. These results are likely conservative estimates because only those bands that were approximately 75% or more the length of the DEJ to crown surface were counted.

Some general patterns in frequency of microdefects were documented during the data collection phase before statistical analysis. For instance, Wilson bands were generally underrepresented in third molars. Slightly marked expressions of enamel prisms occurred with some regularity, but rarely did these instances meet the requirements for a Wilson band per the definition outlined in this dissertation. In the future, a comparison between the third molars in this study to their antimeres (if available) sectioned using a greater thickness would be beneficial to determine if the sections were cut too thin for this tooth type due to differences in tooth architecture (as opposed to canines and incisors). Perhaps the microstructure of molars is best viewed under different conditions.

This chapter is organized by a discussion of the data points collected for the samples at each site, followed by a site-by-site summary of the data. Following the site summaries, each research question is re-addressed and answered.

Actun Uayazba Kab

Of the 9 teeth available for analysis, seven exhibited at least one Wilson band and/or LEH. Six individuals formed Wilson bands, ranging from 1 to 7 bands per tooth. Maxillary central incisors (n=4; 4 affected teeth) retained the most Wilson bands, followed by mandibular canines (n=2; 2 affected teeth). No Wilson bands were noted in the third molars, indicating that acute stress events tapered off later in childhood development.

Table 32. Summary of AUK sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=4)	18	3.23
Mandibular canine (n=3)	4	2.9
Third Molar (mandibular and maxillary) (n=2)	0	N/A
Deciduous maxillary central incisor (n=0)	N/A	N/A
Deciduous mandibular canine (n=0)	N/A	N/A

The earliest instance of defect formation occurred at 1.8 years in the incisor (Burial 98-1), while the latest episode occurred at 5 years in the incisor (Burial 98-4). All other microdefects were encompassed between these age ranges regardless of tooth class.

Of individuals with two or more teeth available for analysis (n=3), only one individual demonstrated microdefects that overlapped in time period. Burial 97-1 formed Wilson bands from ages 2.4 – 2.9 on both the mandibular canine and maxillary central incisor, suggesting that this time period was particularly stressful.

Table 33. Summary of AUK sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	0
4	0
5	1
6	0

Only one individual (Burial 98-4) showed a cluster of bands in the incisor. In this case, five bands were observed which was one of the largest clusters documented in the entire study. Interestingly, Burial 98-4's other teeth were not affected by microdefects, suggesting the incisor was differentially affected during an earlier period of time when the other teeth were not forming.

Instances of linear enamel hypoplasias appear to be infrequent, with only two affected individuals. Burial 98-2 had no hypolastic defects on the incisor or canine, but two defects were noted on the third molar, indicating growth disturbances occurring between ages 13.0 – 13.6 years. Burial 97-1, an adult male, displayed four hypoplastic defects on the mandibular canine (between ages 2.6 – 3.4 years) but none on the maxillary canine or incisor. No Wilson bands terminated in LEHs in this sample. In two instances, linear enamel hypoplasias were not visible macroscopically, but were noted under microscopic view, demonstrating that histology provides a method of confirming faint hypoplasias that may not otherwise be noted macroscopically. Three out of nine teeth exhibited carious lesions (see Table 46 for types). Only Burial 98-2 expressed both carious lesions and enamel hypoplasias.

Je'reftheel

Of the 20 teeth available for analysis, 17 exhibited at least one Wilson band and/or LEH. Fifteen individuals formed Wilson bands, ranging from 1 to 8 bands per tooth. Mandibular canines (n=9; six affected teeth) retained the most Wilson bands, with third molars (n=7; 5 affected teeth) and maxillary central incisors (n=2; 2 affected teeth) following. Two deciduous maxillary central incisors were present but only one showed microdefects.

Table 34. Summary of JRH sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=2)	17	3.15
Mandibular canine (n=9)	23	3.17
Third Molar (mandibular and maxillary) (n=7)	9	11.91
Deciduous mandibular canine (n=0)	N/A	N/A

The earliest instance of defect formation occurred at 1.0 years in the canine (JRH09-5-12), while the latest episode occurred at 13.6 years in the third mandibular molar (Skull C). All other microdefects were encompassed between these age ranges regardless of tooth class.

Of individuals with two or more teeth available for analysis (n=5), no overlaps in developmental time period were addressed. This was due to the formation of microdefects in only one of the teeth, so formation times within the same individual could not be compared. This finding suggests that when individuals did have stress events, they were restricted to a time period during which only one of tooth classes was forming. For instance, Skull A showed clustered defects in the third molar but not in the canine therefore it can be assumed that stress occurred later in childhood development for this individual. Conversely, Skull E showed clusters in the canine and not the molar which indicates stress earlier in life. Skull B exhibited clusters in the incisor but not the canine, meaning that stressors were highly restricted to a particular period of development since these tooth classes partially overlap in developmental time. The two other individuals with multiple teeth available for analysis, Skull C and JRH07-6-5, showed no Wilson bands.

Four individuals (Skull A, Skull B, Skull E, and JRH09-5-12) showed clusters of bands. In all cases, three bands per cluster were noted. Of the four cases, the clusters were discovered in two canines, one incisor, and one molar, though no one individual developed clusters in multiple teeth. This finding indicates that when stress events were rapid in nature, they were confined to a small developmental window that did not overlap with other tooth classes.

Table 35. Summary of JRH sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	4
4	0
5	0
6	0

Of the 20 teeth in the sample, eight have observable LEHs. Half of these teeth have more than one LEH present. All macrodefects were identified visually and there were no slight expressions of LEH that were found microscopically. On four of the teeth, Wilson bands terminated in LEHs though still only 5 of these relationships were recorded (in contrast to the 50 Wilson bands total documented at JRH). Four of the 20 teeth exhibit carious lesions (see Table 46 for types). Only one individual from Chamber 2 had caries, LEH, and Wilson bands.

Sapodilla Rockshelter

Of the 17 teeth available for analysis, 15 of the teeth exhibit at least one Wilson band and/or LEH. Fifteen individuals formed Wilson bands, ranging from 2 to 12 bands per tooth. Maxillary central incisors (n=8; 8 affected teeth) retained the most Wilson bands, Mandibular canines (n=6; 6 affected teeth) with third molars (n=2; 1 affected tooth) and following. One deciduous maxillary central incisor was present but did not show microdefects.

Table 36. Summary of SDR sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=8)	55	3.21
Mandibular canine (n=6)	31	3.63
Third Molar (mandibular and maxillary) (n=2)	3	11.7
Deciduous mandibular canine (n=0)	N/A	N/A

The earliest instance of defect formation occurred at 1.1 years in the incisor (SDR11-12-168), while the latest episode occurred at 12.0 years in the third mandibular molar (Burial 13). All other microdefects were encompassed between these age ranges regardless of tooth class.

Of individuals with two or more teeth available for analysis (n=3), only one instance of developmental overlap occurred. Burial 7 retained Wilson bands in the central incisor and mandibular canine, suggesting that stress events that initiated the physiological disturbance(s) was occurred during the growth of both tooth types. Burial 7's canine was affected by defects during the ages of 2.5 – 3.7 years, while the incisor was affected at ages 1.3 – 3.4 years. It can be determined, then, that the ages of 2.5 – 3.4 years were particularly stressful for Burial 7.

Of the other two individuals with multiple teeth available for analysis, defect sequencing could not be performed due to either one of the teeth not having a band (Burial 10) or the teeth forming at times that did not overlap (Burial 13). Burial 13 showed Wilson bands in the third molar and the canine, suggesting that stress events occurred throughout a period of years from early childhood to adolescence for this individual.

Eight individuals showed clusters of bands representing hyper-events. Two individuals had clusters of four bands each, slightly higher than the three band clusters seen in most of the other samples. No molars were underwent hyper-events, but 5 incisors and 3 canines were affected. Burial 17 was the only individual that showed two distinct clusters of three bands each (5.03 – 5.34mm; 6.91 – 7.11mm) correlated to different age ranges (2.5 – 2.9 and 2.9 – 3.3 years, respectively).

Table 37. Summary of SDR sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	6
4	2
5	0
6	0

Of the 17 teeth in the sample, 7 have observable LEHs. Two of these have more than one LEH present. Only 1 Wilson band terminated in an LEH, further supporting the non-relationship between these defects. Just 1 of the 17 teeth had a carious lesion (see Table 46 for type). No individuals retained a suite of all defects: caries, LEH, and Wilson bands.

Caves Branch Rockshelter

Of the 27 teeth available for analysis, 25 of the teeth exhibited at least one Wilson band and/or LEH. Twenty-five individuals formed Wilson bands, ranging from 1 to 15 bands per tooth. Maxillary central incisors (n=9; 9 affected teeth) retained the most Wilson bands, with mandibular canines (n=10; 10 affected teeth) and deciduous incisors (n=4; 4 affected teeth) following. Deciduous maxillary central incisors (n=4; 2 affected teeth) retained the fewest defects. There were no third molars present in the sample.

Table 38. Summary of CBR sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=9)	54	3.21
Mandibular canine (n=10)	43	2.96
Third Molar (mandibular and maxillary) (n=0)	N/A	N/A
Deciduous mandibular canine (n=4)	6	0.52

The earliest instance of defect formation in the sample occurred at 0.33 years in the deciduous mandibular canine (Burial 19), while the latest episode occurred at 5.0 years in the maxillary central incisor (Burial 53). All other microdefects were encompassed between these age ranges regardless of tooth class.

Of individuals with two or more teeth available for analysis (n=6), three instances of developmental overlap occurred (Burials 10, 38 and 51). Burial 9 showed defects in consecutive age ranges (1.3 – 2.4 years and 2.6 – 3.4 years), while Burials 10, 38, and 51 retained defects in semi-concurrent age ranges (see Appendix 2). When defect sequencing could not be performed, it was due to one of the teeth not having a band (Burial 71). Seven individuals showed clusters of bands representing hyper-events in incisors and canines. In most cases, the clusters consisted of only 3 bands each but Burial 51 exhibited a hyper-event of 6 bands late in enamel development and a cluster of 3 bands earlier in development (see Appendix 2). This pattern indicates increasing stress from the ages of 3.5 – 5.0 years for Burial 51. All other individuals with clusters underwent rapid stress episodes during the ages of approximately 3.7 – 4.5 years, with only Burial 63 exhibiting defects that formed markedly earlier (2.9 – 3.3 years). Overall, the individuals with hyper-events at CBR appear to be experiencing rapid stress episodes at approximately the same age ranges.

Table 39. Summary of CBR sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	8
4	0
5	0
6	1

Of the 27 teeth in the sample, 10 have observable LEHs. Four of these teeth have more than one LEH present. In two cases, Wilson bands terminated in LEHs. Two of the 27 teeth had a carious lesion (see Table 46 for type). No individuals retained a suite of all defects: caries, LEH, and Wilson bands.

Tikal

Of the 33 teeth available for analysis, 25 of the teeth exhibited at least one Wilson band and/or LEH. Twenty-five individuals formed Wilson bands ranging from 1 to 9 bands per tooth. No incisors were collected in the original study by Danforth (1989), so this sample consisted of only mandibular canines, deciduous mandibular canines, and mandibular third molars. Mandibular canines (n=21; 19 affected teeth) retained the most Wilson bands, with mandibular third molars (n=8; 4 affected teeth) following. Deciduous mandibular canines (n=4; 2 affected teeth) retained the fewest bands.

Table 40. Summary of TK sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=0)	N/A	N/A
Mandibular canine (n=21)	83	3.22
Third Molar (mandibular and maxillary) (n=8)	10	11.54
Deciduous mandibular canine (n=4)	2	0.54

The earliest instance of defect formation in the sample occurred at 0.5 years in the deciduous mandibular canine (Burial 215), while the latest episodes occurred at 12.3 years in the mandibular canine (Burials 151 and 182). All other microdefects were encompassed between these age ranges regardless of tooth class. Of individuals with two or more teeth available for analysis (n=6), no instances of developmental overlap occurred so no individuals could be subject to defect sequencing. No overlaps occurred due to either no teeth retaining Wilson bands (Burial 210), one tooth retaining Wilson bands while another did not (Burials 45 and 182), or both teeth retaining Wilson bands but in tooth classes that did not develop concurrently (Burials 109, 151, and 161). If incisors were available for study for the Tikal sample, defect sequencing may have been possible. Five individuals showed clusters of bands representing hyper-events in molars (n=1) and canines (n=4).

In all cases, the clusters consisted of only 3 bands each. Overall, the individuals with hyper-events at TK appear to be experiencing rapid stress episodes at approximately the same age ranges in the canines as microdefects were all measured from 5.7 – 7.01mm from the CEJ. Of the 33 teeth in the sample, 9 have observable LEHs. Five of these teeth have more than one LEH present. In one case, a Wilson bands terminated in an LEH. One of the 33 teeth had a carious lesion (see Table 46 for type). No individuals retained a suite of all defects: caries, LEH, and Wilson bands. Because the teeth were thin sectioned by another researcher (Danforth 1989), no data regarding caries or LEH was available. Any macroscopically visible LEHs would be observed under the microscope, so the frequency of LEH in this sample is confidently reported here. However, it is possible that there were non-linear enamel hypoplasias on the teeth that were not accounted for during microscopic analysis. The caries frequency in this sample is likely underestimated because only those lesions occurring in the midline of the tooth would be visible under the microscope.

Table 41. Summary of TK sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	5
4	0
5	0
6	0

Actun Kabul

Of the 39 teeth available for analysis, 34 of the teeth exhibited at least one Wilson band and/or LEH. Thirty-four individuals formed Wilson bands ranging from 1 to 17 bands per tooth. Maxillary central incisors (n=14; 14 affected teeth) and mandibular canines (n=17; 14 affected teeth) retained the most Wilson bands, with third molars (n=5; 4 affected teeth) and deciduous canines (n=1; 1 affected tooth) and deciduous central incisors (n=2; 1 affected tooth) following.

Table 42. Summary of AKB sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=14)	143	2.99
Mandibular canine (n=17)	77	3.04
Third Molar (mandibular and maxillary) (n=5)	9	12.15
Deciduous mandibular canine (n=1)	4	0.38

The earliest instance of defect formation in the sample occurred at 0.17 years in the deciduous maxillary incisor (AKB11-4-28), while the latest episodes occurred at 13.6 years in the mandibular canine (AKB11-9-45). All other microdefects were encompassed between these age ranges regardless of tooth class. Due to the high incidence of commingling in AKB, only those individuals from "Scatters" in the back chamber were considered candidates for defect sequencing. During excavation in 2013, these scatters were identified as groups of bone and teeth that likely came from the same individual. Two scatters, A and GG, had two teeth. However, in both cases, there was one third molar and one canine so the developmental formation times did not overlap.

Eleven individuals showed clusters of bands representing hyper-events in canines (n=3) and incisors (n=8). Band episodes ranged from 3 bands to 5 bands. Unlike other sites where individuals with hyper-events usually experienced only one rapid episode, 6 individuals showed more than one cluster. This finding suggests that individuals buried at AKB were more likely to experience multi-episode rapid stress events than individuals buried at other sites in the region. Overall, the individuals with hyper-events at AKB experienced the most stress between the ages of 2.4 – 2.9 years of age, with some instances occurring as early as 1.8 years and as late as 4.4 years.

Table 43. Summary of AKB sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	17
4	5
5	1
6	0

Of the 39 teeth in the sample, 16 have observable LEHs. Three of these teeth have more than one LEH present. In three cases, Wilson bands terminated in LEHs. One of the 39 teeth had a carious lesion (see Table 46 for type). No individuals retained a suite of all defects: caries, LEH, and Wilson bands.

Pacbitun

Of the 40 teeth available for analysis, 36 of the teeth exhibited at least one Wilson band and/or LEH. Thirty-six individuals formed Wilson bands ranging from 1 to 18 bands per tooth. Mandibular canines (n=16; 15 affected teeth) and maxillary central incisors (n=13; 13 affected teeth) retained the most Wilson bands, with third molars (n=11; 8 affected teeth) following. No deciduous teeth were present.

Table 44. Summary of PB sample: Wilson bands and ages.

Tooth class	Number of Wilson bands in entire tooth class	Point estimate of average affected age
Central maxillary incisor (n=13)	106	2.89
Mandibular canine (n=16)	60	3.35
Third Molar (mandibular and maxillary) (n=11)	22	11.97
Deciduous mandibular canine (n=0)	N/A	N/A

The earliest instance of defect formation in the sample occurred at 1.1 years in the central maxillary incisor (Burial 2, Mound 6), while the latest episodes occurred at age 12.7 years in the third molar (Burial 3, Mound 6; Burials 1 and 2, Mound 36; Burial 2-4; Burial 4-1). All other microdefects were encompassed between these age ranges regardless of tooth class.

Defect sequencing for the individuals buried at Pacbitun was difficult because multiple individuals were often buried in the same grave. When the samples were collected for analysis at Trent University, the excavation bags noted when multiple individuals were interred (e.g. “M, F, M” on tag) but not which teeth belonged to which individual. Only four individuals, buried in single graves, were available for defect sequencing. Three of these individuals retained teeth that did not overlap in developmental time, so only one individual (Burial 2-3) had dentition that was affected at the same time. Burial 2-3 exhibited Wilson bands from ages 1.8 – 5.3 years of age, but the ages of 2.0 – 2.9 years were particularly stressful as bands were present in both the incisor and canine.

Six individuals showed clusters of bands representing hyper-events in incisors (n=4), third molars (n=3), and canines (n=2). Band episodes ranged from 3 bands to 5 bands. Two teeth showed more than one hyper-event episode. Overall, the individuals with hyper-events at Pacbitun experienced the most stress between the ages of 2.4 – 3.9 years of age, with some instances occurring as early as 1.6 years. There were also three instances of third molars with hyper-event clusters at ages 11.4 – 12.0 years.

Table 45. Summary of PB sample: hyper-events (clusters).

Number of bands per event	Instances in sample of clusters
3	12
4	3
5	1
6	0

Of the 40 teeth in the sample, 6 have observable LEHs. Only one of these teeth has more than one LEH present. Wilson bands never terminated in LEHs in this sample. Seven of the 40 teeth had carious lesions (see Table 46 for type). No individuals retained a suite of all defects: caries, LEH, and Wilson bands.

Descriptive summary of all sites

After data collection, it became clear that it was not possible to run meaningful statistics for some data points. Carious lesions were particularly low across all site types and so the results for caries are presented in Table 46 and not tested for significant correlations between caries and other defects. Studies of the relationship between social status and carious lesions have been performed in the Maya region with varying results (Cucina and Tiesler 2003; Slon and Michael

2013; White 1994). Overall, the pre-Hispanic Maya did not suffer from prevalent caries development, likely due to a combination of factors that changed over time according to new political, economic, and environmental constraints. The populations in this study proved no different.

The frequency of LEHs by site is presented in Table 47 to demonstrate that while the percentage of individuals with enamel macrodefects by site never approaches more than 50%, the total of individuals with enamel microdefects by site never falls below 75%. These frequencies reflect how ubiquitous Wilson bands are in these samples.

Table 46. Instances of caries across all sites.

Type[1]	AKB	JRH	AUK	SDR	CBR	PB	Total types
Occlusal (1)	0	0	1	0	0	4	5
Interproximal (2)	0	1	0	0	0	0	1
Smooth surfaces (3)	1	2	0	0	0	1	4
Cervical (4)	0	1	0	1	1	2	5
Root (5)	0	0	2	0	0	0	2
Large (6)	0	0	0	0	1	0	1
Noncarious pulp exp. (7)	0	0	0	0	0	0	0
TOTAL	1	4	3	1	2	7	18

[1]Following Buikstra and Ubelaker (1994:54).

Table 47. Frequency of LEHs by site.

Site	Individuals with LEHs	Total number of individuals	Frequency of LEHs in the sample
AKB	16	39	41.0%
JRH	8	20	40.0%
AUK	2	9	22.2%
SDR	7	17	41.2%
CBR	10	27	37.0%
TK	9	33	27.3%
PB	6	40	15.0%

Answering the research questions

In order to meet the assumptions for statistical tests, the mean age at defect formation was checked for normal distribution by tooth class. For most sites, the mean, median, and mode for each tooth class were very close or equal. In several instances there was a near normal distribution, with the small sample sizes accounting for the slightly higher differences between means, medians, and modes.

Question 1: Is there a correlation between Wilson bands and LEHs?

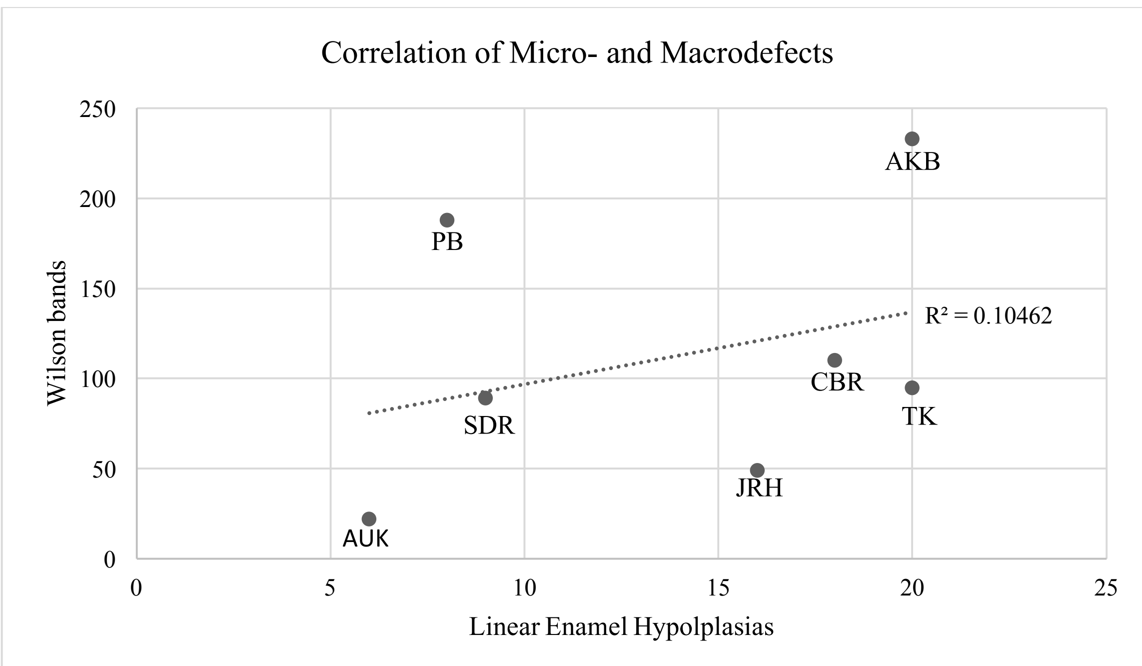
This question explored whether there was a correlation between micro- and macrodefects regardless of tooth class to determine if the relationship between Wilson bands and LEHs (see Table 48 for total counts of macro- and microdefects). Correlations between Wilson bands/caries and LEHs/caries were not explored because there were so few instances of carious lesions in the sample. Other research (Slon and Michael 2013) has demonstrated that frequency of caries is generally low in Central Belize populations. Currently, anthropological literature provides mostly anecdotal evidence for the relationship between these defects. For each defect type, the number of defect instances were summed by site and entered into SPSS. Spearman's rho was used to determine the relationship between LEHs and Wilson bands for all sites. There was no correlation between the number of LEHs and number of Wilson bands in the sample (correlation coefficient, $r_s = .523$, $p = .229$) (Appendix 3).

Table 48. Total defects by site.

Site	Total LEH	Total WB
AKB	20	233
AUK	6	22
JRH	16	49
SDR	9	89
CBR	18	110
PB	8	188
TK	20	95

There is no evidence in this study that Wilson bands and LEHs are correlated, further supporting the hypothesis set forth by other researchers (Simpson 1999; Wright 1990) that the presence of a macrodefect does not necessarily signal the presence of a microdefect. There is disagreement over the extent of the relationship in the literature. Researchers working on large-scale studies of dental defects found that Wilson bands occurred in spite of the absence of enamel hypoplasias (Danforth 1989; Marks 1993). If Wilson bands occur at age intervals at which hypoplasias do not occur, it is reasonable to assume that different etiologies are at work in the formation of these defects.

Figure 5. Correlation of micro- and macrodefects in all sites.



Question 2: In how many instances were LEHs viewed microscopically, but not macroscopically?

While the majority of LEHs viewed macroscopically were confirmed microscopically, there were 22 total instances in which the defects were only visible under microscopic observation. Because LEHs are variably expressed on the surface of the enamel, slight depressions may fail the fingernail and/or putty test. The following table demonstrates that microscopic analysis provides a controlled check of the traditional macroscopic method in scoring LEHs. It is not suggested that future studies of macrodefects always incorporate histological analysis, but researchers should be aware that total counts of LEHs may actually be minimum counts due to slight expressions of defects viewed only microscopically.

Table 49. Percentage of LEHs not visible via traditional analysis.

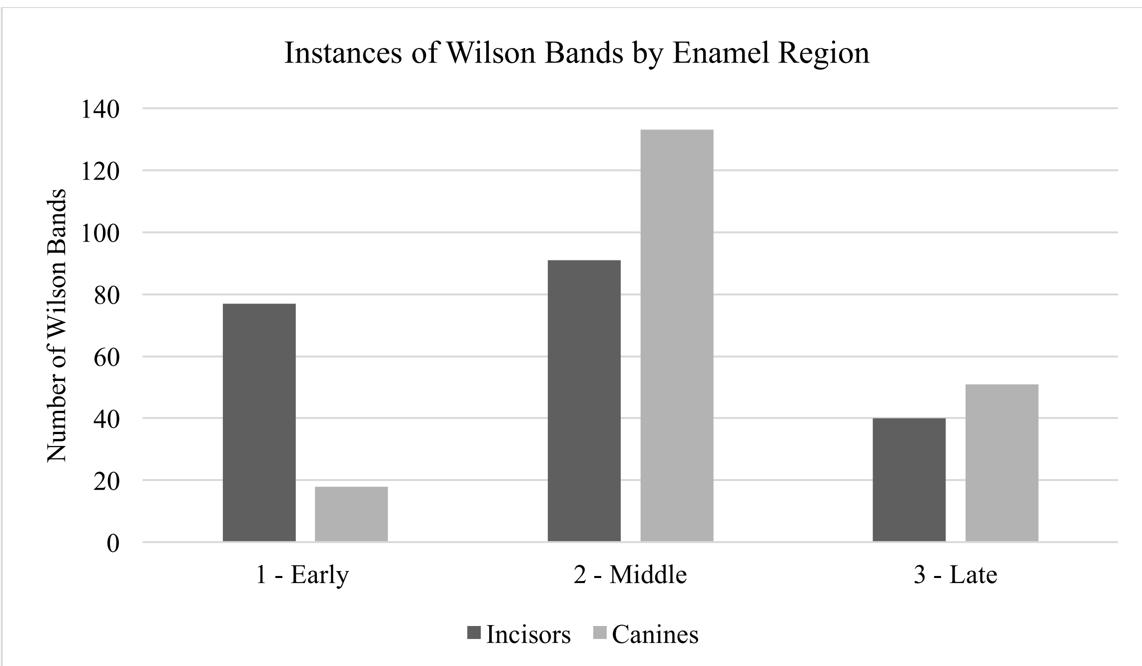
Site	Total LEH	LEH visible under microscope only	% of LEH not counted by traditional method
AKB	20	8	40.0%
AUK	6	1	16.7%
JRH	16	0	00.0%
SDR	9	4	44.4%
CBR	18	6	33.3%
PB	8	3	37.5%

Question 3: Are Wilson bands most prevalent in the middle third of permanent incisors and canines?

Third molars were not included due to later formation period and different tooth architecture. Deciduous canines were not included due to small sample size. For this question, only maxillary central incisors and mandibular canines were assessed. The total age ranges for development for the tooth types were determined by the formation schedules published by developed by Reid and Dean (2000) for incisors (1.1 – 5.0 years) and Danforth (1989) for canines (0.6 – 5.3 years). These total age ranges were then divided into equal thirds (1.3 year increments for incisors, 1.57 year increments for canines) so that three age ranges could be fit to the teeth (Figure 6). Every Wilson band across all site types was pooled by tooth class since this question explores frequency of formation in a particular region when a defect exists. For each instance of Wilson band, the corresponding age range was recorded and fit into the first third (earliest development; starting at cusp), the middle third, or the final third (latest development; towards the CEJ).

The middle third of each tooth class exhibited more microdefects (n=91 for incisors; n=133 for canines) than either the first (n=77 for incisors; n=18 for canines) or last thirds (n=40 for incisors; n=51 for canines) of the tooth crown. This finding articulates with published research suggesting that macrodefects are most prevalent in the middle third of the tooth (Goodman and Rose 1990:74; Simpson 1999:242) due to the internal architecture, susceptibility at particular ages of development, or a combination of both.

Figure 6. Instances of Wilson bands by enamel region.



Yaeger (1980) found that sections of cervical enamel were more likely to exhibit hypoplasias due to the more horizontal structure of the enamel rods. Though micro- and macrodefects are likely born of different etiologies, the region in which the defects will most likely occur is similar. It is hypothesized here that the defects are most present in the middle third of the tooth due to a combination of dental micro-architecture and heightened susceptibility in this particular age range. The internal structure of enamel is not uniform from the cusp to the CEJ and microdefects are more difficult to locate in cuspal enamel potentially resulting in lower band counts. Additionally, the middle third of both canines and incisors reflects an overlapping period of great developmental and physiological changes encompassed during the transition from weaning to solid foods.

Question 4: What is the overall mean age of defect formation at each site (by tooth type)? At which site do individuals show earliest age of defect formation (by tooth type)? Latest?

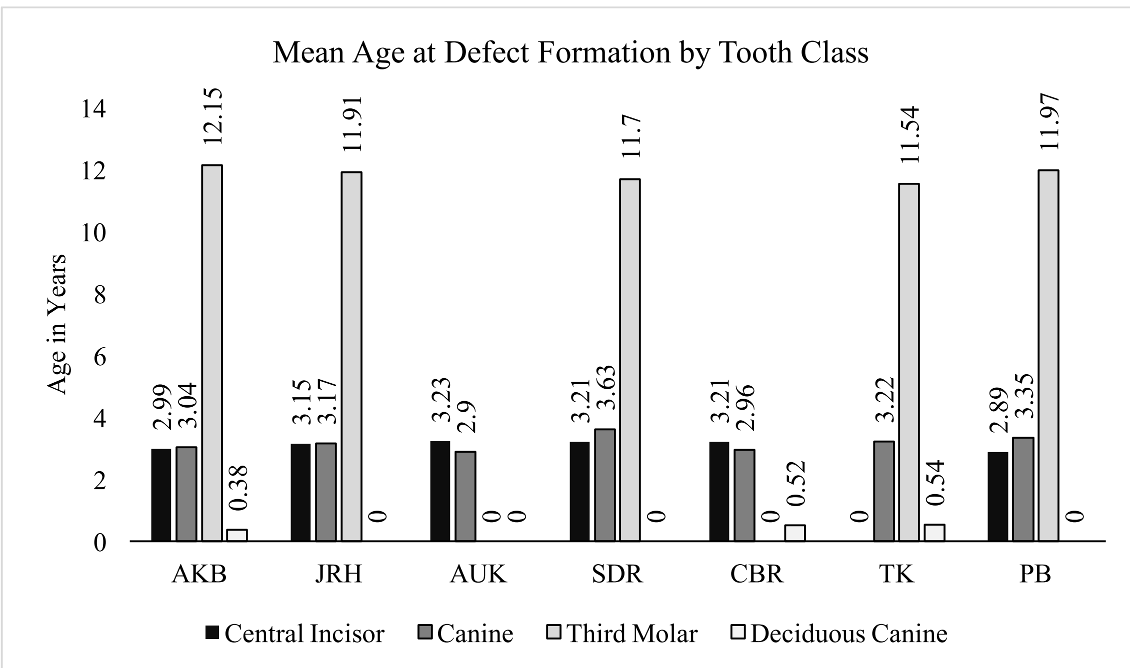
A point estimate for mean age at defect formation was calculated for each tooth by averaging the minimum and maximum age ranges at which each individual was affected. To calculate the average age at defect formation by tooth class for each site, the individual point estimates per tooth class were summed and averaged (e.g. all point estimates for AKB incisors were summed and divided by total AKB incisors). Table 50 and Figure 7 illustrate the mean age at defect formation for each tooth class by site.

Table 50. Mean age of defect formation in tooth classes.

Site	Central incisor	Canine	Third molar	Deciduous canine
AKB	2.99	3.04	12.15	0.38
JRH	3.15	3.17	11.91	N/A
AUK	3.23	2.9	N/A	N/A
SDR	3.21	3.63	11.7	N/A
CBR	3.21	2.96	N/A	0.52
TK	N/A	3.22	11.54	0.54
PB	2.89	3.35	11.97	N/A

When analyzed using one-way ANOVA tests, none of the mean ages at defect formation by tooth class and between sites were significantly different. However, some interesting patterns can be extrapolated from these data. Both incisors and canines from AKB show early ages at defect formation (2.99 years and 3.04 years, respectively) when compared with the mean age of formation at other sites. AKB molars exhibited the latest age of defect formation when compared to other sites. Taken together, these data indicate that individuals at AKB experienced stress at generally earlier and later time periods and may have had longer durations of health stress during the formative years. Similar patterns were observed in the PB sample where individuals showed the earliest age of defect onset at 2.89 years in the incisors and the second to latest age of defect formation at 11.97 years in the molars.

Figure 7. Mean age at defect formation by tooth class.



Another finding of note is the close periods of mean age at defect formation in the incisors and canines at both JRH (3.15 years and 3.17 years, respectively) and AKB (2.99 years and 3.04 years, respectively) indicating that whatever stresses were occurring during these years were closely grouped in duration and affected both tooth classes at overlapping periods of development. The third molars from the Tikal sample showed the earliest mean age at defect formation at 11.54 years suggesting that when these individuals underwent stress, the events were earlier in life.

Question 5: Are there significant differences (by tooth type) in mean ages at defect formation between sites?

One-way ANOVAs by tooth class were run per site. For instance, the incisors from each cave site were compared in order to determine if there were any significant differences between mean age at defect formation within site types, then the incisors from each rockshelter site were compared, followed by the incisors from each surface site. There were no statistically significant differences between incisors by site type, deciduous canines, and third molars by site type. The only instance of significant difference was in mean age at defect formation in mandibular canines between Caves Branch Rockshelter and Sapodilla Rockshelter (Appendices 4 and 5). There was a statistically significant difference between these groups as determined by the one-way ANOVA ($F(2,33) = 12.255$, $p = .004$).

Excluding mandibular canines from rockshelter sites, the rest of the teeth were pooled by class and site type (e.g. all incisors from caves compared to all incisors from rockshelters and surface sites). Again, there were no statistically significant differences for mean age at defect formation in the teeth even between site types. These results suggest that individuals, regardless of burial location, experience health stress around the same ages. This result is further explored in the Discussion chapter.

Question 6: Will third molars exhibit fewer pathological striae as compared to maxillary central incisors and mandibular canines?

It was hypothesized that third molars would exhibit overall fewer defects when compared to incisors and canines due to differential ages at development. Incisors and canines overlap in development, encompassing the ages associated with weaning and transition to cereal foods. Additionally, the ages associated with incisors and canines are markedly younger when individuals are reliant on others for nutrition and caretaking needs. Third molars represent later periods in time when diet is more likely to be stabilized and individuals are more self-sufficient.

Because canines and incisors overlap in development for most of their formation time and do not overlap with molar formation time at all, the anterior teeth were pooled. All individuals with and without microdefect expression were summed by incisor/canine and molar across all sites (Table 51). When the anterior teeth with and without microdefects were compared to the posterior teeth with and without defects using a Fisher's exact test, the results were extremely significant ($p = <0.0001$). For this study sample, it was found that third molars are significantly less likely to exhibit microdefects than central incisors and canines.

Table 51. Individuals with and without defect expression by tooth class.

Tooth Class	Presence	Absence
Incisors and Canines	122	8
Molars	23	13

Question 7: How many individuals at each site experienced hyper-events?

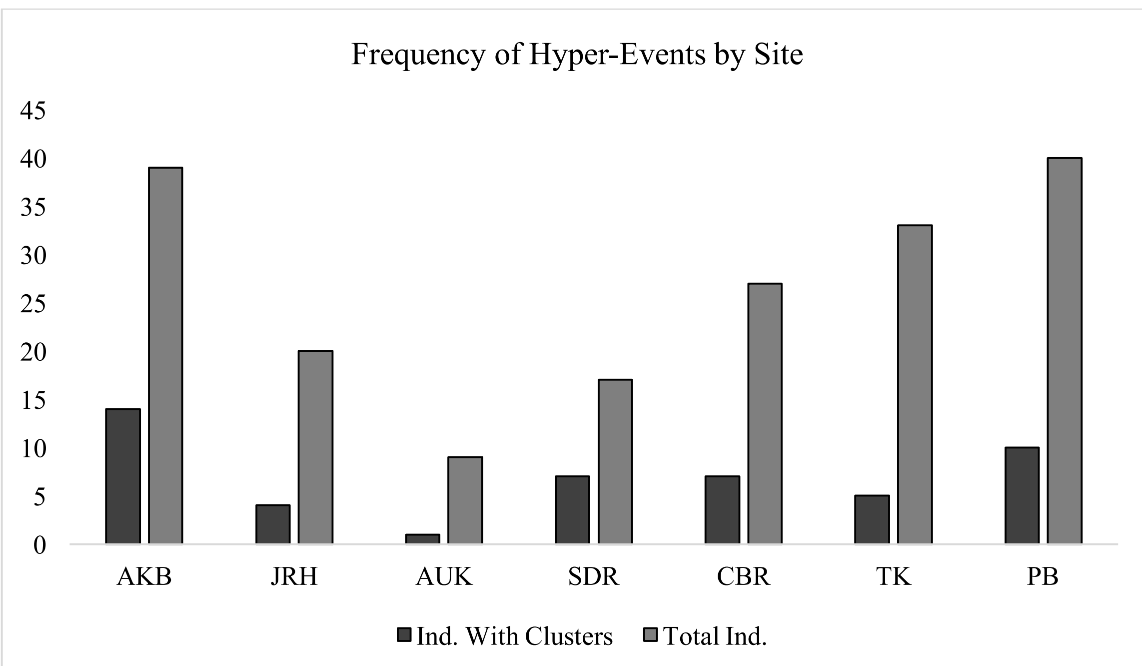
The term "hyper-events" was created for this study because clusters of Wilson band were regularly observed under microscopic analysis. To qualify as a cluster or hyper-event, Wilson bands had to be viewed in groups of three or more and visualized within a 0.5mm space. Hyper-events occurred most often in groups of three bands, though instances of up to four bands or five bands in one cluster were recorded in 10 individuals.

Only one individual from AKB exhibited two hyper-events in a single tooth; all other individuals with clusters showed only one hyper-event per tooth. Hyper-events across all sites by affected tooth class is summarized in Table 52, while the frequency of hyper-events by total number of individuals in each site sample is summarized in Figure 8.

Table 52. Hyper-events summary across all sites.

Site	Total instances of hyper-events	Affected tooth class (number of teeth affected)
AKB	23	Incisor (10) Canine (4) Molar (0)
JRH	4	Incisor (1) Canine (2) Molar (1)
AUK	1	Incisor (1)
SDR	9	Incisor (5) Canine (3)
CBR	8	Incisor (3) Canine (5)
TK	5	Incisor (N/A) Canine (4) Molar (1)
PB	14	Incisor (4) Canine (2) Molar (3)

Figure 8. Total individuals with hyper-events by site.



Biologically, it is unclear what these clustered events mean. Most likely the hyper-events represent a short period of significant stress which disrupted the enamel prisms. It should be noted that of the 48 individuals with hyper-events noted in entire sample, only 10 of these individuals exhibited hyper-events that terminated in an LEH at the enamel surface further supporting previous researchers' claims that LEHs and Wilson bands (even clustered groups of bands in these cases) are not meaningfully related. More research should be done to explore the biological meaning, if any, of these clustered events in dental defect analyses.

Question 8: In cases where sex is estimated, are Wilson bands and LEHs more correlated with males or females?

Nearly all individuals in the sample had Wilson bands in varying numbers, but not all individuals could be reliably sexed. From the entire sample, the sex of only 45 individuals was estimated (N = 23 F, 22 M). When broken down by site, the numbers of individuals of estimated sex were too small for meaningful analysis, so all sexed individuals were pooled. If individuals retained multiple teeth for analysis, the presence of one or more defects within just one of the teeth was counted as "Presence" in the chart below. For instance, if a canine and molar were both available but only the molar exhibited a Wilson band, the individual was counted in the "Presence" column in the table below.

A 2x2 contingency table was created and tested using Fisher's exact test with Yate's correction for small sample sizes (due to low numbers and zero value) to explore the significance of Wilson expression by sex (Table 53). A Fisher's exact test without Yate's correction was run to explore the significance of LEH expression by sex (Table 54). The association between male and female groups and the outcomes of presence or absence of Wilson bands was not statistically significant (x^2=0.571 with 1 degrees of freedom; two-tailed p value = 0.4498). The association between male and female groups and the outcomes of presence or absence of LEHs was also not statistically significant (two-tailed p value = 0.7631).

The correspondence analysis run through R (Appendix 6) visually depicts the non-significant relationships.

Table 53. Total sexed individuals with or without Wilson bands.

Sex	Presence	Absence
Male	20	2
Female	23	0

Table 54. Total sexed individuals with or without LEHs.

Sex	Presence	Absence
Male	8	14
Female	10	13

Previous studies have shown that there is no conclusive evidence for the effect of sex on the formation of dental defects. While dental development and eruption schedules are known to vary between the sexes (Demirjian and Levesque 1980; Moorrees et al. 1963), the difference is relatively small (often less than one month in difference). Differences between the sexes in the formation of dental defects is a markedly more complex issue. Because defects result from a variety of stressors (e.g. physical, nutritional, emotional, social) that are entrenched in specific cultural groups at particular times, it is difficult to conclude that one sex is always more affected by enamel defect formation than another.

Studies of enamel defects generally report on differences between sexes (El-Najjar et al. 1978; Swardstedt 1966; Whittington 1989) but the strength of the relationship between presence/absence of defects and sex estimation depends heavily on other factors such as social status (Cucina and Iscan 1997; Lamphear 1990), subsistence strategy and resource access (Cucina 2002; Rose et al. 1978), and interactions with other groups or migration (Littleton 2005). Further, at the individual level, there may be specific and nuanced social or familial reasons for differences between the sexes at a particular site type during a time period. The most succinct conclusion that can be drawn from this sample is that biological sex did not contribute significantly to the likelihood of an individual forming a dental macro- or microdefect.

Question 9: In cases where time period is known, which time period produces the most Wilson bands? LEHs?

Statistical analysis for this question was not possible because, with the exception of TK, JRH, and AUK, all of the sites span multiple time periods and there is not extensive dating done for each site (see Table 55). AMS dates for JRH and CBR confirmed times for particular burials, but in the case of CBR these dates reflect a hiatus in usage of the mortuary space. The highly commingled site of AKB is difficult to date since both ceramics and human remains were deposited on the cave surface with frequent interruption by ancient peoples, looters, and taphonomic conditions. Ceramic chronologies were used to date a majority of the sites and in cases where AMS dating was not performed, typologies were the only source of dating information. Often, the ceramics present at the sites would span multiple time periods, though their presence does not necessarily signal specific use during those periods. For instance, there is evidence that the Maya participated in a process known as a ritual circuit, which resulted in the deposition of ceramic sherds at mortuary sites that were out of temporal context (Shelton et al. 2015). Because samples were not evenly distributed throughout time periods, in addition to lack of AMS dates at some sites, there was no meaningful way to answer this question.

Table 55. Sites by time period.

Late Preclassic	Protoclassic	Early Classic	Middle Classic	Late Classic	Terminal Classic
CBR	SDR	AUK SDR		TK PB JRH AUK CBR	PB AUK CBR

Question 10: Is there a significant relationship between the formation of microdefects and site type? Is there a significant relationship between the formation of macrodefects and site type?

It was hypothesized that microdefects would be more expressed in rockshelter burials due to the lower socioeconomic status of individuals buried at these locales. The total number of individuals with micro- and macrodefects regardless of site type were calculated for each defect (Tables 56 and 58). Fisher's exact tests were performed on each combination of site types (e.g. caves – rockshelters, caves – surface sites, rockshelters – surface sites) for expression of Wilson bands and LEHs. No statistically significant differences in Wilson band expression between site types was noted at the 0.05 level (Table 57). For LEH expression, no significant difference in expression was noted between caves and rockshelters at the 0.05 level. Differences in macrodefect formation between between rockshelters and surface sites were not quite statistically significant, but the result is on the cusp on significance. However, differences in macrodefect formation between caves and surface sites were significant (Table 59).

These data demonstrate that individuals at surface sites were significantly less likely to form macrodefects than those persons buried in caves, but defect formation between rockshelters and surface sites is not as significantly different. Because this pattern is not seen in the microdefect data, it is reasonable to conclude, again, that Wilson bands and LEHs frequently exist independently of one another. Further, the significant differences between surface sites and caves (as well as the nearly significant difference between surface sites and rockshelters) demonstrates that individuals at Pacbitun and Tikal were experiencing less stress that resulted in hypoplasias. Unfortunately, the nature of that stress (or lack of stress) remains unknown. It can be speculated that the urbanized centers of Pacbitun and Tikal were afforded more insulation from nutritional or disease stress that could have been experienced by persons living in the periphery who might have received burial at caves. Urbanization too comes with biological consequences but perhaps whatever stressors experienced by individuals buried in caves and rockshelters were not a source of physiological, emotional, or social stress at Pacbitun and Tikal.

Table 56. Total individuals with microdefect expression by site.

Site	Absence	Presence
Caves (3)	5	37
Rockshelters (2)	0	32
Surface sites (2)	1	19

Table 57. P-values for site type comparisons of Wilson band expression.

Site type comparison	P-value (at 0.05 level)
Caves – rockshelters	0.065
Caves – surface sites	0.654
Rockshelters – surface sites	0.385

Table 58. Total individuals with macrodefect expression by site.

Site	Absence	Presence
Caves (3)	19	23
Rockshelters (2)	16	16
Surface sites (2)	34	13

Table 59. P-values for site type comparisons of LEH expression.

Site type comparison	P-value (at 0.05 level)
Caves – rockshelters	0.815
Caves – surface sites	0.011
Rockshelters – surface sites	0.058

CHAPTER 8: DISCUSSION

This chapter is organized into a discussion of the relevant sampling issues in bioarchaeological research and this study, followed by interpretations of the research results from the two primary thematic categories: 1) patterns in expression of defects, 2) patterns in expression of hyper-events, 3) relationship between defects and site type, and 4) patterns in age at defect formation. The results are interpreted within the theoretical view of negotiated peripherality, introduced in the first chapter, with consideration of the osteological paradox.

Sampling issues

The main caveat for this study is that, although three tooth classes were examined in order to increase the sample size, most individuals did not retain the three teeth needed for complete analysis. Commingling and differential preservation adversely affected the sampling strategy as many loose teeth could not be attributed to a primary burial. Ideally, analysis would have focused on individual burials, each of whom had a maxillary central incisor, a mandibular canine, and a third molar, allowing analysis of growth disruptions throughout childhood and adolescence. In many cases (as explained in the Results chapter), tooth classes or sites were necessarily pooled in order to generate statistically meaningful conclusions. Descriptive statistics at the individual level reveal some mortuary population “outliers” at each site, but the absence of additional bioarchaeological variables such as attendant grave goods, burial position, and secure time periods often precludes more sophisticated analysis on a case by case basis at each site. Further research and excavation in Central Belize, as well as at sites that could be used for temporal comparison, would strengthen future analyses.

Research questions 1-3 and 6-10 were concerned with defect expression in the teeth. The interpretations of results from Questions 2, 3, and 6 were methodological in nature and are summarized in the preceding chapter. Questions 8 and 9 were concerned with sex and time period differences that could not be conclusively answered due to lack of data; both are summarized in the preceding chapter as well. Questions 1, 7, and 10 require more interpretation here.

Patterns in expressions of defects

Since there was no significant correlation between Wilson bands and LEHs (Question 1), it is reasonable to conclude that these defects are physiological expressions born of disparate etiologies. Interestingly, since this dissertation study found that, when compared by site type, the presence of enamel hypoplasias was not a significant discriminator between burial populations. However, Wilson band expression was nearly significant, illustrating that these dental defects were almost certainly not related etiologically and that expression of defects is a poor predictor of mortuary location since oral health does not appear to align with site type.

Simpson (1999) has suggested that since Wilson bands and enamel hypoplasias can occur independently of one another, the etiology of each defect could be distinctly different. While Wilson bands and surface defects may be found within the same tooth, one defect can exist without the other (Simpson 1999; Witzel et al. 2008; Wright 1990). Accordingly, this study found that Wilson Bands rarely terminated near hypoplasias, even when both defects were recorded on the same tooth. Thus, it is possible that the rare instances of co-occurrence are coincidental, and represent a moment in time in which the individual was suffering from two distinct stresses. The exact cause of Wilson bands is unknown, but it is often stated that their appearance is in response to stressors similar to those that cause macroscopic defects (Fitzgerald and Saunders 2005; Goodman and Rose 1990). Currently, there is no real consensus in the anthropological literature beyond the conclusio that Wilson bands represent some systemic stress event relatively short in duration.

From a bioarchaeological perspective, this finding should be considered in future health studies that take only one of these defects into account. In studies with only an LEH component, there may be significant frequencies of microdefects that go unnoted. Conversely, histological studies can account for even the slightest LEHs since the tooth must be cut in midline and any depressions in the tooth crown can be seen in cross-section under the microscope. Additionally, the widths of these depressions can be measured, as can the distance from each LEH to the cemento-enamel junction or occlusal surface.

A non-significant correlation between the two defect types is useful information, but this study reveals no additional data about the cause of either defect type. For the most effective view of past populations, bioarchaeologists would do well to begin to work with clinicians or at least to consider clinical data to understand the biological basis behind defect formation. Isolating causes for ameloblastic disruption would require many variables to be held constant, but small-scale studies are surely possible in clinical settings when medical histories of patients are known. Currently, bioarchaeologists assume that Wilson bands are representative of acute stress events while LEHs result from chronic stressors (Wright 1990). Due to the appearance of Wilson bands in nearly every individual in this dissertation study, it can be safely assumed that whatever stress event(s) lead to Wilson bands are widely experienced during life. Perhaps a better approach would be to determine the factors that must be in place to halt or disrupt ameloblastic production in living individuals. With experimental studies, researchers could demonstrate that particular types of stress (e.g. nutritional, psychological, environmental, etc.) tend to result in Wilson band formation more frequently than other types.

Patterns in expression of hyper-events

The presence and pattern of clustered microdefects was explored in order to determine if individuals at any particular site experienced more repeated stress events than other sites. If specific individuals or sites exhibited more hyper-events, a reasonable interpretation could be made that that person/site was subject to more stressors and, importantly, more *repeated* stressors than others.

Results showed that there was no site-specific pattern associated with the presentation of hyper-events. The site with the highest percentage of individuals with at least one hyper-event was Sapodilla Rockshelter (41.2%), while the lowest percentage was at Actun Uayazba Kab (11.1%). It is difficult to compare hyper-events across these site types because of the widely variable numbers in sample sizes, but it can be stated that at least one person from each site exhibited a hyper-event. Additionally, since all sites were under 50% frequency for hyper-event expression, it can be stated that the appearance of these clustered bands was not the norm.

Discussions of clustered bands could not be found in the literature on microdefects, though these hyper-events are surely not exclusive to this dissertation sample. It may be useful to investigate the meaning of these clustered bands in conjunction with the clinical studies referenced above. Perhaps clustering signals some concerted physiological response to a stressor that has an appreciable, though not chronic, effect on the body. The study of clustered bands as related to enamel development schedules would be especially useful, as the days or weeks between the bands in the hyper-event could be calculated and the range of the entire health stress episode could be estimated. Additionally, since the clusters represent stresses followed by a brief recovery period, a dedicated search of the clinical literature may assist in the differential diagnosis of the significance of the clusters. Perhaps this timing and recovery pattern could help to narrow down the type(s) of diseases responsible for the dental defects.

Relationship between defects and site type

Question 10 asked if there was a significant relationship between the formation of microdefects and site type, as well as between macrodefects and site type. It was hypothesized that individuals buried in rockshelters may have expressed more defects of both types due to their likely residence in the periphery outside of major site cores (and thus, the potential security that comes with urban settlements). Surface site burials were expected to exhibit fewer defects of both types, while cave burials remained unknown due to the current debate over their social identities and life histories.

There were no significant differences in microdefect formation between site type. This finding further underscores the hypothesis that whatever stress event(s) cause enamel disruption at the microscopic level, they were widely felt by all individuals to some extent. There was no significant difference in LEH expression between caves and rockshelters suggesting that individuals buried at these spaces experienced similar, perhaps chronic, stressors leading to macrodefect formation. The difference in macrodefect formation between rockshelters and surface sites was not quite significant, but a result this close to the 0.05 level would certainly benefit from the addition of more samples to discern if rockshelters and surface sites are more similar or dissimilar in their dental defect frequency and expression. Finally, differences in LEH formation between caves and surface site burials was significant, suggesting that those individuals buried in caves experienced more of whatever stressor(s) cause enamel hypoplasias.

It is important to note that the lack of statistically significant differences in microdefect formation between site types does not substantiate the hypothesis that non-elite individuals buried at rockshelters experienced poorer health when compared to other mortuary site types. Non-elites, in this area and at these times, did not appear to have poorer health despite their lower socioeconomic standing.

Patterns in age at defect formation

The age at dental defect formation was a main focus of this study, so the results of the pathological investigation were carefully interpreted to avoid oversimplification or overstatement of results. Developmental age was reduced to time increments of variable durations (after Danforth 1989 and Reid and Dean 2000) in this study for the purposes of comparison and interpretation. However, this equation of chronological age intervals to locations on the enamel surface does need to be understood as a function of the need to compare data, not of absolute inflexible categories that can be linked to social age.

As Sofaer (2011:290 referencing Gowland 2006) warned, the reduction of age to techniques such as the equal divisions method, “has the effect of naturalizing methodologically driven age intervals, turning them into ‘real’ social categories, despite the fact that the relationship between chronological age categories and social age categories are culturally variable.” Because aging is a process, not a succession of bounded developmental periods, it is important to recognize that even though dental pathologies were linked to chronological age intervals for this study, the reality remains that individuals cannot be reduced to discrete age categories. Every effort has been made to interpret the defect formation/age interval results in a manner that reflects the process of age rather than prioritizing a punctuated view of individuals’ health history.

When the mean age at microdefect formation was calculated for each tooth type and compared across sites (Question 4), there was no statistically significant differences in age at formation. Since there were no meaningful differences between site types, it can be concluded that all groups in this sample generally experienced health stress in the late 2nd and early 3rd years of life (for incisors and canines) and in the mid to late 11th year and early 12th year of life (third molars).

The most parsimonious interpretation for physiological disruptions during the earlier age range lies in the attribution of stress events to weaning. Many childhood health studies show that stress markers peak around the ages of 6 – 24 months when subadults experience significant changes in the diet (Cook 1981; Rose et al. 1978; Simpson 1999). However, the peak periods of stress may be affected by cultural group or time period. While Wright (1990) discovered that Maya children experienced most of their stress during the ages of 2 – 3.5 years, Danforth (1989) found that individuals from three Late Classic sites revealed significantly more health stress events at the ages of 4 – 5 years than did the Colonial period Maya. These findings could point to stress caused by weaning (in the case of Wright's study) and stress caused by some other environmental or social factor (in the case of Danforth's study).

The period of stress in the 2nd to 3rd years of life is corroborated in other Maya-specific studies (Colli et al. 2009; Tetlow 2003; Vance 2014) and in other studies of the health effects of weaning in pre-industrial societies (Corrucini et al. 1985). Generally, the weaning period lasts from the ages of 1 – 2 years, with a period of stress following into the 3rd to 5th years as the child adjusts to new diet supplemented by cereals and/or meats (Corrucini et al. 1985; Perry 2006). Some degree of stress is expected during this time period across all cultures and time periods as children develop the antibodies needed to protect against exposure to pathogens and infection (Perry 2006). The reduced consumption of breast milk, which lowers immunological aid, can result in a stress event (Wright 2006).

Question 5 asked if there were significant differences by tooth type in mean ages at defect formation between sites. This question explored whether a particular tooth was more affected by defects so that specific age ranges associated with the formation of that tooth could be isolated. If an age range and/or tooth was more affected, perhaps some inference of cultural or environmental aspects that would have favored that tooth/age could be made.

When all site types were compared, there was only one statistically significant difference in age at defect formation, which was between mandibular canines at Caves Branch Rockshelter and Sapodilla Rockshelter. The reason for this difference is unclear, especially given the similarities in defect formation in other tooth types between these sites. The mandibular canine overlaps in developmental time with the maxillary central incisor, but does form over a more extended period. Perhaps the differences exhibited in enamel formation time suggest that the individuals at the rockshelters experienced health stress over a longer period of time than individuals at surface or cave sites.

However, because the age at defect formation in this tooth type between these two sites was the only instance of significant difference, a more appropriate conclusion would probably be that the small sample sizes skewed the results. Only if the incisors and third molars showed a significant age at defect formation difference, would it be reasonable to conclude that the rockshelter populations were experiencing greater and/or longer degrees of stress. Of course, we must also consider our lack of temporal control. These groups are lumped together into broad time periods lasting several hundred years. It is possible that, while generally the rural populations that SDR and CBR served had similar lives, short term fluctuations in environments may have had an effect on the health of particular individuals, leading to inter-site differences.

When considering the results of these questions, there is a complicating factor that microdefects are simply not as visible in some regions of the enamel. Reeves (2013) devoted much of her dissertation work to the inclusion of “hidden” cuspal enamel, which may account for the disparity in ages at peak stress. If microdefects are present in the cuspal enamel but not able to be observed via microscopy, it is possible that earlier stress events are not being recorded. Unfortunately, beyond estimation of the percentage of “hidden” enamel, there is no way to conclude how many defects (if any) remain uncounted in a particular dental thin section. The repercussions on analysis and interpretation are varied. For instance, if a study asks only if enamel microdefects occur, then it is likely that unseen defects in cuspal enamel do not matter; as this dissertation has demonstrated, nearly every individual has a Wilson band. However, given a different set of burials from a different time period, a different case may arise altogether. If a study asks the age at which enamel microdefects occur, then there is likely to be some data lost in the earlier periods of life and researchers should frame their conclusions accordingly.

Discussion of theoretical applications in bioarchaeology

In order to move the study of health and the biological consequences of unequal health experiences beyond descriptive analyses of the skeleton, it is necessary to examine the underlying social mechanisms that influenced biological response. Descriptions and frequency tabulations of pathologies are not intrinsically important to interpreting the past; rather, assessing the mutual relationship between social structure and biological adaptation through the application of theoretical modeling is key to unpacking the intricacies of past cultures. Past research endeavors have focused on the identity and influence of the elite class, those thought to have controlled and, in part, directed the Maya world.

However, the role of commoners as “active ideological agents” (Lohse 2007:1) in the processes of creating, influencing, rejecting, and manipulating the history of polities and the structure of communities needs to be critically examined in the archaeological record. The efforts of the underclass in the shaping and maintenance of Mayan society cannot be underestimated as these are the masses responsible for specialized labor, construction of public works, movement and trade of goods, and food production (Marcus 2004). Interestingly, Marcus (2004:259) stated that, “actual archaeological data suggest that the remains of ‘elites’ and ‘commoners’ can be difficult to distinguish as two completely discrete categories with clear-cut boundaries.” Certainly Marcus’s statement is supported by the data presented in this study as individuals of all site types remain largely undifferentiated in dental health.In the remainder of this chapter, potential theoretical applications for the study results are discussed. In the remainder of this chapter, potential theoretical applications for the study results are discussed.

Four of the ten research questions were methodological in nature and are not subject to theoretical applications. The remaining six questions were hindered by the small and incomplete samples in this study, which barred the application of much social and archaeological theory. In many instances, the rest of the body associated with the sampled teeth sampled was fragmentary or commingled with other individuals. None of the samples from any of the sites in this study can truly be considered a population.

In recent years, the bioarchaeology of small samples and individuals has been explored in the literature (Hamilakis 2002; Sofaer 2006; Wrobel 2015). The human body, as well as the placement of that body after death, is embedded with cultural and biological data that can be analyzed at the individual, group, and population level. It is the reality of archaeology in the tropics that human remains often do not preserve, a problem exacerbated by the secondary movement of remains that was common in the Maya region. However, the patterns and trends answered in the research questions above can be viewed in light of several archaeological theories in a cursory manner, with hope for more samples and excavation in the future.

The three main findings are explored below within a negotiated peripherality framework, the details of which were outlined in Chapter 1. This archaeological theory is used to explore social interactions between core and periphery populations based on economic relationships, but it is argued in this dissertation that the theory can be used to examine biological data.

Result 1: microdefect formation

No significant differences in microdefect formation between site types were observed. This result indicates that, at least for the sites in this study, individuals living in peripheral zones did not experience short-term health stress in greater degrees than those persons living at urban centers. While residents of a city may be thought to be more protected from health stress due to their status, the living conditions of urban life may have yielded more pathogen loads and disease. Storey (1985) noted the problems of hygiene and sanitation at urban centers that are not experienced by rural populations. Perhaps the ability to retain enough food resources and protect against acute stress events was a significant feature of rural community life. Non-elite populations were not "internally homogenous" (Lohse and Valdez 2004:4) or necessarily impoverished; rather, they were agents acting in their own best interests regarding health security.

Result 2: hyper-event formation

Less than half the individuals at all sites formed clustered bands, indicating that persons at all site types experienced occasional rapid, short-term stress. It can be concluded that residents of the core were as likely to suffer acute stress as the non-elites living in the periphery. Again, it may be assumed that residence in the core would have protected persons against health stress that resulted in brief enamel disturbances, but the data in this study indicates that non-elites were not at any greater risk to suffer from bursts of stress. A NP perspective holds that non-elites must have been adept at controlling their physical, nutritional, and psychological health even though their socioeconomic standing was inferior.

Result 3: age at defect formation

No significant differences in age at defect formation between site types were observed. This is perhaps the most important finding, considering that the result means that no one site type was associated with significantly earlier or later health stress. Rather, individuals at all sites experienced health stress at similar ages, reflecting a biological period of stress most likely associated with weaning. Because the time period of greatest stress occurs during a process felt by all individuals, it can be concluded that residence in the periphery did not significantly affect dental health. From a NP standpoint, the individuals in the peripheral zones managed this period of stress as well as the core zone residents who presumably had better access to resources. The similarity of age at stress onset and duration across site types illustrates how physiologically disruptive the weaning transition is despite social status or affluence.

While these three main results seem to uphold the view that individuals in the periphery effectively advocated for their own health experience and must have sought ways in which to buffer themselves against stress, there is one result from the study that does not fit into the NP theory model. Individuals at Pacbitun were found to be significantly less likely to form enamel hypoplasias than individuals buried in caves and rockshelters. Since hypoplasia data was not collected for the urban site, Tikal, only a cautious interpretation can be made about this finding. Multiple other factors could be contributing to this result, not the least of which was the difficulty in assessing enamel defects on the teeth from Pacbitun due to taphonomic deterioration.

Ultimately, it can be said that non-elites likely had strategies to manage many aspects of their lives away from the surveillance of the ruling class. Residence in peripheral zones should not be assumed to be inherently detrimental to health. NP theory is especially useful during times of increased sociopolitical change when urban cores went through leadership changes, abandonment, and reconstruction, and future studies of cave and rockshelter samples with better dates should be pursued. In Central Belize, it is possible that the construction of urban cores, like Tipan Chen Uitz, heralded the incorporation of previously peripheral zones in more complex political and economic networks. There is some evidence that increasing reliance on agricultural resources that had value in an increasingly integrated market economy may have accounted for dietary deficiencies (Wilk 1985; see Wrobel's 2014 case study). The discussion of NP theory as related to health experience above has merit only if more research and excavation is done to secure dates of these sites and create larger comparative samples. Populations living during the Classic period experienced complex social changes and political interactions that must have influenced food procurement and pathogen loads, so a continued assessment of skeletal and dental health of non-elites buried in peripheral sites is still necessary to understand core-periphery interaction.

Limitations of the study

Although physical anthropologists have studied enamel microdefects for many decades, there are still multiple and serious limitations to these methods. The four biggest limitations are the incongruities in definitions of Wilson bands, unknown etiological basis for Wilson bands, lack of standards in methodology or imaging, and the destructive method of analysis.

Definitions

As reported previously in this dissertation, there are multiple definitions of Wilson bands and inconsistencies in the literature regarding the microfeatures required for a disruption to be considered a pathological stria of Retzius. Most researchers agree that disruption of enamel prisms is necessary for the defect to be termed a Wilson band, but the extent to which the prisms exhibit chaotic orientation is still debated. Additionally, researchers have differing opinions on the utility of the variables of color, length, and width in the assessment of Wilson bands. In the future, intra- and inter-observer error tests should be performed in order to address issues of replicability especially when variable criteria are used between studies. Both Rudney (1980) and Reilly (1986) reported changes in their counts of Wilson bands after reevaluation of their data. Again, these admissions underscore the problems inherent in undertaking research with no clear and concise definitions of defects or imaging standards.

Etiology

The exact etiologies of both linear enamel hypoplasias and Wilson bands are currently unknown (though many researchers have hypothesized about the origins and meaning of the defects). In modern dental studies, the presence of hypoplasias and Wilson bands cannot be predicted even when lifestyle variables and medical history is known (Neiburger 1990). However, the sum of bioarchaeological studies of dental defects has revealed patterns in the development of defects which trend toward disease, trauma, and nutritional stress as causes (Ogilvie and Trinkaus 1990). Carefully controlled, longitudinal clinical studies that examine threshold formation levels and studies of individuals with documented medical and dental history are needed to reveal the complex biological processes guiding and resulting in defect formation. Further, because the processes of mineralization are also not fully understood, defects may be more prevalent in certain areas of the tooth thereby affecting any analyses that depend on age at formation data. Because mineralization is not a homogenous process and the cervical portion of the tooth may contain more organic components, enamel microfeatures may be influenced by differential mineralization in parts of the tooth (Antonova 2011). Again, controlled clinical studies are needed to address underlying physiological reasons for defect formation and to determine if differential mineralization across the enamel plane is related to the appearance of micropathologies.

Methodology

A review of the last thirty years of dental histology studies in the anthropological literature revealed that there is no standardized methodology in data collection and analysis. Hillson (2005; 2014) has likely dedicated the most energy to trying to standardize collection procedures in dental anthropology, but the failure (or inability due to journal article length restrictions) of researchers to publish both the details and the limitations of their methodologies has resulted in a field that is impeded by considerable trial and error. The analysis of microdefects in archaeological samples is a difficult process, both in terms of preparing the sample and imaging the thin section, so researchers have had to tailor their approaches to their specific samples and their machinery, rendering comparative studies and replication of results difficult to achieve.

Because each tooth must be cut in half in order to examine the internal structure, dental histology is a destructive process. However, the relevant data from each tooth can be collected prior to thin sectioning (e.g. measurements, photographs, caries and hypoplasia counts, and isotope samples). If the tooth is not embedded in a chemical resin, isotope analysis may still be performed on the cut tooth.

Future research in dental histology

Studies of dental microdefects have considerable promise in bioarchaeology. Skeletal and dental materials are often too friable or fragmentary due to taphonomic or mortuary processes, and so traditional macroscopic methods may not be applicable to archaeological samples. Histological methods allow for the collection of different data types that can still be used to address common research questions. Perhaps the most powerful aspect of dental histology is in the matching of dental pathologies to age at defect formation. These data can be examined as part of a life history approach that accesses all available information about the individual over the course of time. Future studies should consider variability between individuals, within and between sites, and within and between time periods. The remainder of this chapter is dedicated to the multiple lines of research that can, and should, be pursued in future studies of dental histology in anthropology.

Increased sample size

Increased samples from sites featuring burials that can be confidently aged and sexed would also contribute to future histological studies. Many studies have shown that there is virtually no quantifiable difference in dental health (as measured by microscopic dental defects) between the sexes (Cook 1981; Condon 1981; Rose 1977; Rudney 1981; Wright 1987), so other biological and social variables such as age, social status, burial location, etc. can be examined in combination with histological analyses.

Originally, one of the research questions for this study asked, "In cases where age is estimated (e.g. young, middle, old), which age category exhibits more instances of dental microdefects and macrodefects?" The hypothesis was that young individuals would exhibit the most dental defects due to their overall poorer health that resulted in their earlier age at death.

Previous research has demonstrated that individuals who die as subadults have higher frequencies of enamel hypoplasias and pathological striae than adults (Cook 1981; Goodman et al. 1981; Rose 1977). When the sites were analyzed it became clear that age estimations were not reliable enough to meaningfully explore this question due to the poor preservation of skeletal samples. The addition of samples from sites with well-preserved skeletal remains that may be confidently aged would also contribute to further understanding of defect expression and health experience. Issues of commingling and poor preservation, both of which complicate the estimation of age, must be addressed before patterns of defect formation as related to age at death may be explored. Future analyses should continue to include incisors and canines, as these teeth have been shown to exhibit a lower threshold for buffering against stress (Usher 2000), while adding in other tooth classes to generate data about microdefect patterning in understudied tooth classes (e.g. premolars, molars).

Additionally, samples of individuals with full sets of dentition would be useful for exploring the overlap of dental defects. In this study defect sequencing was attempted, but the parameters of the study (e.g. only maxillary central incisors, third molars, and mandibular canines) as well as the poor preservation of the burials inhibited the defect sequencing analysis. A useful endeavor may be to identify individuals in cave and rockshelter samples of interest that have full or nearly complete dentition. Even if there are no macroscopic markers of stress observable, the complete dentition can be thin sectioned and subjected to microscopic analysis. Defect sequencing of all teeth in the dental arcade would be a time-consuming process, but would provide highly useful information about health stress episodes linked to age. This type of project would work best in the investigation of small mortuary caves and rockshelters in Central

Belize, such as that of J'reftheel, where familial relation is suspected and health experience could be a useful interpretive factor in the analysis of the site.

When exploring the relationship between age at death and defect formation is explored in the future, two hypotheses should prove particularly useful in understanding the etiology of dental pathologies: 1) the Barker hypothesis, which states that prenatal stress events have negative health consequences in adulthood; 2) the Developmental Origins of Health and Disease hypothesis, which states that postnatal stress has similar negative health consequences in adulthood (Armelagos et al. 2009). Other studies have demonstrated that individuals who experienced health stress in childhood are at risk for dying earlier in adulthood (Cook 1981; Rose 1977). If patterns arise in different burial locales, it may be argued that childhood (and associated health during this period) was differentially experienced between social classes. Local and regional traditions in cave and rockshelter mortuary programs may preclude analogizing the Central Belize cases to other locales. Comparative value of other sites to the sample described in this study must be decided by the researcher after an investigation of the archaeology, ethnohistory, and iconography of the region to be compared. Mortuary traditions and practices were (and still are) fluid, guided by the nuances of culture, time, and individual (or group) will.

Application of different microscopic methods

There has been some discussion of the use of confocal microscopy in the assessment of dental histology (Antonova 2011), but currently this type of imaging is more suitable to researchers interested in the surface anatomy of teeth (Bromage et al. 2005). Confocal microscopes are now available in portable units making them ideal for traveling research or field work. However, because confocal imaging creates images from extremely thin optical planes (1 – 50 microns) at and just below the surface of the specimen it is not ideal for the study of dental microdefects which require thin sections in a particular orientation (midline) and at a specific thickness. Scanning electron microscopy (SEM) has been used in dental histology with varying degrees of success (Reeves 2013). The tooth still has to be cut in midline and the internal surface of the thick section is then subjected to the SEM. Due to the plane of visualization in SEM, it does not appear that this type of microscopy is particularly useful in imaging pathological striae. More experimental approaches and comparative studies of different types of microscopy, as well as involvement of polarizing filters, are needed to determine the best approach to gathering histological data. It is possible that the current method, simple light-transmitted microscopy, is the best route for visualizing microfeatures but other avenues are worth exploring in more depth.

Non-destructive approaches: counting perikymata

McFarlane et al. (2014) compared traditional dental thin sections to external crown surfaces in a study that explored non-destructive methods of estimating age at formation of enamel defects. If all perikymata are visible on the external surface and the crown is not worn, the authors stated that counts of these features were comparable to counts of striae of Retzius internally. The sample size (n=11) was small and this method has only recently been published, but in cases of well-preserved teeth that cannot be thin sectioned due to museum or governmental restrictions, this method may be a suitable alternative to the traditional thin sectioning technique but *pathological* bands would not be revealed via this method. Perhaps a combination of counting perikymata and micro-CT analysis or other virtual imaging could be useful.

Non-destructive approaches: virtual histology

Paleoanthropologists working with invaluable early hominid specimens have begun to pursue virtual histology with the use of high-powered microtomography imaging that does not require the thin sectioning of the sample to view the internal anatomy (Le Cabec et al. 2015; Tafforeau and Smith 2008; Smith and Hublin 2008). Ideally, this technology would be used for all projects, thereby eliminating the tedious and destructive process of thin sectioning teeth for analysis. By removing the invasive element of histology, synchrotron microtomography may provide a better alternative for bioarchaeologists working with prehistoric skeletal remains from museum collections or countries whose governments are not in support of traditional histological research. Currently, the technology is cost-prohibitive and has been reserved for researchers working on small high-value samples such as fossil hominds.

Isotopic studies and life history approach

Through a combined study of dental microdefects and isotopic sub-sampling procedures, it may be possible to correlate an array of human behaviors (e.g. migration, weaning, attainment of personhood, dietary shifts, etc.) to biology. In particular, migration may be particularly interesting to explore via the combined histological/isotopic approach in the future. Human migration, whether at the individual or population level, is a complex process guided by social, economic, and environmental variables that bioarchaeologists can only speculate about. Model building to predict migration is useful but cannot fully encapsulate the intricacies of past movement across the prehistoric landscape (Cucina 2015). A combined dental histology and isotope analysis study would address changes in residence, diet, and health experience over the course of the dental formation period. Traditionally researchers have taken an aggregate approach, either homogenizing enamel samples or indiscriminately removing a portion of enamel for isotopic analysis. This imprecise selection of enamel may be obscuring important anthropological interpretations, leading to a need for more controlled and site-specific sampling procedures. Additionally, it has been noted that strontium concentrations in human dentition vary within a single tooth along a spectrum of development (Michael and Deskaj 2014; Reitznerová et al. 2000) due to various interactive factors (e.g. differential mineralization, environmental contribution, etc.). This finding supports the application of a sub-sampling approach in isotopic studies.

In the future, I plan to explore questions of isotope sub-sampling by isolating enamel from specific sections of the tooth crown that can be reliably associated with age ranges based on published dental schedules. Comparisons of isotopic signatures at particular age categories of individuals at the same site may be particularly illuminative about the similarities or dissimilarities in health experience of individuals buried in the same mortuary conditions. The incorporation of isotopic data, along with enamel micro- and macrodefect data, will allow for a life history or life course approach (Agarwal 2016) that contextualizes age-related biological data to understand more complex aspects of social identity.

Further subdividing populations by biological attributes can aid in isolating chemical differences in the teeth that may have a cultural explanation. For instance, future studies should investigate the relationship between sex and sampling location. These investigations should take a biocultural approach by addressing physiological differences in dental development and mineralization between the sexes, as well as social processes that differentially affect males and females (e.g. possible female relocation post-marriage, etc.). Incorporation of anthropological data from the material record of the past, in addition to ethnography and iconography, will provide a human dimension to otherwise purely technical chemical results of isotopic studies.

Beyond isotopic studies centered on human migration, it is possible that the sub-sampling procedures could benefit studies of dietary shifts using other isotopes. If diet is linked meaningfully to age, perhaps shifts in isotopic signatures could be read using the sub-sampling method that isolates different ages at formation across the enamel crown. Combining dietary information with dental microdefects could be valuable in assessing archaeological samples for which little other information is known.

Interdisciplinary work across sub-fields

In recent years, physical anthropologists have called for reassessments of health in bioarchaeological studies. Reitsema and McIlvaine (2014) promoted sub-disciplinary awareness and research bridging bioarchaeology with primatology, molecular anthropology, and biomechanics to investigate health in the past. Temple and Goodman (2014) also pressed for the incorporation of methodological and theoretical advances in the sub-fields in the bioarchaeological study of health. Reitsema and McIlvaine (2014:182) argued that “health” and “stress” are not “coterminous” and future research should focus on the critical differences between the terms and their skeletal and dental manifestations. To illustrate their point, Reitsema and McIlvaine (2014) relayed examples in living populations of the disconnect often noted between individuals’ personal perceptions of their health VS. their skeletal and dental indicators of un-health. This disparity between perception of health and the bioarchaeologist’s assessment of health is not easily reconciled. Temple and Goodman (2014) warn of uncritical typological research that characterizes populations as either “healthy” or “unhealthy” in lieu of addressing social and cultural factors that may have shaped health experiences in the past.

Tellingly, a search for the term, “Wilson bands” in the Journal of Dental Research, Advances in Dental Research, the British Dental Journal, and the Australian Dental Journal returned no results save for the original article by Wilson and Shroff published in the Australian Dental Journal in the 1970s. The lack of research on these dental micropathologies in the clinical literature further underscores the need for bioarchaeologists to take up the mantle of experimental and applied research on this topic. A similar search for “hypoplasias” reveals that clinicians do continue to pursue research on these pathological features, albeit often with regard to environmental variables that cannot be deduced in the past (e.g. congenital allergies) or population-specific studies of hypoplastic interaction with other skeletal and dental lesions or defects. It appears that research on the interaction between Wilson bands and enamel hypoplasias, then, is the domain of bioarchaeologists who can usefully apply results of dental defect studies to the past.

In future studies of health and stress, researchers should be careful to note that skeletal and dental indicators of stress are tied only to a particular period of time; no singular bioarchaeological method of health evaluation can provide data on an individual’s entire life course. In this way, bioarchaeologists are taking a measure of health in a particular community (represented by the burial sample ideally) at a particular time, rather than making sweeping statements about healthy or unhealthy populations. Articulation of bioarchaeological studies with methodological technologies and theoretical concepts in other sub-fields of human biology and physiology will serve to strengthen future health and/or stress studies.

CHAPTER 9: CONCLUSIONS

This biocultural study set out to explore mortuary variability in caves and rockshelters in Central Belize through a combined inquiry of dental micro- and macrodefects. The presence of, and relationship between, three types of dental defects was examined across three mortuary site types. The incorporation of multiple tooth classes served to access a wider age range during life. This multiple tooth sampling protocol differentiates this dissertation study from previous research focused on only one or two tooth classes.

Conclusions from this dissertation can be drawn in two arenas, social and methodological. From a social perspective, the dental defect data demonstrates that individuals distinguished in death by burial in caves and rockshelters were not greatly distinguished in life by dental health disparities. The ritual significance of caves (and, by extension, cave burials) is still debated in the Maya literature. However, this study further substantiates the view that individuals in caves were not exceptional in life, as they experienced overall macrodental health comparable to individuals interred at other site locales. Therefore, individuals buried in caves were likely not necessarily elites or sacrificial victims. But, *if* they were either, then their macrodental health remained markedly similar to other populations and, therefore, potentially interesting anthropological interpretations about dental health related to a host of other socioeconomic variables can begin to be investigated across site types. There are reasons why some persons received cave burial and others were interred at surface sites or rockshelters, but the biological variables related to dental health are not sufficient for interpreting these differences.

From a methodological perspective, the almost-significant results of the microdefect comparisons illustrated that more research should be devoted to identifying the etiological basis for both micro- and macrodefects; if the cause(s) of these stress markers can be established, bioarchaeologists can make better judgements about the lived experiences of past populations. This research has attempted to address problems inherent in identifying and imaging dental microdefects since the discord in the published literature has largely prohibited replicability of methods. The Methods chapter described these problems in detail in the hope that a larger discussion about sampling protocol in dental microdefect studies will place in the future. Dental microdefects are a powerful data source for bioarchaeologists if the following criteria are achieved: 1) uniform definitions and sampling methods that can be replicated by all researchers, 2) integration of multiple teeth from the dental arcade in microdefect studies to access the widest age range possible per individual, 3) engagement with clinical stress studies that explore the biological basis for, and potential threshold formation of, dental defects.

These data do not aim to disprove the extraordinariness of caves; rather, it is argued that, for *these* samples in *these* time periods at *these* locations, individuals buried in caves were not unique when compared to those persons in rockshelters based on the three dental defects explored in this study. While the association of caves with elite interments and as mortuary spaces for the upper tiers of Maya society is not unreasonable and is supported by previous studies, the evidence presented in this study demonstrates that there were no conclusively significant differences in dental health between individuals that received cave burials vs. rockshelter burials.

This finding alone is important as bioarchaeologists often utilize dental health to make inferences about life experience and social status in prehistory. Now, future research can be directed toward exploring other biological variables as they relate to potential health and social differences across disparate mortuary sites in Central Belize. Alternatively, more samples could be added to the data presented here to either bolster the conclusions drawn or reassess the nature of dental health in cave and rockshelter burials.

Perhaps receiving burial in a particular site type was based in part on some social or cultural aspect that archaeologists are not yet privy to. Some of the mortuary practices of the past will remain forever lost to time, unable to be retrieved for analysis by archaeologists. However, of those practices that left an archaeological imprint, it is important to consider the effects of local and personal/familiar traditions that may manifest archaeologically as outliers or "problematical" deposits. Caves and rockshelters have "signatures" to be sure, but only bioarchaeologically-grounded investigations utilizing all available methodological techniques can result in the careful interpretation of those signatures. The differences between these spaces do mean *something*; it is the task of the anthropologist to keep sensitively investigating the idiosyncrasies of the burials at these mortuary spaces that were once so important to the pre-Hispanic Maya.

APPENDICES

APPENDIX 1: Dental defects in AUK sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 60. Wilson bands in AUK dental sample.

Bur.	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
97-1	RC_	1			-		-	1	-	-	-	-
	RI^1	4	-	-	-	-	1	1	2	-	-	-
98-1	LI^1	4	-	-	2	1	-	-	-	1	-	-
98-2	LI^1	3	-	-	-	1	-	-	1	1	-	-
	RM^3	0			-	-	-	-	-	-	-	
98-3	RC_	3	-	-	-	-	-	2	1	-	-	-
98-4	RI^1	7	-	1	5*	-	-		-	6	1	
	LC_	0	-	-	-	-	-	-	-	-	-	-
	LM^3	0	-	-	-	-	-	-	-	-	-	

Table 61. Linear enamel hypoplasias in AUK dental sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. of co-occurrences of LEH and WB
			0.0-0.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
97-1	RC_	4	-	-	-	-	-	3	1	-	-	-	0
	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
98-1	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
98-2	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RM^3	2	-	-	-	-	-	-	-	-	-	2 (13.0-13.6)	0
98-3	RC_	0	-	-	-	-	-	-	-	-	-	-	0
98-4	RI^1	0	-	-	-	-	-	-	-		-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	LM^3	0	-	-	-	-	-	-	-	-	-	-	0

APPENDIX 2: Dental defects in JRH sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 62. Wilson bands in JRH sample.

Burial	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
Skull A	LC_	5	-	-	-	-	1	1	-	2	-	1
	RM^3	3	-	-	-	-				-	-	-
Skull C	RC_	6	-	-	-	-	-	2-	2	2	-	-
	LM$_3$	1	-	-	-	-	-	-	-	-	-	1 (13.0-13.6)
Skull B	LI^1	5	-	-	-	-	-	-	-	3*	1	1
	LC_	5	-	-	-	-	-	-	2	1	1	1
Skull F	LI^1	4	-	-	1	1	2	-	-	-	-	-
Skull H	RM^3	1	-	-	-	-	-	-	-	-	-	1 (11.4-12.0)
Skull D	RM$_3$	-	-	-	-	-	-	-	-	-	-	-
Skull E	LC_	8	-	-	-	-	-	2	3	-	-	3*
	LM$_3$	2	-	-	-	-	-	-	-	-	-	2 (10.9-11.4; 11.4-12.0)
JRH10-5-26	LC_	0	-	-	-	-	-	-	-	-	-	-
JRH09-3-41	RC_	0	-	-	-	-	-	-	-	-	-	-
Ch 2, Feature 7, Unit 5C	LM^3	2	-	-	-	-	-	-	-	-	-	2 (11-4-12.0)
JRH07-6-5	RC_	2	-	-	-	1	1	-	-	-	-	-
	LC_	0	-	-	-	-	-	-	-	-	-	-
	LM^3	0	-	-	-	-	-	-	-	-	-	-
JRH09-5-12	RC_	5	-	-	1	1	-	-	3*	-	-	-

Table 63. Linear enamel hypoplasisas in JRH sample.

Burial	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. co-occurrences of LEH and WB
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
Skull A	LC_	3	-	-	-	-	-	-	1**	-	-	-	1
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
Skull C	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
Skull B	LI^1	1	-	-	-	-	-	-	-	1**	-	-	1
	LC_	1	-	-	-	-	-	-	-	1	-	-	0
Skull F	LI^1	1	-	-	-	-	-	1	-	-	-	-	0
Skull H	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
Skull D	RM_3	0	-	-	-	-	-	-	-	-	-	-	0
Skull E	LC_	4	-	-	-	1	-	-	1**	1	1**	-	2
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
JRH10-5-26	LC_	2	-	-	1	-	-	-	-	1	-	-	0
JRH09-3-41	RC_	0	-	-	-	-	-	-	-	-	-	-	0
Ch 2, Feature 7, Unit 5C	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
JRH07-6-5	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	1	-	-	-	-	-	-	-	-	1	-	0
	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
JRH09-5-12	RC_	3	-	-	-	-	-	1	1**	1	-	-	1

APPENDIX 3: Dental defects in SDR sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 64. Wilson bands in SDR sample.

Burial	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
SDR10-1-17	LI^{1A}	5	-	-	-	-	-	4*	-	-	1	-
	LI^{1B}	6	-	-	-	-	-	1	1	2	2	-
SDR11-40-344	LI^1	6	-	-	-	-	-	-	2	2	-	2
SDR11-12-168	LI^1	7	-	-	2	1	2	2	-	-	-	-
SDR11-41-553 Burial 10	RM^3	0	-	-	-	-	-	-	-	-	-	-
	RC_	2	-	-	-	-	-	1	1	-	-	-
SDR11-65-491, Burial 14	LI^1	10	-	-	-	1	1	1	4*	-	1	2
SDR11-15-170 Burial 2	RI^1	7	-	-	-	-	2	-	-	-	3*	2
SDR11-38-341 Burial 9	RC_	4	-	-	-	-	-	-	1	2	-	1
SDR11-34-567 Burial 6	RC_	4	-	-	-	-	-	-	-	1	3*	-
SDR11-34-262 Burial 7	RC_	5	-	-	-	-	-	1	2	2	-	-
	RI^1	10	-	-	1	1	3	3*	2	-	-	-
SDR11-93-676 Burial 17	RC_	12	-	-	-	-	1	3*	3*	5	-	-
SDR11-61-677 Burial 13	LM_3	3	-	-	-	-	-	-	-	-	-	3 (11.4-12.0)
	LC_	4	-	-	-	-	-	1	1	-	-	2
SDR11-78-723 Burial 12	LI^1	4	-	-	-	-	-	-	-	4*	-	-

Table 65. Linear enamel hypoplasias in SDR sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. co-occurrences LEH and WB
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
SDR10-1-17	LI^{1A}	1	-	-	-	-	-	-	-	1	-	-	0
	LI^{1B}	1	-	-	-	-	-	-	-	1	-	-	0
SDR11-40-344	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-12-168	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-41-553 Burial 10	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
	RC_	1	-	-	-	-	-	-	-	-	1	-	0
SDR11-65-491, Burial 14	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-15-170 Burial 2	RI^1	1	-	-	-	-	-	-	1	-	-	-	0
SDR11-38-341 Burial 9	RC_	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-34-567 Burial 6	RC_	2	-	-	-	-	-	-	-	1	1**	-	1
SDR11-34-262 Burial 7	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-93-676 Burial 17	RC_	0	-	-	-	-	-	-	-	-	-	-	0
SDR11-61-677 Burial 13	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	2	-	-	-	-	1	-	-	-	1	-	0
SDR11-78-723 Burial 12	LI^1	1	-	-	-	-	-	-	-	-	1	-	0

APPENDIX 4: Dental defects in CBR sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar and deciduous ages are in parentheses when applicable.

Table 66. Wilson bands in CBR sample.

Bur.	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-0.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
38	LI^1	10	-	-	-	1	1	2	2	-	3*	1
	RC_	3	-	-	-	-	-	-	3	-	-	-
9	RC_	3	-	-	-	-	-	2	1	-	-	-
	LI^1	5	-	-	2	2	1	-	-	-	-	-
10	RI^1	6	-	-	-	-	1	-	-	2	3*	-
	LC_	1	-	-	-	1	-	-	-	-	-	-
51	RC_	7	-	-	-	1	-	-	3	3*	-	-
	LI^1	15	-	-	-	2	1	1	1	3	1	6*
246	LC_	6	-	-	-	-	3	-	-	-	-	3*
63	LC_	3	-	-	-	-	-	-	3*	-	-	-
41	RI^1	7	-	-	-	1	2	1	-	1	1	-
23b	rc_	1	1 (6-7 mos.)	-	-	-	-	-	-	-	-	-
46A	LI^1	5	-	-	-	-	-	2	1	1	1	-
53	RI^1	4	-	-	-	-	-	-	-	-	1	3
86	RC_	7	-	-	-	-	2	2	3*	-	-	-
11	LC_	3	-	-	-	-	-	-	2	1	-	-
14a	LI^1	5	-	-	-	-	2	-	2	1	-	-
2	LC_	1	-	-	-	-	-	1	-	-	-	-
1a	RI^1	4	-	-	-	-	1	-	2	-	1	-
19	rc_	1	1 (4-5 mos.)	-	-	-	-	-	-	-	-	-
46C/42	LC_	9	-	-	-	1	1	-	3*	1	3*	-

Table 67. Linear enamel hypoplasias in CBR sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. co-occurrences LEH and WB
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
38	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RC_	0	-	-	-	-	-	-	-	-	-	-	0
9	RC_	5	-	-	-	-	-	-	1	2	-	2	0
	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
10	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	3	-	-	-	-	-	-	-	1	2	-	0
51	RC_	2	-	-	-	1	1	-	-	-	-	-	0
	LI^1	1	-	-	-	-	-	-	1	-	-	-	0
246	LC_	0	-	-	-	-	-	-	-	-	-	-	0
63	LC_	0	-	-	-	-	-	-	-	-	-	-	0
41	RI^1	1	-	-	-	-	-	-	-	-	1**	-	1
23b	rc_	0	-	-	-	-	-	-	-	-	-	-	0
46A	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
53	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
86	RC_	1	-	-	-	-	-	-	-	1	-	-	0
11	LC_	0	-	-	-	-	-	-	-	-	-	-	0
14a	LI^1	1	-	-	-	-	-	-	-	1	-	-	0
2	LC_	2	-	-	-	-	-	-	-	1	1	-	0
1a	RI^1	1	-	-	-	-	-	-	-	1	-	-	0
19	rc_	0	-	-	-	-	-	-	-	-	-	-	0
46C/42	LC_	1	-	-	-	-	-	-	-	-	1**	-	1

APPENDIX 5: Dental defects in TK sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 68. Wilson bands in TK sample.

Burial	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
2	LC_	3	-	-	-	-	-	2	1	-	-	-
41	LC_	0	-	-	-	-	-	-	-	-	-	-
45	LC_	6	-	-	-	1	1	3	-	-	-	1
	LM_3	0	-	-	-	-	-	-	-	-	-	-
49	LC_	2	-	-	-	-	-	1	1	-	-	-
50	LC_	9	-	-	-	2	1	2	2	2	-	-
52	LC_	4	-	-	-	-	-	-	2*	1	1	-
55	LC_	5	-	-	-	-	-	-	2	1	2	-
57	LC_	6	-	-	-	1	1	3	1	-	-	-
91	LC_	6	-	-	-	-	2	1	1	1	1	-
96	LC_	4	-	-	-	1	2	-	-	-	-	-
97	LC_	3	-	-	-	-	-	-	3	-	-	-
97A	LC_	4	-	-	-	-	-	1	1	2	-	-
97B	lc_	0	-	-	-	-	-	-	-	-	-	-
103	LC_	6	-	-	-	-	-	-	4*	1	1	-
105	LM_3	0	-	-	-	-	-	-	-	-	-	-
109	LC_	2	-	-	-	-	2	-	-	-	-	-
	LM_3	5	-	-	-	-	-	-	-	-	-	2 (10.2-10.8); 3 (10.9-11.4)
151	LC_	5	-	-	-	-	-	2	2	1	-	-
	LM_3	1	-	-	-	-	-	-	-	-	1	-
161	LC_	2	-	-	-	-	-	-	2	-	-	-
	lc_	1	1 (6-7 mos.)	-	-	-	-	-	-	-	-	-
168	LC_	5	-	-	-	2	1	1	1	-	-	-
174	LC_	3	-	-	-	-	-	-	-	-	1	2
180	LC_	3	-	-	-	-	1	1	1	-	-	-
182	LC_	5	-	-	-	1	1	-	1	2	-	-
	LM_3	0	-	-	-	-	-	-	-	-	-	-
186	LM_3	1	-	-	-	-	-	-	-	-	-	1 (11.4-12.0)
201	LM_3	3	-	-	-	-	-	-	-	-	-	2 (10.9-11.4); 1 (11.4-12.0)
210	LC_	0	-	-	-	-	-	-	-	-	-	-
	lc_	0	-	-	-	-	-	-	-	-	-	-
214	LM_3	0	-	-	-	-	-	-	-	-	-	-
215	lc_	1	1 (6-7 mos.)	-	-	-	-	-	-	-	-	-

Table 69. Linear enamel hypoplasias in TK sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. co-occurrences LEH and WB
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
2	LC_	1	-	-	-	-	-	-	-	1	-	-	0
41	LC_	0	-	-	-	-	-	-	-	-	-	-	0
45	LC_	3	-	-	-	-	-	2	1	-	-	-	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
49	LC_	0	-	-	-	-	-	-	-	-	-	-	0
50	LC_	6	-	-	-	-	-	-	1**	2	1	2	1
52	LC_	0	-	-	-	-	-	-	-	-	-	-	0
55	LC_	0	-	-	-	-	-	-	-	-	-	-	0
57	LC_	3	-	-	-	-	-	-	-	1	1	1	0
91	LC_	0	-	-	-	-	-	-	-	-	-	-	0
96	LC_	0	-	-	-	-	-	-	-	-	-	-	0
97	LC_	1	-	-	-	-	-	-	-	-	1	-	0
97A	LC_	0	-	-	-	-	-	-	-	-	-	-	0
97B	lc_	0	-	-	-	-	-	-	-	-	-	-	0
103	LC_	0	-	-	-	-	-	-	-	-	-	-	0
105	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
109	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
151	LC_	1	-	-	-	-	-	-	-	-	-	1	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
161	LC_	2	-	-	-	-	-	-	-	1	-	1	0
	lc_	0	-	-	-	-	-	-	-	-	-	-	0
168	LC_	1	-	-	-	-	-	-	-	1	-	-	0
174	LC_	0	-	-	-	-	-	-	-	-	-	-	0
180	LC_	2	-	-	-	-	-	-	-	-	-	2	0
182	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
186	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
201	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
210	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	lc_	0	-	-	-	-	-	-	-	-	-	-	0
214	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
215	lc_	0	-	-	-	-	-	-	-	-	-	-	0

APPENDIX 6: Dental defects in AKB sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 70. Wilson bands in AKB sample.

Burial	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
AKB11-9-45	LM_3	4	-	-	-	-	-	-	-	-	-	1 (13.0-13.6); 1 (12.0-12.7); 2 (11.4-12.0)
AKB11-12-44	LC_	7	-	-	-	-	2	3*	2	-	-	-
AKB11-13-32	LC_	0	-	-	-	-	-	-	-	-	-	-
AKB11-7-24	LM^3	1	-	-	-	-	-	-	-	-	-	1 (12.0-12.7)
	LC_	5	-	-	-	-	1	2	2	-	-	-
	RI^1	11	-	1	1	2	-	3*	3	1	-	-
	RI^1	10	-	-	-	-	-	2	-	4*	4*	-
	LC_	1	-	-	-	-	-	-	1	-	-	-
AKB13-19-108	RI^1	17	-	-	1	3*	-	4*	4*	2	2	1
AKB11-4-28	rc_	4	3	1	-	-	-	-	-	-	-	-
	RC_	0	-	-	-	-	-	-	-	-	-	-
AKB11-10-40	LC_	3	-	-	-	1	1	1	-	-	-	-
	LM_3	0	-	-	-	-	-	-	-	-	-	-
Scatter GG AKB13-15-136	RM_3	2	-	-	-	-	-	-	-	-	-	1 (12.0-12.7); 1 (11.4-12.0)
	LC_	3	-	-	-	-	-	1	1	1	-	-
AKB13-15-97 RSD	LC_	8	-	-	-	-	1	1	2	2	2	-
Scatter HH AKB13-15-130	LC_	9	-	-	-	-	2	3	1	3	-	-
Scatter Q AKB13-15-72	LC_	10	-	-	1	3*	2	3	1	-	-	-

Table 70 (cont'd).

Scatter O AKB13-15-89	RC_	0	-	-	-	-	-	-	-	-	-	-
Scatter Y AKB13-15-127	RI^1	7	-	-	-	4	-	1	2	-	-	-
Scatter EE AKB13-15-132	LI^1	9	-	-	3	2	1	1	1	1	-	-
Scatter JJ AKB13-15-124	RI^1	16	-	-	-	1	3	4*	3	1	4*	-
Scatter A AKB13-16-40	RC_	3	-	-	-	-	-	1	1	1	-	-
	RM_3	2	-	-	-	-	-	-	-	-	-	2 911.4-12.0)
Scatter R AKB13-15-55	LI^1	13	-	-	1	3*	3	-	-	2	4*	-
Scatter U AKB13-15-90	RI^1	12	-	-	3	2	2	3	-	-	1	-
Chamber 4, Scatter 3, Unit 6	LI^1	4	-	-	-	-	-	-	-	2	1	1
Chamber 4, Scatter 3 AKB13-6-43	RC_	4	-	-	-	-	-	2	1	1	-	-
	RC_	7	-	-	-	1	1	2	3*	-	-	-
	RI^1	7	-	-	-	1	-	-	-	5*	1	-
AKB13-8-36	RC_	3	-	-	-	-	1	-	-	-	2	-
AKB13-1-11	RI^1	11	-	-	1	1	-	4	2	2	1	-
AKB13-18-110	LI^1	10	-	-	1	2	2	-	2	3*	-	-
	LC_	6	-	-	-	1	1	2	2	-	-	-
	RC_	8	-	-	-	1	3	1	1	1	1	-
AKB13-11-44	LI^1	4	-	-	1	-	1	1	1	-	-	-

Table 71. Linear enamel hypoplasias in AKB sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years)										No. co-occurrences LEH and WB
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	
AKB 11-9-45	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
AKB 11-12-44	LC_	0	-	-	-	-	-	-	-	-	-	-	0
AKB 11-13-32	LC_	0	-	-	-	-	-	-	-	-	-	-	0
AKB 11-7-24	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	3	-	-	-	-	-	1	1	1	-	-	0
	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	1	-	-	-	-	-	-	-	1	-	-	0
AKB 13-19-108	RI^1	1	-	-	-	-	-	-	-	1	-	-	0
AKB 11-4-28	rc_	1	-	1	-	-	-	-	-	-	-	-	0
	RC_	0	-	-	-	-	-	-	-	-	-	-	0
AKB 11-10-40	LC_	2	-	-	-	-	-	-	1	1	-	-	0
	LM_3	0	-	-	-	-	-	-	-	-	-	-	0
Sc. GG	RM_3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
AKB 13-15-97 RSD	LC_	0	-	-	-	-	-	-	-	-	-	-	0
Sc. HH	LC_	0	-	-	-	-	-	-	-	-	-	-	-
Sc. Q	LC_	1	-	-	-	-	-	-	-	1	-	-	0
Sc. V	RI^1	1	-	-	-	-	-	-	1	-	-	-	0
Sc. Y	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
Sc. O	RC_	0	-	-	-	-	-	-	-	-	-	-	0
Sc. EE	LI^1	1	-	-	-	-	-	-	1	-	-	-	0
Sc. JJ	RI^1	0	-	-	-	-	-	-	-	-	-	-	0

Table 71 (cont’d).

Sc. A	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	RM$_3$	0	-	-	-	-	-	-	-	-	-	-	0
Sc. R	LI^1	1	-	-	-	-	-	-	-	-	1	-	0
Sc. U	RI^1	1	-	-	-	-	-	-	-	1	-	-	0
Ch. 4, Sc. 3, Unit 6	LI^1	1	-	-	-	-	-	-	-	1	-	-	0
Ch. 4, Sc. 3	RC_	1	-	-	-	-	-	1	-	-	-	-	0
	RC_	1	-	-	-	-	-	-	-	-	-	1	0
	RI^1	1	-	-	-	-	-	-	-	-	1	-	0
AKB 13-8-36	RC_	0	-	-	-	-	-	-	-	-	-	-	0
AKB 13-1-11	RI^1	1	-	-	-	-	-	1**	-	-	-	-	1
AKB 13-18-110	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	RC_	2	-	-	-	-	-	-	1**	-	1**	-	2
AKB 13-11-44	LI^1	1	-	-	-	-	-	-	1	-	-	-	0

APPENDIX 7: Dental defects in PB sample.

Presence of hyperevents marked with asterisk. Presence of co-occurrence of LEH and WB marked with double asterisk. Molar ages are in parentheses when applicable.

Table 72. Wilson bands in PB sample.

Burial	Tooth	No. WB	No. of Wilson bands within specific age ranges (in years)									
			0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+
2-3	RI^1	3	-	-	-	-	2	1	-	-	-	-
	RC_	2	-	-	-	-	-	-	-	2	-	-
	LM^3	0	-	-	-	-	-	-	-	-	-	-
-	LC_	3	-	-	-	-	-	2	-	-	1	-
2-2	RC_	9	-	-	-	2	2	1	2	2	-	-
	LI^1	16	-	-	-	2	2	3*	5*	3	1	-
4-2	LI^1	3	-	-	-	1	1	1	-	-	-	-
	LC_	6	-	-	1	-	1	1	1	-	-	-
2-4	RM^3	1	-	-	-	-	-	-	-	-	-	1 (12.0-12.7)
1-7	RC_	1	-	-	-	-	-	-	1	-	-	-
4-1	RI^1	8	-	-	2	-	-	2	1	2	1	-
	RM^3	4	-	-	-	-	-	-	-	-	-	1 (12.0-12.7); 2 (11.4-12.0); 1 (10.9-11.4)
2-5	LI^1	13	-	-	-	2	1	2	1	5*	1	-
	RM^3	4	-	-	-	-	-	-	-	-	-	4* (11.4-12.0)
2-3, Ind 2	LI^1	4	-	-	-	-	2	2	-	-	-	-
	LC_	10	-	-	1	-	-	1	3*	2	-	3*
1-2	LI^1	6	-	-	-	-	2	1	1	2	-	-
1, Mound 3	LC_	4	-	-	-	1	1	-	1	-	1	-
	RM^3	3	-	-	-	-	-	-	-	-	-	3* (11.4-12.0)
2, Mound 6	RM^3	0	-	-	-	-	-	-	-	-	-	-
	LC_	6	-	-	-	-	-	3*	3	-	-	-
	RI^1	6	-	1	1	1	-	1	1	-	1	-
1, Mound 36	LC_	7	-	-	-	-	1	2	3	-	-	1
	RC_	4	-	-	-	1	2	1	-	-	-	-
	RM^3	0	-	-	-	-	-	-	-	-	-	-
	LI^1	6	-	-	-	1	2	1	1	-	1	-
	LM^3	3	-	-	-	-	-	-	-	-	-	2 (12.0-12.7); 1 (11.4-12.0)

Table 72 (cont'd).

95-1	LM^3	4	-	-	-	-	-	-	-	-	-	3*(11.4-12.0); 1 (10.9-11.4)
Bu btwn Strs 1 and 4	LC_	1	-	-	-	-	-	-	-	1	-	-
5-1	LI^1	6	-	-	-	2	-	1	1	-	2	-
2, Mound 36	LC_	6	-	-	-	1	1	3*	-	1	-	-
	LI^1	8	-	-	-	-	2	1	2	3*	-	-
	RM^3	2	-	-	-	-	-	-	-	-	-	2 (12.0-12.7)
1, Mound 42	LC_	2	-	-	-	-	-	1	-	-	1	-
	LI^1	5	-	-	-	-	-	-	1	3	1	-
1, Mound 6	RC_	0	-	-	-	-	-	-	-	-	-	-
3, Mound 6	RM^3	1	-	-	-	-	-	-	-	-	-	1 (12.0-12.7)
	LC_	1	-	-	-	-	-	-	1	-	-	-
	RI^1	18	-	3*	1	2	-	3*	3	3	3*	-

Table 73. Linear enamel hypoplasias in PB sample.

Bur.	Tooth	No. LEH	No. of LEHs within specific age ranges (in years) 0.0-.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	3.01-3.5	3.51-4.0	4.01-4.5	4.51-5.0+	No. co-occurrences LEH and WB
2-3	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
1-8	LC_	0	-	-	-	-	-	-	-	-	-	-	0
2-2	RC_	0	-	-	-	-	-	-	-	-	-	-	0
	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
4-2	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	1	-	-	-	-	-	-	-	-	1	-	0
2-4	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
1-7	RC_	1	-	-	-	-	-	-	-	1	-	-	0
4-1	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
2-5	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
2-3, Ind 2	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
1-2	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
1, Mo. 3	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
2, Mo. 6	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	RI^1	0	-	-	-	-	-	-	-	-	-	-	0
1, Mo. 36	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	RC_	1	-	-	-	-	-	-	-	-	1	-	0
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
	LI^1	3	-	-	-	-	-	1	-	1	1	-	0
	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
95-1	LM^3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
Bu btwn Strs 1 and 4	LC_	1	-	-	-	-	-	1	-	-	-	-	0
5-1	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
2, Mo. 36	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
1, Mo. 42	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	LI^1	0	-	-	-	-	-	-	-	-	-	-	0
1, Mo. 6	RC_	0	-	-	-	-	-	-	-	-	-	-	0
3, Mo. 6	RM^3	0	-	-	-	-	-	-	-	-	-	-	0
	LC_	0	-	-	-	-	-	-	-	-	-	-	0
	RI^1	1	-	-	-	-	-	1	-	-	-	-	0

APPENDIX 8: Caries frequency and type by site.

Table 74. Caries frequency and type at AUK.

Burial	Tooth	No. of caries	Type
Burial 97-1	RC_	1	5
	RI^1	0	-
Burial 98-1	LI^1	0	-
Burial 98-2	LI^1	0	-
	RM^3	1	1
Burial 98-3	RC_	1	5
Burial 98-4	LC_	0	-
	RI^1	0	-
	LM^3	0	-

Table 75. Caries frequency and type at JRH.

Individual	Tooth	No. of caries	Type
Skull A	LC_	0	-
	RM^3	0	-
Skull C	RC_	0	-
	LM_3	0	-
Skull B	LI^1	0	-
	LC_	0	-
Skull F	LI^1	0	-
Skull H	RM^3	0	-
Skull D	RM_3	0	-
Skull E	LC_	0	-
	LM_3	0	-
JRH10-5-26	LC_	0	-
JRH09-3-41	RC_	0	-
Ch 2, Feature 7, Unit 5C	LM^3	1	4
JRH07-6-5	RC_	0	-
	LC_	0	-
	LM^3	2	3; 3
JRH09-5-12	RC_	0	-

Table 76. Caries frequency and type at SDR.

Individual	Tooth	No. of caries	Type
SDR10-1-17	LI^{1A}	0	-
	LI^{1B}	0	-
SDR11-40-344	LI^{1}	0	-
SDR11-12-168	LI^{1}	0	-
SDR11-41-553 Burial 10	RM^{3}	0	-
	RC_	0	-
SDR11-65-491 Burial 14	LI^{1}	1	4
SDR11-15-170 Burial 2	RI^{1}	0	-
SDR11-38-341 Burial 9	RC_	0	-
SDR11-34-567 Burial 6	RC_	0	-
SDR11-34-262 Burial 7	RC_	0	-
	RI^{1}	0	-
SDR11-93-676 Burial 17	RC_	0	-
SDR11-61-677 Burial 13	LM_{3}	0	-
	LC_	0	-
SDR11-78-723 Burial 12	LI^{1}	0	-

Table 77. Caries frequency and type at CBR.

Individual	Tooth	No. of caries	Type
Burial 38	LI^1	0	-
	RC_	0	-
Burial 9	RC_	0	-
	LI^1	0	-
Burial 10	RI^1	0	-
	LC_	0	-
Burial 51	RC_	0	-
	LI^1	0	-
Burial 246	LC_	1	4
Burial 63	LC_	0	-
Burial 41	RI^1	0	-
Burial 23b	rc_	0	-
Burial 46A	LI^1	0	-
Burial 53	RI^1	0	-
Burial 86	RC_	0	-
Burial 11	LC_	0	-
Burial 14a	LI^1	0	-
Burial 2	LC_	0	-
Burial 1a	RI^1	0	-
Burial 19	rc_	1	6
Burial 46C/42	LC_	0	-

Table 78. Caries frequency and type at TK.

Individual	Tooth	No. of caries	Type
Burial 2	LC_	0	-
Burial 41	LC_	0	-
Burial 45	LC_	0	-
	LM_3	0	-
Burial 49	LC_	0	-
Burial 50	LC_	0	-
Burial 52	LC_	0	-
Burial 55	LC_	0	-
Burial 57	LC_	0	-
Burial 91	LC_	1	4
Burial 96	LC_	0	-
Burial 97	LC_	0	-
Burial 97A	LC_	0	-
Burial 97B	lc_	0	-
Burial 103	LC_	0	-
Burial 105	LM_3	0	-
Burial 109	LC_	0	-
	LM_3	0	-
Burial 151	LC_	0	-
	LM_3	0	-
Burial 161	LC_	0	-
	lc_	0	-
Burial 168	LC_	0	-
Burial 174	LC_	0	-
Burial 180	LC_	0	-
Burial 182	LC_	0	-
	LM_3	0	-
Burial 186	LM_3	0	-
Burial 201	LM_3	0	-
Burial 210	LC_	0	-
	lc_	0	-
Burial 214	LM_3	0	-
Burial 215	lc_	0	-

Table 79. Caries frequency and type at AKB.

Individual	Tooth	No. of caries	Type
AKB11-9-45	LM_3	0	-
AKB11-12-44	LC_	0	-
AKB11-13-32	LC_	0	-
AKB11-7-24	LM^3	0	-
	LC_	0	-
	RI^1	0	-
	RI^1	0	-
	LC_	0	-
AKB13-19-108	RI^1	0	-
AKB11-4-28	rc_	0	-
	RC_	0	-
AKB11-10-40	LC_	0	-
	LM_3	0	-
Scatter GG AKB13-15-136	RM_3	0	-
	LC_	0	-
AKB13-15-97	LC_	0	-
Scatter HH	LC_	0	-
Scatter Q	LC_	0	-
Scatter V	RI^1	0	-
Scatter Y	RI^1	0	-
Scatter O	RC_	0	-
Scatter EE	LI^1	0	-
Scatter JJ	RI^1	0	-
Scatter A	RC_	0	-
	RM_3	0	-
Scatter R	LI^1	0	-
Scatter U	RI^1	0	-
Chamber 4, Scatter 3	LI^1	0	-
Chamber 4, Scatter 3 AKB13-6-43	RC_	0	-
	RC_	0	-
	RI^1	0	-
AKB13-8-36	RC_	0	-
AKB13-1-11	RI^1	0	-
AKB13-18-110	LI^1	0	-
	LC_	0	-
	RC_	0	-
AKB13-11-44	LI^1	0	-

Table 80. Caries frequency and type at PB.

Individual	Tooth	No. of caries	Type
Bu 2-3	RI^1	0	-
	RC_	0	-
	LM^3	0	-
Bu 1-8	LC_	0	-
Bu 2-2	RC_	0	-
	LI^1	0	-
Bu 4-2	LI^1	0	-
	LC_	0	-
Bu 2-4	RM^3	0	-
Bu 1-7	RC_	0	-
Bu 4-1	RI^1	0	-
	RM^3	0	-
Bu 2-5	LI^1	0	-
	RM^3	0	-
Bu 2-3, Ind 2	LI^1	0	-
	LC_	0	-
Bu 1-2	LI^1	0	-
Bu 1, Mound 3	LC_	0	-
	RM^3	0	-
Bu 2, Mound 6	RM^3	0	-
	LC_	0	-
	RI^1	0	-
Bu 1, Mound 36	LC_	0	-
	RC_	0	-
	RM^3	0	-
	LI^1	0	-
	LM^3	1	3
Bu 95-1	LM^3	1	1
	LC_	0	-
Bu btwn Strs 1 and 4	LC_	0	-
Bu 5-1	LI^1	0	-
Bu 2, Mound 36	LC_	0	-
	LI^1	0	-
	RM^3	1	1
Bu 1, Mound 42	LC_	0	-
	LI^1	0	-
Bu 1, Mound 6	RC_	2	4; 4
Bu 3, Mound 6	RM^3	2	1; 1
	LC_	0	-
	RI^1	0	-

APPENDIX 9: Correlations of Wilson bands and linear enamel hypoplasias.

Table 81. Correlations of Wilson bands and linear enamel hypoplasias (total sample).

			Total LEH	Total WB
Spearman's rho	Total LEH	Correlation coefficient	1.000	.523
		Sig. (2-tailed)	.	.229
		N	7	7
	Total WB	Correlation coefficient	.523	1.000
		Sig. (2-tailed)	.229	.
		N	7	7

APPENDIX 10: Mean age at defect formation (descriptives and ANOVA).

Table 82. Descriptives of incisors from caves (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	14	2.9893	.46375	.12394	2.7215	3.2570	2.35	4.20
2.00	2	3.1500	1.83848	1.30000	-13.3681	19.6681	1.85	4.45
3.00	4	3.2250	.92601	.46301	1.7515	4.6985	2.20	4.45
Total	20	3.0525	.68604	.15340	2.7314	3.3736	1.85	4.45

Table 83. ANOVA - incisors from caves (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.194	2	.097	.188	.830
Within Groups	8.748	17	.515		
Total	8.942	19			

Table 84. Multiple comparisons with point estimate of age as dependent variable (Tukey HSD).

(I) Cave	(J) Cave	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.16071	.54228	.953	-1.5518	1.2304
	3.00	-.23571	.40671	.833	-1.2791	.8076
2.00	1.00	.16071	.54228	.953	-1.2304	1.5518
	3.00	-.07500	.62126	.992	-1.6687	1.5187
3.00	1.00	.23571	.40671	.833	-.8076	1.2791
	2.00	.07500	.62126	.992	-1.5187	1.6687

Table 85. Descriptives of canines from caves (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	17	2.5059	1.24748	.30256	1.8645	3.1473	.00	3.50
2.00	9	2.0778	1.68636	.56212	.7815	3.3740	.00	4.10
3.00	3	1.9333	1.69288	.97738	-2.2720	6.1387	.00	3.15
Total	29	2.3138	1.40082	.26013	1.7809	2.8466	.00	4.10

Table 86. ANOVA - canines from caves (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.563	2	.781	.381	.687
Within Groups	53.382	26	2.053		
Total	54.944	28			

Table 87. Multiple comparisons with point estimate of age as dependent variable (Tukey HSD).

(I) Cave	(J) Cave	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.42810	.59068	.751	-1.0397	1.8959
	3.00	.57255	.89730	.801	-1.6572	2.8023
2.00	1.00	-.42810	.59068	.751	-1.8959	1.0397
	3.00	.14444	.95525	.987	-2.2293	2.5181
3.00	1.00	-.57255	.89730	.801	-2.8023	1.6572
	2.00	-.14444	.95525	.987	-2.5181	2.2293

Table 88. Descriptives of third molars from caves (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	5	9.7200	5.44227	2.43385	2.9625	16.4775	.00	12.50
2.00	7	8.5071	5.84925	2.21081	3.0975	13.9168	.00	13.30
3.00	2	.0000	.00000	.00000	.0000	.0000	.00	.00
Total	14	7.7250	5.99544	1.60235	4.2633	11.1867	.00	13.30

Table 89. ANOVA – third molars from caves (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	143.534	2	71.767	2.438	.133
Within Groups	323.755	11	29.432		
Total	467.289	13			

Table 90. Multiple comparisons with point estimate of age as dependent variable (Tukey HSD).

(I) Cave	(J) Cave	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	1.21286	3.17664	.923	-7.3668	9.7925
	3.00	9.72000	4.53901	.127	-2.5392	21.9792
2.00	1.00	-1.21286	3.17664	.923	-9.7925	7.3668
	3.00	8.50714	4.34980	.169	-3.2410	20.2553
3.00	1.00	-9.72000	4.53901	.127	-21.9792	2.5392
	2.00	-8.50714	4.34980	.169	-20.2553	3.2410

Table 91. Descriptives of incisors from rockshelters (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
4.00	8	3.2063	.66945	.23669	2.6466	3.7659	2.00	3.95
5.00	9	3.2056	.66588	.22196	2.6937	3.7174	1.85	4.45
Total	17	3.2059	.64636	.15676	2.8736	3.5382	1.85	4.45

Table 92. ANOVA – incisors from rockshelters (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.000	1	.000	.000	.998
Within Groups	6.684	15	.446		
Total	6.684	16			

Table 93. Descriptives of canines from rockshelters (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
4.00	6	3.6333	.45019	.18379	3.1609	4.1058	3.10	4.10
5.00	10	2.9600	.32128	.10160	2.7302	3.1898	2.30	3.40
Total	16	3.2125	.49278	.12320	2.9499	3.4751	2.30	4.10

Table 94. ANOVA – canines from rockshelters (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.700	1	1.700	12.255	.004
Within Groups	1.942	14	.139		
Total	3.643	15			

Table 95. Descriptives of canines from surface sites (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
6.00	16	3.1438	1.05355	.26339	2.5824	3.7051	.00	4.70
7.00	21	2.9143	1.09157	.23820	2.4174	3.4112	.00	4.50
Total	37	3.0135	1.06664	.17536	2.6579	3.3692	.00	4.70

Table 96. ANOVA – canines from surface sites (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.478	1	.478	.413	.524
Within Groups	40.480	35	1.157		
Total	40.958	36			

Table 97. Descriptives of third molars from surface sites (point estimate of age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
6.00	11	8.7045	5.59850	1.68801	4.9434	12.4657	.00	12.35
7.00	8	5.7688	6.17737	2.18403	.6043	10.9332	.00	11.95
Total	19	7.4684	5.87117	1.34694	4.6386	10.2982	.00	12.35

Table 98. ANOVA – canines from surface sites (point estimate of age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	39.919	1	39.919	1.169	.295
Within Groups	580.552	17	34.150		
Total	620.471	18			

APPENDIX 11: Mean age at defect formation by tooth class for all sites.

Table 99. Descriptives for incisors for all sites (point estimate age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	14	2.9893	.46375	.12394	2.7215	3.2570	2.35	4.20
2.00	2	3.1500	1.83848	1.30000	-13.3681	19.6681	1.85	4.45
3.00	4	3.2250	.92601	.46301	1.7515	4.6985	2.20	4.45
4.00	8	3.2063	.66945	.23669	2.6466	3.7659	2.00	3.95
5.00	9	3.2056	.66588	.22196	2.6937	3.7174	1.85	4.45
6.00	12	2.8917	.36045	.10405	2.6626	3.1207	2.35	3.65
Total	49	3.0663	.60822	.08689	2.8916	3.2410	1.85	4.45

Table 100. ANOVA – incisors for all sites (point estimate age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.895	5	.179	.456	.806
Within Groups	16.862	43	.392		
Total	17.757	48			

Table 101. Multiple comparisons for all sites with point estimate of age as dependent variable (Tukey HSD).

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	-.16071	.47337	.999	-1.5723	1.2509
	3.00	-.23571	.35503	.985	-1.2944	.8230
	4.00	-.21696	.27754	.969	-1.0446	.6107
	5.00	-.21627	.26755	.964	-1.0141	.5816
	6.00	.09762	.24635	.999	-.6370	.8322
2.00	1.00	.16071	.47337	.999	-1.2509	1.5723
	3.00	-.07500	.54231	1.000	-1.6922	1.5422
	4.00	-.05625	.49506	1.000	-1.5325	1.4200
	5.00	-.05556	.48953	1.000	-1.5153	1.4042
	6.00	.25833	.47828	.994	-1.1679	1.6846
3.00	1.00	.23571	.35503	.985	-.8230	1.2944
	2.00	.07500	.54231	1.000	-1.5422	1.6922
	4.00	.01875	.38347	1.000	-1.1248	1.1623
	5.00	.01944	.37631	1.000	-1.1027	1.1416
	6.00	.33333	.36154	.939	-.7448	1.4115
4.00	1.00	.21696	.27754	.969	-.6107	1.0446
	2.00	.05625	.49506	1.000	-1.4200	1.5325
	3.00	-.01875	.38347	1.000	-1.1623	1.1248
	5.00	.00069	.30428	1.000	-.9067	.9081
	6.00	.31458	.28582	.878	-.5377	1.1669
5.00	1.00	.21627	.26755	.964	-.5816	1.0141
	2.00	.05556	.48953	1.000	-1.4042	1.5153
	3.00	-.01944	.37631	1.000	-1.1416	1.1027
	4.00	-.00069	.30428	1.000	-.9081	.9067
	6.00	.31389	.27613	.863	-.5095	1.1373
6.00	1.00	-.09762	.24635	.999	-.8322	.6370
	2.00	-.25833	.47828	.994	-1.6846	1.1679
	3.00	-.33333	.36154	.939	-1.4115	.7448
	4.00	-.31458	.28582	.878	-1.1669	.5377
	5.00	-.31389	.27613	.863	-1.1373	.5095

Table 102. Descriptives for canines for all sites (point estimate age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	17	2.5059	1.24748	.30256	1.8645	3.1473	.00	3.50
2.00	9	2.0778	1.68636	.56212	.7815	3.3740	.00	4.10
3.00	3	1.9333	1.69288	.97738	-2.2720	6.1387	.00	3.15
4.00	6	3.6333	.45019	.18379	3.1609	4.1058	3.10	4.10
5.00	10	2.9600	.32128	.10160	2.7302	3.1898	2.30	3.40
6.00	16	3.1438	1.05355	.26339	2.5824	3.7051	.00	4.70
7.00	21	2.9143	1.09157	.23820	2.4174	3.4112	.00	4.50
Total	82	2.8049	1.16962	.12916	2.5479	3.0619	.00	4.70

Table 103. ANOVA – canines for all sites (point estimate age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.004	6	2.501	1.958	.082
Within Groups	95.804	75	1.277		
Total	110.808	81			

Table 104. Multiple comparisons for all sites with point estimate of age as dependent variable.

(I) Site	(J) Site	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
					Lower	Upper
1.00	2.00	.42810	.46591	.968	-.9835	1.8397
	3.00	.57255	.70777	.983	-1.5719	2.7170
	4.00	-1.12745	.53669	.363	-2.7535	.4986
	5.00	-.45412	.45042	.951	-1.8188	.9106
	6.00	-.63787	.39367	.670	-1.8306	.5549
	7.00	-.40840	.36874	.924	-1.5256	.7088
2.00	1.00	-.42810	.46591	.968	-1.8397	.9835
	3.00	.14444	.75348	1.000	-2.1384	2.4273
	4.00	-1.55556	.59568	.137	-3.3603	.2492
	5.00	-.88222	.51930	.619	-2.4556	.6912
	6.00	-1.06597	.47092	.275	-2.4928	.3608
	7.00	-.83651	.45029	.514	-2.2008	.5278
3.00	1.00	-.57255	.70777	.983	-2.7170	1.5719
	2.00	-.14444	.75348	1.000	-2.4273	2.1384
	4.00	-1.70000	.79918	.348	-4.1214	.7214
	5.00	-1.02667	.74400	.811	-3.2808	1.2275
	6.00	-1.21042	.71108	.617	-3.3648	.9440
	7.00	-.98095	.69758	.797	-3.0945	1.1326
4.00	1.00	1.12745	.53669	.363	-.4986	2.7535
	2.00	1.55556	.59568	.137	-.2492	3.3603
	3.00	1.70000	.79918	.348	-.7214	4.1214
	5.00	.67333	.58364	.909	-1.0950	2.4417
	6.00	.48958	.54105	.971	-1.1497	2.1289
	7.00	.71905	.52319	.814	-.8661	2.3042
5.00	1.00	.45412	.45042	.951	-.9106	1.8188
	2.00	.88222	.51930	.619	-.6912	2.4556
	3.00	1.02667	.74400	.811	-1.2275	3.2808
	4.00	-.67333	.58364	.909	-2.4417	1.0950
	6.00	-.18375	.45560	1.000	-1.5641	1.1966
	7.00	.04571	.43424	1.000	-1.2700	1.3614
6.00	1.00	.63787	.39367	.670	-.5549	1.8306
	2.00	1.06597	.47092	.275	-.3608	2.4928
	3.00	1.21042	.71108	.617	-.9440	3.3648
	4.00	-.48958	.54105	.971	-2.1289	1.1497
	5.00	.18375	.45560	1.000	-1.1966	1.5641
	7.00	.22946	.37505	.996	-.9069	1.3658
7.00	1.00	.40840	.36874	.924	-.7088	1.5256
	2.00	.83651	.45029	.514	-.5278	2.2008
	3.00	.98095	.69758	.797	-1.1326	3.0945
	4.00	-.71905	.52319	.814	-2.3042	.8661
	5.00	-.04571	.43424	1.000	-1.3614	1.2700
	6.00	-.22946	.37505	.996	-1.3658	.9069

Table 105. Descriptives for third molars for all sites (point estimate age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	5	9.7200	5.44227	2.43385	2.9625	16.4775	.00	12.50
2.00	7	8.5071	5.84925	2.21081	3.0975	13.9168	.00	13.30
3.00	2	.0000	.00000	.00000	.0000	.0000	.00	.00
4.00	2	5.8500	8.27315	5.85000	-68.4813	80.1813	.00	11.70
6.00	11	8.7045	5.59850	1.68801	4.9434	12.4657	.00	12.35
7.00	8	5.7688	6.17737	2.18403	.6043	10.9332	.00	11.95
Total	35	7.4786	5.84697	.98832	5.4701	9.4871	.00	13.30

Table 106. ANOVA – third molars for all sites (point estimate age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	189.609	5	37.922	1.131	.367
Within Groups	972.752	29	33.543		
Total	1162.361	34			

Table 107. Multiple comparisons for all sites with point estimate of age as dependent variable.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	1.21286	3.39124	.999	-9.1253	11.5510
	3.00	9.72000	4.84564	.363	-5.0518	24.4918
	4.00	3.87000	4.84564	.965	-10.9018	18.6418
	6.00	1.01545	3.12378	.999	-8.5073	10.5382
	7.00	3.95125	3.30175	.835	-6.1141	14.0166
2.00	1.00	-1.21286	3.39124	.999	-11.5510	9.1253
	3.00	8.50714	4.64365	.462	-5.6489	22.6632
	4.00	2.65714	4.64365	.992	-11.4989	16.8132
	6.00	-.19740	2.80023	1.000	-8.7338	8.3390
	7.00	2.73839	2.99746	.940	-6.3993	11.8761
3.00	1.00	-9.72000	4.84564	.363	-24.4918	5.0518
	2.00	-8.50714	4.64365	.462	-22.6632	5.6489
	4.00	-5.85000	5.79165	.911	-23.5057	11.8057
	6.00	-8.70455	4.45207	.391	-22.2766	4.8675
	7.00	-5.76875	4.57870	.804	-19.7268	8.1893
4.00	1.00	-3.87000	4.84564	.965	-18.6418	10.9018
	2.00	-2.65714	4.64365	.992	-16.8132	11.4989
	3.00	5.85000	5.79165	.911	-11.8057	23.5057
	6.00	-2.85455	4.45207	.987	-16.4266	10.7175
	7.00	.08125	4.57870	1.000	-13.8768	14.0393
6.00	1.00	-1.01545	3.12378	.999	-10.5382	8.5073
	2.00	.19740	2.80023	1.000	-8.3390	8.7338
	3.00	8.70455	4.45207	.391	-4.8675	22.2766
	4.00	2.85455	4.45207	.987	-10.7175	16.4266
	7.00	2.93580	2.69115	.881	-5.2681	11.1397
7.00	1.00	-3.95125	3.30175	.835	-14.0166	6.1141
	2.00	-2.73839	2.99746	.940	-11.8761	6.3993
	3.00	5.76875	4.57870	.804	-8.1893	19.7268
	4.00	-.08125	4.57870	1.000	-14.0393	13.8768
	6.00	-2.93580	2.69115	.881	-11.1397	5.2681

Table 108. Descriptives for deciduous canines for all sites (point estimate age).

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1.00	1	.3750	.	.	.	.	.38	.38
5.00	4	.5200	.10464	.05232	.3535	.6865	.38	.63
7.00	4	.2700	.31177	.15588	-.2261	.7661	.00	.54
Total	9	.3928	.23712	.07904	.2105	.5750	.00	.63

Table 109. ANOVA – deciduous canines for all sites (point estimate age).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.125	2	.063	1.159	.375
Within Groups	.324	6	.054		
Total	.450	8			

APPENDIX 12: Correlation analysis.

Figure 9. R correlation analysis for sex and Wilson bands.

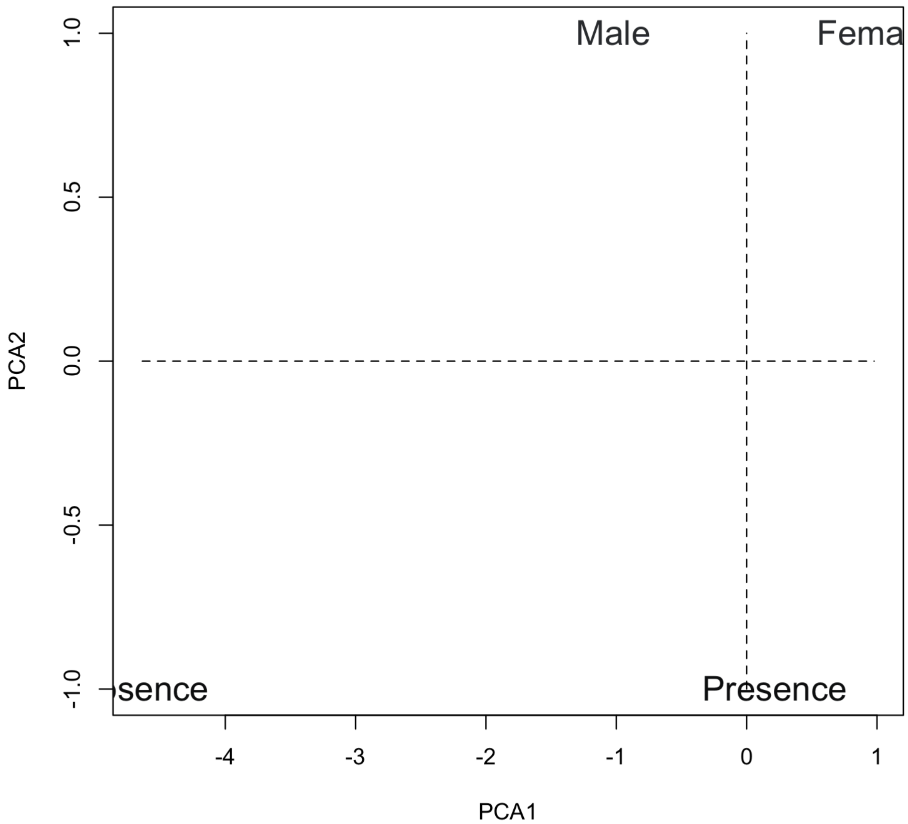
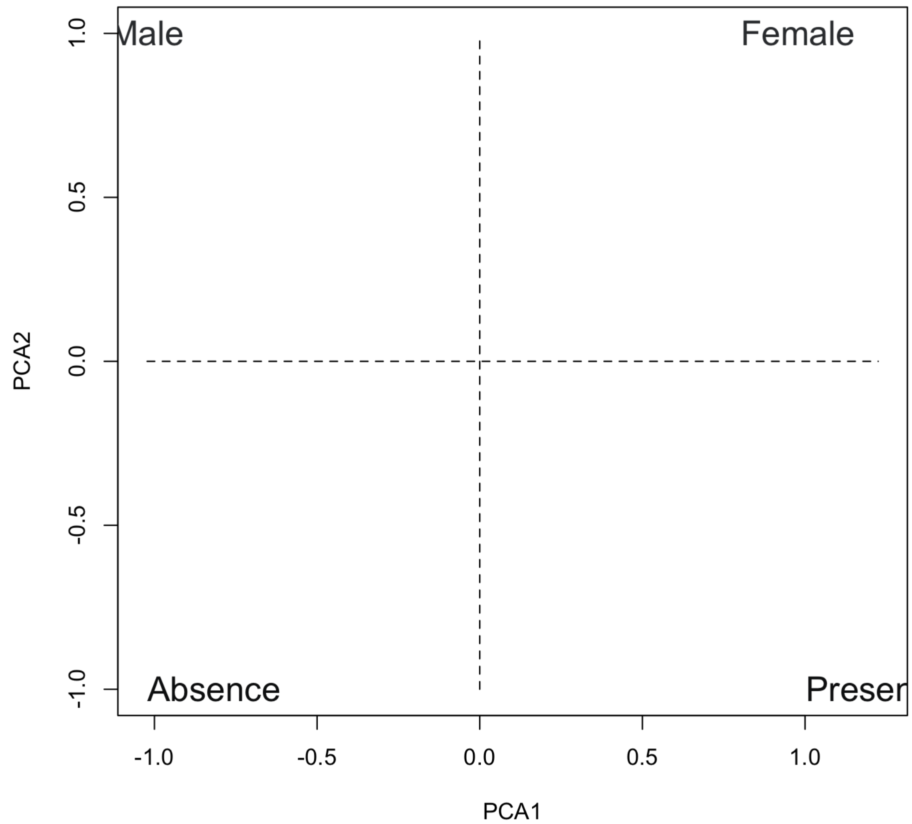


Figure 10. R correlation analysis for sex and LEHs.



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