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Meroitic Childhood Diet and Weaning at Sai Island, Sudan: A Carbon and Nitrogen Isotopic Study of Site 8-B-52.B

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MEROITIC CHILDHOOD DIET AND WEANING AT SAI ISLAND, SUDAN: A CARBON AND NITROGEN ISOTOPIC STUDY OF SITE 8-B-52.B

by

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ABSTRACT

This research explores the diet and weaning patterns of non-adult individuals from an elite Meroitic (300 BCE – 350 CE) cemetery (8-B-52.B) at Sai Island, Sudan. This was accomplished by conducting stable isotopic analyses of carbon and nitrogen on a sample of 54 individuals. These analyses focused on differences in adult and non-adult diet, non-adult weaning patterns, and intra-elite differences between contemporaneous cemeteries at Sai Island in order to shed light on the patterns of non-adult diet and weaning and the mother-infant dynamic. The non-adult individuals range from 36 weeks gestational age to 16.5 years of age, and the adult individuals ranged from 18 to 60 years of age. The non-adult individuals were divided into five age categories based on physiological stages of childhood to explore life course changes. The isotopic values for each individual and age category were analyzed and compared to determine the diet and weaning patterns of this sample. The results suggest that the adults and non-adults were consuming a homogenous diet with the exception of breastfeeding children, who exhibited enriched $\delta^{15}N$ and $\delta^{13}C$ values compared to the other adults and non-adults in the sample. The isotopic data suggest that non-adults in this sample were likely weaned by 3 years of age as inferred from the assimilation of non-adult $\delta^{15}N$ values to those exhibited by adult females. Lastly, no statistically significant differences in non-adult diet and weaning existed between the contemporaneous sites 8-B-52.B and 8-B-5.A on Sai Island, suggesting homogenous patterns of diet and weaning between the religious and wealthy elite in this population. This study demonstrates the relationship between social status, age, and dietary patterns during the Meroitic period, but more significantly illustrates the patterns of early life feeding and weaning behaviors that influence the relationship between a mother and her infant.

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CHAPTER ONE: INTRODUCTION

Of all the bonds formed between humans, that between a mother and her infant is arguably the most intimate and synergistic. When a woman is pregnant, she and her child share not only a body and DNA, but nutrition, an immune system, and stress; her child experiences social, environmental, and biological forces in utero, and this is just the beginning of the nexus formed between mother and infant (Gowland and Halcrow, 2020). This is known as the mother-infant (M-I) dynamic. The moment the child is born, the M-I dynamic does not cease; the relationship becomes so that both the mother *and* her infant possess the agency to elicit a response from the other to ensure the health and wellness of each (Lozoff et al., 1977; Winberg, 2005; Palmquist, 2020). The impact of this relationship is one that ultimately affects our understanding of human evolution, biological adaptation, social interaction and development, cultural beliefs, and especially feeding and care strategies (Gowland and Halcrow, 2020).

Since the early 1970s, bioarchaeologists have gained a wealth of information about past societies from studying the skeletal remains of past humans. However, little work has been conducted specifically on the health of perinates and infants with regard to the M-I dynamic. This is problematic, as the understanding of environmental stress and social development can be assessed and informed by the perinatal and infant periods of life, including early diet (Halcrow, 2020). One method of study that may allow for facets of the M-I dynamic to be explored is stable isotope analysis. Since the 1970s, bioarchaeologists have used stable isotopes to understand the diet and weaning patterns of past individuals and populations. These analyses can provide the data necessary to consider infant and maternal health, sociocultural norms surrounding infant feeding and weaning, female fertility, and the presence and/or absence of dietary resources used during the weaning period (King et al., 2018; Halcrow, 2020).

The purpose of this research is to analyze and compare childhood dietary patterns of individuals from an elite Meroitic (300 BCE – 350 CE) cemetery (8-B-52.B) on Sai Island, Sudan to better understand childhood diet and weaning and the mother-infant dynamic. This research will focus on observing childhood diet and weaning patterns, differences between adult and childhood diet, and intra-class differences in diet and weaning patterns. Both juvenile and adult samples from site 8-B-52.B will be analyzed, and previously analyzed stable isotopic data from a contemporary religious elite cemetery (8-B-5.A) (Gregoire, 2019) will also be utilized to conduct inter-cemetery comparisons.

Beyond the biological focus of the project, archaeological and sociocultural theoretical constructs will be utilized to contextualize these data and present the most holistic analysis possible. In addition to isotopic methods, social identity and life history theories will be used to inform the analysis and provide a more detailed account of the lives of the individuals being analyzed, particularly in terms of age and social class. Due to the lack of comprehensive literature regarding childhood and social class in Meroitic period Sudan, this research will contribute to the body of literature on social identity and childhood on Sai Island, Sudan and in the Meroitic period in general. In addition, this study will contribute to the body of literature on the isotopic relationships between childhood diet, as well as the literature on the biological, cultural, and social relationships between mother and infant.

This study will be based around the primary research question, “What are the patterns of childhood diet and weaning of the elite Meroitic population interred on Sai Island, Sudan?” This question will be followed by three additional questions, which are as follows:

1. Are there differences in dietary patterns between and/or among adults and non-adults in this cemetery sample?
2. At what age are non-adults in this sample weaned?
3. Are there dietary differences within the elite social classes on Sai Island?

Based on these research questions, it is hypothesized that there will be statistically significant differences between adult and non-adult isotopic values. I expect the non-adults individuals to exhibit greater variation in carbon and nitrogen values as a result of the breastfeeding and weaning process. The weaning age is hypothesized, based on previous studies in the immediate and surrounding geographic areas (Dupras and Tocheri, 2007; Eerkens et al., 2018; Gregoire, 2019; Turner et al., 2007), to be around 2.5 years of age. It is hypothesized that there will be observable differences in the isotopic values of the wealthy elite individuals from 8-B-52.B compared to religious elite individuals from the contemporaneous 8-B-5.A Meroitic cemetery on Sai Island. Even though the sites are contemporaneous and geographically similar, the status difference (wealthy vs religious elite) is expected to result in dietary differences.

To address the research questions mentioned above, stable carbon and nitrogen isotope values from the bone collagen of 71 individuals from site 8-B-52.B on Sai Island, Sudan will be analyzed. These 71 individuals were broken down into age and sex categories, which consist of 15 perinatal individuals (36-40 weeks gestational age), 18 infants (0-1 years), 10 young children (1-6 years), seven old children (7-12 years), four adolescents (13-17 years), two young adults (18-29 years), nine middle adults (30-49 years), and six old adults (50+ years). In addition, the adults in this sample consist of eight males and 11 females.

The isotopic data will be used in conjunction with existing literature and theoretical approaches to answer the aforementioned research questions. Chapter Two is a review of the literature, which consists of background information on Meroitic period Sudan, Sai Island archaeology, social identity and life history theories, the history and perception of children in bioarchaeology, bone biology, breastfeeding and weaning the age categories used in this research, and stable isotope analysis. Chapter Three is an overview of the materials and methods use in this study, including demography, how the age at death was estimated, and the methods used to extract the collagen from the bone samples. Chapter Four is the results section, and Chapter Five is a discussion of these results, their respective interpretations, and how they relate to the research questions. Chapter Six is the conclusion, which includes the limitations of this study and any areas for future research.

CHAPTER TWO: LITERATURE REVIEW

The purpose of this chapter is to provide a review of the pertinent literature regarding stable isotopic studies, life during the Meroitic period, and children in bioarchaeology. To give structure to the background information that will be provided in this section, the existing literature will be broken up into the following sections: the historical context of Meroitic Period Sudan, Sai Island Archaeology, Theoretical Approaches, the History and Perception of Children in Bioarchaeology, Breastfeeding and Weaning, Stable Isotope Analysis, and Bone Biology. Each section will consist of a review of the existing literature of the topic, as well as a discussion of each topic's significance as it pertains to this research project.

Meroitic Period Sudan

Archaeology in Sudan began as an extension of research conducted on the Egyptian frontier in Nubia with a focus on Egyptian monumental and artistic remains in the Middle Nile (Edwards, 2007). Further, though very limited resources for archaeological investigation have been spread thin across the region, salvage archaeology in the Nubian north was prominent in the 20th century, as the Nile was flooded by the creation of the Aswan Dam (Edwards, 2007; Edwards et al., 2012). In addition, the Merowe dam project began in 2003 that further pressed archaeologists in Sudan to pursue archaeological salvage missions (Kleinitz and Naser, 2011). Current archaeology in the area focuses on central riverine areas and aims to continue the construction of cultural-historical databases and refining the cultural frameworks that were defined over the last century or so (Edwards, 2007). Though the body of archaeological literature on the Meroitic period in Sudan is far from rich, the period can be placed into the larger context of the Nile River valley throughout the history of the area (Edwards, 2004; 2007). In order to do

this, a brief introduction to the geography of Nubian Sudan followed by the known history of occupation sites in Sudan through time will be discussed to contextualize the present research and provide pertinent cultural background to support the isotopic study at hand.

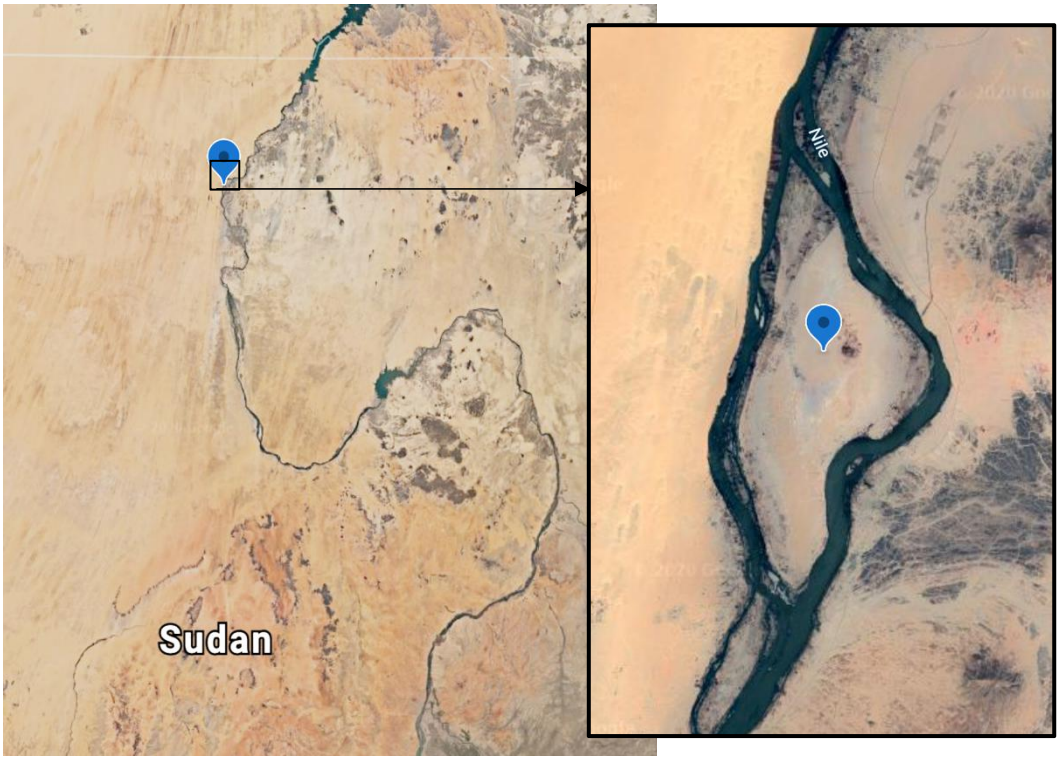

Figure 1. Map of Northern Sudan showing the location of Sai Island (Blue Marker) within the Nile River (inset). Map courtesy of Google Earth.

The term 'Nubia' refers to a region of land located in northeastern Africa and encompasses the southernmost portion of Egypt and the northern half of modern-day Sudan (Lacovara, 2012). The region is broken up into two main areas: Lower Nubia in the north and Upper Nubia in the south and is further broken up into six cataracts that follow geologic changes in the Nile (Lacovara, 2012). For reference, Sai Island is located within the Nile River in Lower Nubia (Figure 1).

In the early Holocene period around 8500 BCE, intense climatic change led to the northward shift of the desert margins in northern Africa (Kuper and Kropelin, 2006); this shift

was accompanied by increasingly improved environmental conditions that led to the eventual recolonization of the area (Edwards, 2007). Pottery and other material found from this period suggest the beginning of regionally diverse but long-lived occupation sites that relied on hunting, gathering, and fishing for subsistence (Fernandez, 2003; Haaland, 2005). The subsequent Neolithic period, roughly 5000 – 3000 BCE, saw increased aridity that led to the movement of populations towards well-watered areas in southern and eastern Nubia; these favorable growing areas led to significant changes in subsistence patterns, including the introduction of food production and domesticated livestock, though material evidence suggests fishing and hunting was more prevalent than domestication of animals (Fisher, 2012; Kuper and Kropelin, 2006).

By around 2500 BCE, the political and religious center at Kerma in Upper Nubia began to develop into the capital of the first Nubian Kingdom of Kush (Fisher, 2012; Reisner, 1923). As time passed, Kerma extended its political power throughout Lower Nubia and was able to pose the first real threat to Pharaonic Egypt; this threat continued until Egypt eventually conquered Kerma during the New Kingdom period (1450 BCE) (Edwards, 2007; Fisher, 2012; Reisner, 1923). The ebb and flow of Egyptian and Kushite conflict during this time period led to exchange of goods and ideas between the two entities, which led to a large Egyptian colonial influence in the Kushite areas of Nubia—an influence that is evident in the archaeological record of these areas (Edwards, 2007; Smith, 1995). After this period of Egyptian rule, very little archaeological evidence exists for any political and/or social changes in Nubia until the seventh century BCE (Edwards, 2007).

Around 700 BCE, a new, larger Kushite kingdom had appeared in the Napatan region of Upper Nubia (Török, 1997; Fisher, 2012). This period of political revival of the Kushite kingdom is divided into two main time periods—the Napatan and the Meroitic periods—which

coincide with the change in location of royal cemeteries from Napata to Meroe around 300 BCE (Török, 1997; Edwards, 2004). The Egyptian colonial influence of the Kerma-era persisted during the Napatan period, most prominently in the evidence of pyramid burials; little else is known about the Napatan period with regards to social or economic conditions (Fisher, 2012). When the location of royal cemeteries shifted from Napata to Meroe around 300 BCE, the Meroitic period began (Edwards, 2004; 2007; Fisher, 2012).

At the site of Meroe, located between the fifth and sixth cataracts of Upper Nubia, the Meroitic Kushite kingdom maintained its control for nearly 600 years (Edwards, 2004). This kingdom included all of Upper Nubia, while Lower Nubia became the intermediate area between Upper Nubia and Egypt (Fisher, 2012). The strategic location of Meroe made it a hub for travel and external trade to the Red Sea, Ethiopia, and other areas of Sub-Saharan Africa (Fisher, 2012; Haaland, 2014). During this period, important improvements in Meroe regarding irrigation and agriculture indicate that the area did, in fact, house a sophisticated society (Fisher, 2012). Important agricultural crops during this time period included sesame, date palms, wheat, millet, barley, and sorghum, while domesticated livestock included oxen, sheep, goats, and horses (Edwards, 2004; Fisher, 2012; Haaland, 2014). Additionally, certain foods—like pepper, wine, and bread—were part of the extensive trade and redistribution network operating through Meroe and controlled by the Meroitic, Ptolemaic, and Roman rulers; as a result, foods eaten during the Meroitic period may have been determined by social class and position within the society (Haaland, 2014). Elite Kushites during the Meroitic period tended to consume a Roman-influenced diet, including wine, bread, and pepper, as cultural contact and trade with the Roman-Hellenistic world was common during this period (Haaland, 2014). Additionally, while the

elites' diet was based on bread made from wheat and barley grown near the Nile, the masses relied on traditional African millet porridge (Haaland, 2014).

With regards to mortuary practices during this period, the archaeology of royal and elite cemeteries attributed to the Meroitic period suggest a Napatan influence, including extended burials with an east-west orientation in chambers that could be accessed by sloping ramps; in addition, multiple burials and the re-use of tombs was common, perhaps for related individuals (Edwards, 2004; Usai et al., 2014). Other types of burials include a burial pit with a pear-shape or a north-south oriented chamber with an ellipsoidal shape (Usai et al., 2014). Royal and elite burials tend to be marked with stone pyramids, while slightly lower status burials were marked by brick structures or smaller pyramids called superstructures. These pyramid and superstructure burials, however, were rare outside of urban centers, as they were essentially non-existent in larger rural cemeteries (Edwards, 2004). Török (2002) suggests a strong correlation between burial structures and marking and maintaining social identities among Meroites. The grave goods associated with Meroitic burials further suggest a correlation between social identity, social status, and mortuary practice. Grave goods are very common in Meroitic burials and are usually determined by the age, wealth, or the social status of the individual (Edwards, 2004). These materials range from small feeding vessels for children and a simple jar or cup for the common Meroite, all the way to royal burials lavishly furnished with ornamental jewelry and ceramics (Adams, 1977).

The political timeline and cultural evidence of diet and mortuary practices in the Meroitic period presented above will be used in conjunction with the isotopic evidence gained from this study to contextualize data and construct a more holistic picture of childhood diet and weaning in this time period.

Sai Island Archaeology

One of the largest islands in the Middle Nile Valley, Sai Island is located between the second and third cataracts of the Nile River in Upper Nubia (Francigny, 2014; Lacovara, 2012). The island is approximately 12 km north-south and 5.5 km east-west and is situated only 20 km north of Sedeinga, another prominent Meroitic site. There are currently four identified Meroitic necropoli on the northern portion of Sai Island: 9-B-5.SN/SAS2, 8-B-5.A, 9-B-5.B, and, the focus of this research, 8.B.52.B; and the southern portion has one, 8-G-49 (Francigny, 2009). Due to excavations being more heavily focused on 8-B-5.A, little is known about 8-B-52.B, though preliminary excavations revealed it could possibly have been used by an elite population (Francigny, 2009; Pouriel, 2003).

A thesis written in 2003 by Raphael Pouriel, a then Master's student at Université Charles de Gaulle, Lille III in France, outlines the excavation of site 8-B-52.B during the 1996-2003 field seasons. The site was discovered in January of 1996 and was identified via ceramic analysis as a Meroitic period cemetery. Throughout the excavations, 5 surface superstructures/pyramids were identified and excavated, along with each associated substructure located on each of the directional faces. Thirty-nine subterranean substructures were identified and further broken down into two types: substructure type 1, and substructure type 2 (Pouriel, 2003). Type 1 substructures are deep structures with a descent into a main axial cavity and are east-west oriented; twenty of these were identified at 8-B-52.B. Type 2 substructures are small pits that are further broken down into four sub-types: a pit covered or delimited by raw bricks, a pit with a lateral cavity, a pit with a casket, and a pit with coffin stalls made by blocking raw bricks or shale; eighteen type 2 substructures were identified (Pouriel, 2003). At least 31 of these

substructures contained human burials yielding a minimum number of individuals of 147 individuals. Excavations of this cemetery were resumed during the 2018 and 2019 excavation seasons on Sai Island. In 2018, ten substructures/tombs were excavated, and materials from this season are included in this analysis.

Theoretical Approaches

Within this research, two main theoretical approaches will be applied: social identity theory and life history theory. When combined, these two approaches will provide a unique perspective that emphasizes the relationship between the skeletal and social or cultural evidence that will be collected and analyzed. This approach will help create a holistic approach to understanding this population, rather than analyzing each aspect on its own. Each individual theory and its relevance to the research will be discussed further below.

Social Identity Theory

As discussed by Trepte (2006) and Tajfel and Turner (1979), Social Identity Theory is based on the idea that people categorize themselves as belonging to various social groups and that these groups represent one's social identity. Individuals show solidarity within these social groups and discriminate against out-groups as part of the identity-building and self-enhancement process. Using this information, Social Identity Theory provides a theoretical framework to understand the "group in the individual" (Hogg and Abrams, 1988); in other words, the aim is to explain individual thoughts and behaviors through their associated group processes (Tajfel and Turner, 1979; Trepte, 2006). Halcrow and Tayles (2011) and Lewis (2007) discuss social identity theory in relation to the social identity of the human body, stating that if the body's social and

biological constructions can be understood in duality rather than separately, it can further bioarchaeological research by creating well-rounded understandings of individuals, and, by proxy, social groups.

Within this research, the use of social identity theory is relevant to the understanding of social identities of different age groups—specifically non-adults. Baxter (2008) states that in previous bioarchaeological research, children were often marginalized; they were seen as unimportant to the social life of a population and were therefore underrepresented in the archaeological record (Gottlieb, 2000; Lewis, 2007). Further, Sofaer (2011) and Hockey and James (1993) argue that age is a major factor in the creation and transformation of individual and group social identities and that it should be considered in the understanding of the social identities of past individuals. Using the intersection between age and social identity will provide this research with a unique theoretical perspective that may allow for changing and transforming social identities to be understood.

Life History Theory

As discussed by McDade (2003) and Roksandic and Armstrong (2011), Life History Theory is a branch of evolutionary thought that is concerned with variations in energy and resources allocation strategies in the body. The approach provides comparative frameworks for understanding developmental and reproductive strategies and how they vary within and among species (McDade, 2003; Stearns, 1992). Biologically, resources are limited and are strategically allocated to growth, reproduction, and maintenance; physiological constraints on these events require trade-offs and adaptations to adverse situations (McDade, 2003). By understanding this,

Life History Theory approaches focus on age-specific schedules of lifespan, reproduction, growth, and death in order to explain variation among groups.

With regard to this research, this framework will be used to help understand infant diet and weaning patterns by focusing on the dietary resources they have access to. The process of weaning places a high pathological load on an individual due to the introduction of pathogens from food sources other than breastmilk (McDade and Worthman, 1998; McDade, 2003). In order to account for this, an individual must make physiological trade-offs. However, the quality of the foods used during weaning can affect the magnitude of these trade-offs. By focusing on the dietary resources available to the non-adults in this sample during weaning, it is possible to determine the effect of weaning foods on the health and wellness of weaning children.

The History and Perception of Children in Bioarchaeology

Throughout the history of bioarchaeological research—dating back to the early 1970s—archaeologists and anthropologists have gained a wealth of information about past societies from studying the skeletal remains of past humans; however, the past humans being used to make inferences about these past societies have been overwhelmingly adult. Through the dismissal of non-adult remains as irrelevant or unimportant, archaeology has inadvertently marginalized children and the relevance of the concept of childhood within the discipline, and only recently have efforts been made to combat and address this problem.

When viewed from the perspective of an archaeologist who studies material remains, it is easy to see how factors like the lack of children in mortuary contexts and the lack of understanding and/or methods of differentiating the material remains of adults versus those of children could have led to the dismissal of children as important to the understanding of a past

group. However, this marginalization has led to a perceived erasure or lack of children in past societies at all. This is problematic, as children in the archaeological record have the power to assist in the reconstruction of the networks and social identities of past societies (Lally and Ardren, 2008). In addition, children are highly sensitive to cultural and environmental factors and often provide the first signs of cultural and/or environmental change in a society (Goodman and Armelagos, 1989).

While it is nothing new for scholars in the fields of sociology and philosophy to observe and study children, it was not until the middle of the twentieth century that researchers began making attempts to understand children in the past (Inglis and Halcrow, 2018). With his 1962 work, French philosopher Philippe Ariés began the movement of past childhood studies. In this volume, Ariés argues based on analyses of Medieval paintings that there was no awareness of a distinction between childhood and adulthood until one was 'invented' in the early modern period (Pollock, 1983; Ariés, 1962). While this work was highly contested and led to a number of rebuttals from other scholars at the time, Ariés' work ultimately led the influence of scholarship on past children and childhood (deMause, 1974; Inglis and Halcrow, 2018).

It would not be for another several decades that the idea of studying children and childhood in archaeological contexts would be considered plausible or relevant. In the meantime, however, another field of study was beginning to set the stage for what would eventually be the arrival of the children and childhood research: gender archaeology (Baxter 2008). The mid 1970s through the early 1980s brought about the inception of gender archaeology. Proponents of gender archaeology worked to emphasize a number of problems and prejudices that were present in archaeology at the time, specifically relating to the androcentric nature of archaeological investigation and interpretation (Inglis and Halcrow, 2018; Sofaer Derevenski, 1997). Though

the initial goal of gender archaeology was to 'find' women in archaeological contexts, it eventually translated into increased awareness of female contribution to societies and a gradual increase in studies related to women and the gendered division of labor (Conkey and Spector, 1984; Sofaer Derevenski, 1997; Spector, 1993). The effect of gender archaeology on the archaeology of children is two-fold but was neither immediate nor simple (Inglis and Halcrow, 2018). First, the inception of gender archaeology paved the way for 'finding' women in archaeology. A group that was once blatantly marginalized and muted in archaeological research was beginning to become a focus of archaeological inquiry. Because women in the past had been associated with the domestic sphere—including birthing and caring for children—children slowly began to appear at the forefront of archaeological research (Inglis and Halcrow, 2018; Sofaer Derevenski, 1997). However, the second and most impactful result of gender archaeology was the push towards more social archaeologies—those which aim to understand and describe complex social interactions and social dynamics of past societies (Meskell and Preucel, 2007). While the movement towards social archaeologies did not directly lead to the study of children, it created a new context through which the first influential researchers of children and childhood (i.e. Kamp, 2001; Lillehammer, 1989; Sofaer Derevenski, 1996) would begin to question where the children were in archaeological study (Inglis and Halcrow, 2018).

A 1989 work by Grete Lillehammer acted as the seminal call to action for archaeologists to recognize the presence and usefulness of children in the archaeological record (Inglis and Halcrow 2018). Using the gender archaeology movement of the 1970s as a marker, Lillehammer claims that the increased focus on women and their social conditions and social dynamics led to an increased focus on the lives of children; this, she argues, led to the distinction between the public and private lives of individuals becoming less rigid. By weakening the dichotomy

between the public and private lives of individuals, Lillehammer (1989) argues that people became more concerned with the living conditions of children, therefore becoming more interested in their wellbeing as a group and recognizing them as active creators of their own unique worlds. Lillehammer (1989) felt strongly that archaeology was on the right track in beginning to open its mind to the study of children, but that much more information can and should be sought out in the realm of children and childhood research.

Following this, several anthropologists and archaeologists began theorizing about why children may have been absent from the archaeological record for, essentially, the history of the discipline. In a 1996 publication, Joanna Sofaer Derevenski touches on an issue not previously discussed in detail in archaeological literature: the perceived invisibility of children in the archaeological record. Because children are often grossly underrepresented in mortuary contexts and it is difficult to determine what kinds of archaeological deposits may have resulted from the activities of children, archaeologists often believed that children were simply absent (Boddington 1987). This, in turn, led to the absence of children and childhood data from any studies of populations and their spaces and/or households. This idea is echoed by Boddington (1987), Blake (2018), and Buckberry (2000), who all suggest that the idea of 'missing' children in mortuary contexts is due to the bones of children being much more likely to decompose over time or to be buried in shallower, more easily disturbed graves. These perceived absences of children led the entire discipline of archaeology at the time to believe that the absence of children in the archaeological record was the norm, and this even further complicate the issue of childhood erasure (Buckberry 2000).

In the last ten to fifteen years, archaeology has seen a slow increase in focus on children and childhood studies (Mays et al. 2017). In 2015 Grete Lillehammer, the same scholar who

began the childhood archaeology movement back in 1989, published an article that highlighted the advances that have been made since her initial article was published twenty-five years prior. Lillehammer claims that since the year 2000, a significant shift has taken place in the discourse surrounding children and childhood in archaeology. She argues that through the introduction of a number of new initiatives, theories, and methodologies, researchers have been able to form a "meta-theory of childhood," focused on biological, social, and cultural aspects of childhood (Lillehammer 2015:80).

As a whole, most recent bioarchaeological studies of children have begun using a biocultural approach to help understand the past through the study of human remains (Mays et al. 2017; Zuckerman and Armelagos 2011). This approach not only utilizes some of the underpinnings of social theories, but also emphasizes "the dynamic interaction between humans and their larger social, cultural, and physical environments," (Zuckerman and Armelagos 2011:20). This has led to an increase in researchers studying the effects of political and social processes on the biology of individuals through topics like paleopathology, diet and weaning, and life history studies (Mays et al. 2017; Zuckerman and Armelagos 2011). Zuckerman and Armelagos (2011) argue that the biocultural approach takes bioarchaeological analyses beyond simple interpretations of the past and shed light on experiences that affect the human body but that may not be visible in the archaeological record. This addition of social theory and the shift towards the biocultural approach has undoubtedly contributed to the recent prominence of the study of children in bioarchaeology (Goodman and Armelagos 1989; Zuckerman and Armelagos 2011).

As is evidenced by the theoretical and methodological innovations in the field of childhood bioarchaeology in the last ten to fifteen years, the study of children and childhood has

advanced by leaps and bounds since Grete Lillehammer published her first call to action in 1989. Bioarchaeologists are beginning to focus on the children themselves rather than using them as a tool for learning about adults, and this is a development that has been a long time coming (Mays et al. 2017). By continuing to understand the value of engaging with the lives of past children and the synergistic effects these studies have with studies of both children and adults in other disciplines, bioarchaeology will continue to produce information about past societies that is less biased and more valuable than ever before.

Age Categories

When it comes to understanding all aspects of what makes a 'child', it is important to note that childhood is the time when skills and belief systems are learned and one's personality and values are developed (Kamp, 2001). These are very context-, time-, and culture-specific traits that are difficult to measure and understand in a manner which is universal and consistent (Inglis and Halcrow, 2018; Kamp, 2001). This leads to one of the largest issues facing childhood studies in bioarchaeology, which is the inability to create a consistent means by which to determine the age of a child in an archaeological context (Halcrow and Tayles, 2011; Inglis and Halcrow, 2018).

While nearly every human culture recognizes a stage of life called 'childhood', this stage is understood differently in every society (Bogin, 1997). From an evolutionary and physiological standpoint based on feeding behaviors, childhood is defined as the period following infancy, usually between the years of three and seven, when an individual is weaned from its mother but must still depend on others for feeding assistance due to his or her limited deciduous dentition and small, sensitive digestive system (Bogin, 2009). After childhood, the stage of juvenility

begins when the permanent dentition begins to erupt, and the child become able to procure and process his or her own foods. When the juvenile period ends at the onset of puberty, the individual is considered an adolescent until their post-pubertal growth is complete (Bogin, 1997). While these definitions of the stages of childhood may be a biological reality, the physiological definition fails to encompass the cultural and social aspects that make up a child's life; the age at which individual becomes independent and takes on his or her own social responsibility is far from discrete or universal (Halcrow and Tayles, 2011; Inglis and Halcrow, 2018; Lewis, 2007).

For the purposes of this research, a physiological model of age will be used that is based on the work of Baker et al. (2005); these categories are summarized in Table 1. This decision was made based on the lack of written information regarding the social ages of Meroitic period individuals in Sudan, but also on the fact that weaning is a physiological phenomenon. All individuals younger than 18 years of age will be termed non-adults. Because this study includes samples of individuals who are at or around the time of birth, the term perinate or perinatal individual will be used for any individual 36-40 weeks gestational age. Any individual between the ages of 0 and 1 years is considered an infant. The term 'child' generally refers to individuals from 1 year old to the time of puberty (Baker et al., 2005). For the purposes of this study, this stage is broken into two categories: young children are those aged between 1 and 6 years, while old children are those aged between 7 and 12 years. The final age category is adolescents, which includes individuals between 12 and 17 years of age (Baker et al., 2005).

Table 1. Table showing the age categories used in this research. Adapted from Baker et al. (2005).

Age Category	Age Range
Perinatal	36-40 weeks gestational age
Infant	0-1 years
Young Child	1-6 years
Old Child	7-12 years
Adolescent	13-17 years

Breastfeeding and Weaning

Breastfeeding and weaning are two important social and biological stages of child-rearing and infancy that can be inferred via stable isotope analysis. By understanding the timing of these events, one can begin to understand aspects of a society, including infant and maternal health, the roles of adults, fertility, age-related dietary practices, and infant morbidity and mortality in a population (Beaumont et al., 2015; Halcrow and Tayles, 2011; Herring et al., 1998; Katzenberg et al., 1996; Turner et al., 2007) The direct impact breastfeeding and weaning have on infant health and survivorship has become of interest to bioarchaeologists, as it is hypothesized that adult diet and any dietary shifts, like those from hunting and gathering to domestication of plants and animals, may play a role in changing infant feeding practices (Buikstra et al., 1986; Katzenberg et al., 1996).

By definition, breastfeeding is the process in mammals by which a mother provides nutrition to her young via the process of lactation (Humphrey, 2010). After six months, breastmilk cannot continue to support the infant's nutritional needs and must be supplemented with alternative foods to support healthy growth (Lawrence and Lawrence, 2016). Weaning is the process of supplementing an infant's exclusively-breastmilk diet with solid foods (Bogin, 1999); in other words, weaning is the transition between exclusive breastfeeding and eating exclusively solid foods (Humphrey, 2010). While the introduction of outside foods is less likely to increase infant morbidity after six months of exclusive breastfeeding, alternative foods are a potential source of malnutrition, pathogens, and poisoning (Beaumont et al., 2015; Katzenberg et al., 1996). These potential detriments to the infant, however, must be weighed against cultural practices and economic factors when a mother is determining the length of time she will

breastfeed (Beaumont et al., 2015). When weaning is complete and an infant is no longer breastfeeding, the infant's diet will tend to assimilate to that of the adults in the population (Herring et al, 1998; Katzenberg et al., 1996). As a result, it is expected that the diets of older children and adolescents will be similar or identical to the diets of the adults in the population (Katzenberg et al., 1996).

These different stages in the breastfeeding and weaning process can be broken up into four life-stages: gestation, exclusive breastfeeding, weaning, and fully weaned (Humphrey et al., 2007). While the ages at which each of these stages occurs varies from infant to infant, they represent important markers in the life history of the individual (Humphrey, 2014). Humphrey (2014) describes each stage as follows. During the gestation period, a fetus' nutritional needs are supplied completely by the mother via the placenta. After birth and during the exclusive breastfeeding stage, the infant is still receiving all of its nutritional requirements from its mother via breast milk. This stage is followed by weaning, where supplementary foods are introduced, but the infant is still being breastfed. Lastly, when an infant is fully weaned, they no longer receive any breastmilk and are consuming only outside foods. These stages are able to be inferred via isotopic analysis of bone and will be directly relevant to the research at hand.

Stable Isotopes

In this section, the definition and chemical properties of stable isotopes will be discussed in order to provide context to the methodological approach for the research and elaborate on the manner in which stable isotope analysis works. Following this will be discussions of some of the specific uses of stable isotope analysis in bioarchaeological research for both carbon and nitrogen isotopes, respectively.

Definition and Chemical Properties

Before discussing the uses of stable isotope analysis in bioarchaeology and in this research, it is necessary to give a brief but thorough introduction to the definition of an isotope and the chemical properties they possess that allow for their systematic study in relation to diet.

Isotopes are elements whose nuclei contain the same number of protons but differing numbers of neutrons (Hoefs, 2015). Because atomic mass is determined by the number of protons and neutrons in an atom's nucleus, isotopes of the same element will vary in mass; this causes different isotopes of the same element to have different chemical and/or physical properties, or "isotope effects" (Fry, 2006; Hoefs, 2015). For example, heavier isotopes tend to react more slowly in chemical processes than lighter isotopes of the same element (Hoefs, 2015). When these "isotope effects" lead to differences in the ratios of one isotope to another in a substance, it is called fractionation, which is the basis for any variation in stable isotopes in natural biological and geochemical systems (Fry, 2006). Isotope fractionation is produced by two main phenomena: isotope exchange, in which no net reaction takes place but the isotope distributions between substances is altered, and kinetic processes, in which different reaction rates in biological or chemical reactions between isotopes of different masses leads to differing ratios of these isotopes in a substance (Hoefs, 2015). In simpler terms, isotope fractionation occurs when the isotopic ratios of the products of a reaction differ from the ratios of its reactants (DeNiro, 1987). In many substances, including human tissues, these variations in isotopic ratios can be studied and understood in terms of the mechanisms that caused them and can, in turn, answer a wide range of chemical and biological questions (Katzenberg, 2008).

While the study of stable isotopes is relevant in a number of scientific fields including chemistry, ecology, geology, biology, forensics, and medicine, this research will focus on the

applications of stable isotopic analysis in bioarchaeology (Britton, 2017; Katzenberg, 2008). The first studies of stable isotopes in archaeological bone samples were published in the 1970s and focused on agriculture and maize consumption in North America (Vogel and van der Merwe, 1977; van der Merwe and Vogel, 1978). These studies undoubtedly established the potential of use of stable isotope analysis in archaeology, and the technical and methodological advances that soon followed further advanced archaeologists' ability to investigate and understand isotopic variation within and among populations (Britton, 2017; Katzenberg, 2008). When it comes to the isotopic study of human remains in bioarchaeological contexts, carbon and nitrogen are the two most common isotopes of interest due to their potential in paleodietary reconstruction (Katzenberg, 2008). In the following sections, the applications and limitations of carbon and nitrogen stable isotopes in bioarchaeological contexts will be discussed.

Applications of Stable Carbon Isotopes in Bioarchaeology

In bioarchaeological research, analysis of stable carbon isotopes in bone collagen gives researchers the ability to study paleodiet via determining the types of plants a population or individual may have been consuming and differentiating between terrestrial and marine diets (Britton, 2017; DeNiro, 1987; DeNiro and Epstein, 1978; Hoefs, 2015; Schoeninger et al., 1983; Schoeninger and DeNiro, 1984; van der Merwe and Vogel, 1977). Each of these will be discussed further below, but first a brief introduction to the chemical and physiological mechanisms that affect carbon values will be provided.

Chemically, carbon exists in two stable isotopes: ^{12}C and ^{13}C (Hoefs, 2015). The lighter isotope, ^{12}C, makes up 98.93% of all the carbon in the atmosphere—the standard against which carbon isotope analyses are based—while the heavier ^{13}C isotope makes up the remaining 1.07%

of atmospheric carbon. All the carbon in the atmosphere and throughout the environment is distributed via either the inorganic carbonate system, which maintains the inorganic carbon in the environment in materials such as rocks, and metals; or the organic carbon system, which cycles organic carbon through all living things in the environment (Hoefs, 2015). Within the organic carbon system, the two main carbon isotopes are discriminated via biological carbon fixation, which consists of two main steps: the uptake and intracellular diffusion of carbon dioxide, and the biosynthesis of cellular components (Hoefs, 2015; Park and Epstein, 1960).

Within the organic carbon system, atmospheric CO_2 cycles throughout plants, using one of three physiological pathways: C_3, C_4, or CAM (DeNiro and Epstein, 1978; DeNiro, 1987; Hoefs, 2015). In C_3 plants such as trees, wheat, rice, tubers, beans, nuts, and cool-season grasses, an enzyme in the plant called ribulose biphosphate carboxylase/oxygenase ("rubisco") converts CO_2 from the plant's mesophyll cells into a 6-carbon molecule, which is then cleaved into two molecules of phosphoglycerate (PGA), each a 3-carbon compound (DeNiro, 1987; Hoefs, 2015). In C_4 plants, such as sugar cane, sorghum, maize, amaranth, and millet, CO_2 is fixed by the carboxylation of phosphoenvolpyruvate (PEP), a process that occurs via the enzyme PEP carboxylase to make the 4-carbon molecule oxaloacetate (DeNiro, 1987; Hoefs, 2015). Lastly, CAM (Crassulacean Acid Metabolism) plants, such as yucca, pineapple, and agave, fix CO_2 using the enzyme phosphoenol pyruvate carboxylase; depending on the environment, though, CAM plants are able to switch between the C_3 and C_4 pathways (DeNiro, 1987).

By understanding these pathways and the ways in which they allow for fractionation of carbon isotopes, the diets of past populations and individuals can be reconstructed (DeNiro, 1987; Fry, 2006). For example, because C_4 and CAM plants minimize water loss during CO_2 fixation, they discriminate less against the heavier ^{13}C isotope than do those plants that use the C_3

pathway; knowing this allows for relative $\delta^{13}C$ values to be determined for each type of plant (DeNiro, 1987). C_4 plants have a $\delta^{13}C$ value ranging from –9 to –14 ‰, while C_3 plants' $\delta^{13}C$ values range from –20 to –35 ‰ (DeNiro, 1987). The fact that these values do not overlap allows researchers conducting stable isotopic analyses of carbon to construct food webs for the population being studied (Katzenberg, 2008).

The same biological processes that allow for food webs to be created using stable carbon isotopes allow for the distinction between marine and terrestrial diets to be made (DeNiro, 1987; DeNiro and Epstein, 1978; Tauber, 1981). Marine organisms get the majority of their carbon from dissolved carbonate, which has a $\delta^{13}C$ value of 0‰; terrestrial organisms, on the other hand, gain most of their carbon from atmospheric CO_2, which has a $\delta^{13}C$ value of –7‰ (Tauber, 1981). These differing values allow for marine and terrestrial diets to be distinguished in isotopic studies (Schoeninger and DeNiro, 1984; DeNiro, 1987).

Applications of Stable Nitrogen Isotopes in Bioarchaeology

A number of applications of stable nitrogen isotopes exist in bioarchaeology, most revolving around reconstructing past diet via trophic level analyses; however, analysis of stable nitrogen isotopes can also provide insight into the type of environment an individual lived in, the presence of water and/or protein stress, pregnancy and weaning patterns, and the presence of pathological conditions (Katzenberg, 2008). These will be discussed in further detail below, but first a brief introduction to the chemical and physiological mechanisms that affect nitrogen values will be provided.

Chemically, nitrogen exists in two stable forms: ^{14}N and ^{15}N. The lighter isotope, ^{14}N, makes up 99.63% of atmospheric nitrogen—the standard against which nitrogen isotope analyses

are based—while the heavier ^{15}N isotope makes up a mere 0.37% (Hoefs, 2015). Nitrogen is distributed in and around the environment via the biological nitrogen cycle, which consists of fixation, nitrification, and denitrification (Hoefs, 2015). For the purposes of this research, only the fixation step of the cycle will be discussed in detail.

Nitrogen fixation involves the conversion of inert, unreactive atmospheric nitrogen into reactive forms of nitrogen like nitrate or ammonium (Brill, 1977; Hoefs, 2015). This fixation process is usually facilitated by a select group of symbiotic bacteria in the roots of plants (Brill, 1977; Hoefs, 2015). Some legumes, for example, have a symbiotic relationship with bacteria of the genus *Rhizobium,* which fix nitrogen from the atmosphere, convert it to a reactive form, and make it directly available for the plant to use; other plants get nitrogen from decomposed organic matter in the soil (Brill, 1977; Hoefs, 2015). The uptake of fixed nitrogen from different sources leads to differences in $\delta^{15}N$ values in different organisms (Hoefs, 2015; Katzenberg, 2008). For example, leguminous plants have $\delta^{15}N$ values closer to that of atmospheric nitrogen, but non-leguminous plants tend to be enriched in, or have higher levels of, ^{15}N relative to ^{14}N, leading to $\delta^{15}N$ values higher than atmospheric nitrogen (DeNiro, 1987). When these plants are consumed, the consumers' $\delta^{15}N$ are further affected or enriched, which leads to differing levels of ^{15}N across trophic levels (DeNiro, 1987; Hoefs, 2015). The principal of enrichment via successive trophic levels will be discussed further below.

First recognized by Schoeninger and DeNiro (1984) and Minagawa and Wada (1984), the trophic level enrichment effect states that $\delta^{15}N$ should increase, or become more positive, as nitrogen is transferred across trophic levels, from plants, to herbivores, to carnivores, and finally to secondary carnivores. Through laboratory experiments, DeNiro and Epstein (1981) found that, on average, $\delta^{15}N$ values of terrestrial animals' tissues are about 3‰ higher than the foods they

consumed, providing evidence for the trophic level enrichment effect. Variation exists in the magnitude of this effect, dependent upon the tissue tested within an organism, but also within different taxa (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984). This effect, when studied relative to other organisms in an environment, can provide insight into the diet and resources available to a population (Schoeninger and DeNiro, 1984). This trophic level effect is not limited to terrestrial organisms, however; marine and freshwater fish also exhibit a similar effect that results in higher $\delta^{15}N$ values and allows for inferences to be made about the reliance on fish in the diet (Schoeninger and DeNiro, 1984). Due to the general lack of fish in the archaeological record, the ability to understand the dietary reliance on marine and freshwater resources is particularly significant (Katzenberg, 2008).

In addition to allowing for inference about the reliance upon freshwater resources, stable nitrogen isotopic analysis can allow for inferences to be made about water stress in a particular area (Heaton et al., 1986). Ambrose (1991) presented evidence that there are significant variations in nitrogen values between different regions, with hot, arid environments exhibiting higher $\delta^{15}N$ values and cool, wet environments exhibiting lower $\delta^{15}N$ values. If humans consume terrestrial animals from these different environments, it can lead to variations in $\delta^{15}N$ values (Ambrose, 1991). Recognizing this difference in $\delta^{15}N$ values between types of environment is important, as it can lead to incorrect dietary analyses; for example, if an individual from a hot, arid environment has high $\delta^{15}N$ values, this could be attributed incorrectly to a reliance upon marine resources if the contribution of the environment is not taken into consideration (Katzenberg, 2008). Physiologically this is attributed to preferential ^{14}N excretion in water-stressed individuals, which ultimately leads to higher levels of ^{15}N in the tissues and a higher $\delta^{15}N$ value (Ambrose, 1991; Ambrose and DeNiro, 1986; Schwarcz et al., 1999).

Further, a number of studies (Katzenberg and Lovell, 1999; White and Armelagos, 1997) have suggested that pathological conditions of the bone, like osteomyelitis, osteoporosis, fracture, periostitis, rickets, atrophy, and other degenerative bone conditions, can affect $\delta^{15}N$ values. These pathologies tend to affect the growth and repair of bone, in turn affecting the carbon and nitrogen uptake of the bone (Katzenberg and Lovell, 1999; Olsen et al., 2014). When new bone is being produced, more nitrogen is being taken in than is being excreted, leaving the individual in a positive nitrogen balance; this is common in instances of periostitis, osteomyelitis, osteopenia, and fracture repair (Katzenberg and Lovell, 1999; White and Armelagos, 1997). However, when body tissues are lost during periods of stress, more nitrogen is being excreted than is being taken in, thus resulting in a negative nitrogen balance; this is most likely to occur in instances of bone atrophy due to a nutritional stress (Katzenberg and Lovell, 1999).

Lastly, studies have suggested that pregnancy and weaning can affect $\delta^{15}N$ values of reproducing females (Fuller et al., 2004; Fuller et al., 2005; Fuller et al., 2006; Fogel et al., 1989). In a study comparing pre-conception hair $\delta^{15}N$ values of females to their post-partum $\delta^{15}N$ values among modern women, Fuller et al. (2004) found that the mother's $\delta^{15}N$ values decreased after gestation, suggesting that the metabolic and/or physiological processes related to pregnancy affect $\delta^{15}N$ values. However, in subsequent studies, Fuller et al. (2005) and Olsen et al. (2014) found that pregnant women who experience morning sickness or weight loss, which leads to subsequent protein stress, have increased nitrogen isotope values compared to women who are not pregnant or women who are pregnant but do not experience morning sickness.

Further, studies of infant breastfeeding and weaning and their effects on $\delta^{15}N$ values have found that when an infant is breastfeeding exclusively, meaning no other foods have been introduced into the diet yet, their nitrogen isotope levels tend to be one trophic level above their

mother's, which corresponds to an increase in $\delta^{15}N$ values by approximately 2 – 3 ‰ (Fogel et al., 1989; Fuller et al., 2004; Fuller et al., 2006). As the weaning process begins and foods other than breastmilk are introduced into the infant's diet, their $\delta^{15}N$ will begin to slowly equilibrate with that of their mother's (Fuller et al., 2004; Fuller et al., 2006).

Lastly, studies have found that fertilizing agricultural fields, specifically with animal manure, can result in a ^{15}N enrichment in the plants grown and the individuals who consume the plants (Bogaard et al., 2007; Choi et al., 2003; Hedges and Reynard, 2007). Animal manure is enriched in ^{15}N compared to plants, and the use of this manure can cause a further ^{15}N enrichment in the plants grown using the manure (Bogaard et al., 2007; Hedges and Reynard, 2007). Bogaard et al. (2007) found that cereal grains in particular, like millet and barley, are susceptible to ^{15}N enrichment due to manuring; because of this, human diets with major cereal grain components could exhibit $\delta^{15}N$ values closer to those with largely animal-based diets.

The examples discussed above provide insight into the many ways nitrogen isotope values can be used in the analysis of bioarchaeological samples, but also into the many conditions under which isotopic values can vary. The analysis of carbon and nitrogen isotopic values, when used in conjunction, allows for the possibility of a vast array of inferences to be made about the lives of the individuals being studied.

Bone Biology

Mammalian bone is made up of two main components: an inorganic, mineral portion and an organic portion (White et al., 2012). The inorganic portion is composed of a crystalline matrix of hydroxyapatite ($Ca_{10}(PO_4)_6(OH_2)$), a form of calcium phosphate which gives bone its stiff structure (White et al., 2012). The organic, or protein-based, portion of bone is made up of

roughly 90% collagen, with additional proteins making up the remaining 10%; these large protein molecules are situated within the hydroxyapatite structure to give bone its stiff but flexible structural integrity (White et al., 2012). Due to its chemical structure, its preservation qualities, and its turnover rate, bone collagen is useful in stable isotopic studies of an individual's diet (van der Merwe and Vogel, 1978). For these reasons, bone collagen will be the focus of this study.

When conducting studies of bone collagen, however, the turnover rates of bone must be further taken into consideration, especially regarding the turnover rates of non-adult bone, as the rate of turnover ultimately determines what period of an individual's life is represented by the bone collagen being analyzed. While Hedges et al. (2007) found that adult human femoral shafts have a turnover rate of approximately 3% per year, the authors found that bone collagen turnover in adolescents aged 10-15 years can range from 10-30% per year. Hedges et al. (2007) argue that a percentage of the bone collagen synthesized at any period during an individual's life is present in the bone at death but that ultimately bone collagen is mostly turned over every 25-30 years depending on age and biological sex, while others argue bone collagen is completely turned over at rates ranging from 10-30 years (Libby et al., 1964; van der Merwe and Vogel, 1978).

When it comes to non-adults, the rates of bone turnover roughly correspond to the rate of bone growth (Szulc et al., 2000). Szulc et al. (2000) found that the chemical markers for bone growth and resorption increase rapidly during the first month of life, reaching their peak around the second month of life; the levels increase at a slower rate from the third month of life to the third year of life as bone growth is still increasing, but not at the same rate as the first few days of life. After the third year of life, bone growth and resorption markers stay constant or very slightly decrease until puberty, when increases in growth hormone (GH) and insulin-like growth

factor I (IGF-I) create an increase in skeletal growth and turnover (Szulc et al., 2000). At the cessation of puberty, bone growth and turnover slow while the individual's bone mineral content (BMC) increases; at this point, bone remodeling slows to a maintenance level (Szulc et al., 2000). This cycle of bone growth and turnover must be taken into consideration when conducting stable isotopic analyses of bone, as faster bone growth and turnover result in shorter periods of representation in the isotopic data.

However, Beaumont et al. (2015) suggest that more research needs to be conducted regarding the effects of non-adult bone turnover on isotopic levels, as several factors can cause variation in isotopic values. These include the actual growth and resorption of bone, environmental factors, nutrition, and climate.

CHAPTER THREE: MATERIALS AND METHODS

Sample

The materials being analyzed in this research consist of skeletal samples taken from the femora of 71 individuals interred at Sai Island, Sudan, acquired by Dr. Tosha Dupras in 2018. The samples represent a Meroitic-period elite population of both adult males and females, and non-adults of a wide-range of ages (Table 2).

Age estimations for all individuals were performed in the field by Dr. Tosha Dupras and Dr. Yann Ardagna using multiple methods. Age estimates of non-adult individuals were made using dental development (Liversidge et al., 1998; Moorrees et al., 1963a; 1963b; Smith 1991) and eruption methods (Liversidge et al., 1998; Ubelaker 1978) when possible, in addition to long bone development (Fazekas and Kósa, 1978; Maresh, 1970; Scheuer et al., 1980) and epiphyseal fusion (Scheuer and Black, 2000). Age estimations for adults were conducted using methods including pubic symphyseal changes (Brooks and Suchey, 1990), rib end changes (Işcan and Loth, 1985; 1986), auricular surfaces changes (Lovejoy et al., 1985), and suture closure (Meindl and Lovejoy, 1985). Given the large ranges for adult aging, individuals were placed into the categories of "young adult" (18 – 35 years), "middle adult" (35-50 years), and "old adult" (50 years and over) for purposes of interpreting isotopic data. In addition, due to age ranges given for non-adults, the midpoint of the age range was used for graphing purposes. Sex estimate for adult individuals were made following morphological assessment methods as outlined in Buikstra and Ubelaker (1994).

This sample consists of 15 perinates, 18 infants, 10 young children, 7 old children, 4 adolescents, 2 young adults, 9 middle adults, and 6 older adults. Of the 71 samples, there are 8 biological males and 11 biological females, leaving 52 individuals of indeterminate sex, all of

whom are non-adults (Figure 3). As can be seen in Figure 2, when samples removed from analysis due to poor preservation are taken into account, the numbers are reduced, consisting of 7 perinates, 13 infants, 7 young children, 7 old children, 4 adolescents, 2 young adults, 8 middle adults, and 6 old adults.

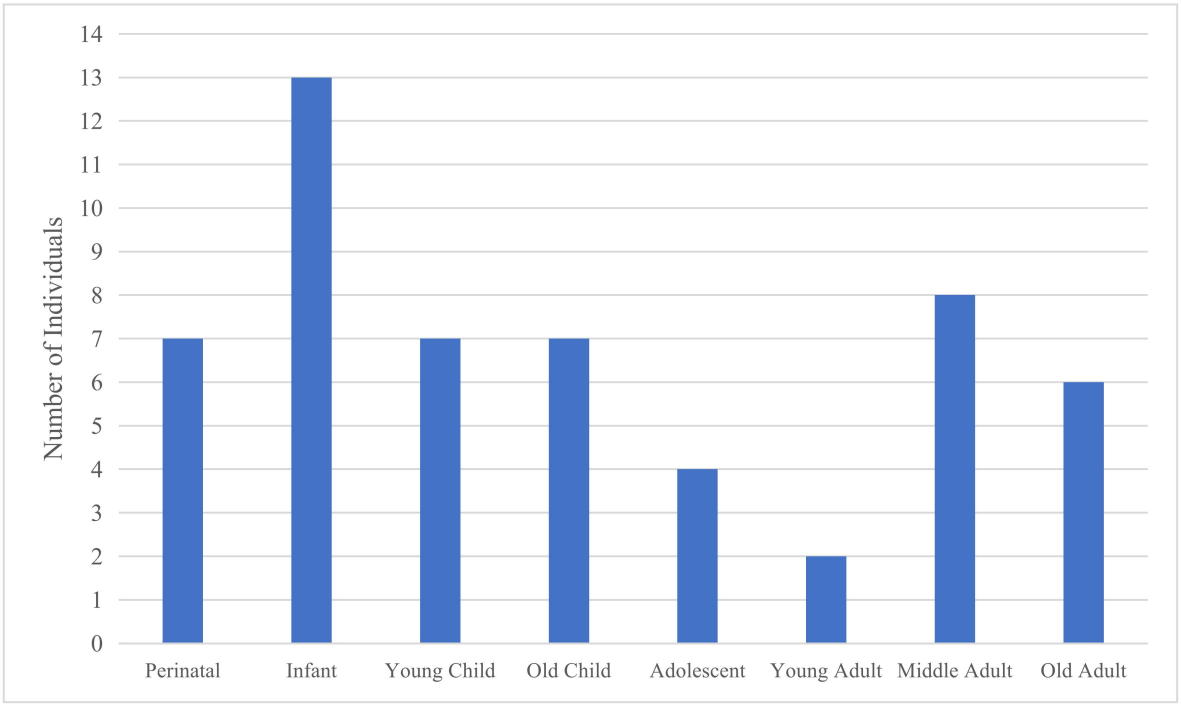

Figure 2. Graph showing the number of individuals in each age category after poorly preserved samples were removed.

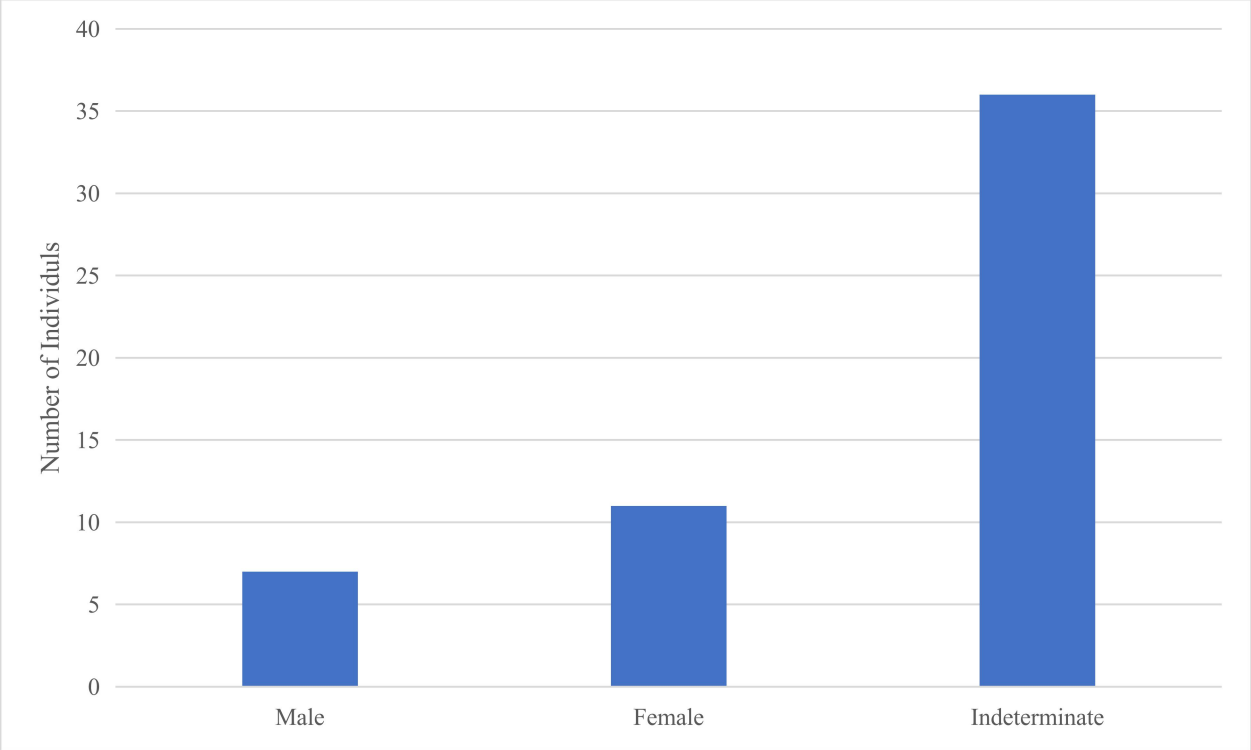

Figure 3. Graph showing the number of samples of each biological sex after poorly preserved samples were removed.

Table 2. Table showing the sample number, tomb number, individual number, sex, and age for all samples used in this study.

#	Site	Tomb	Individual #	Sex	Age
1	8.B.52.B	T-01	1	Female	Old adult
2	8.B.52.B	T-01	2	N/A	10-11 years
3	8.B.52.B	T-01	4	N/A	2-3 years
4	8.B.52.B	T-01	5	N/A	10-12 years
5	8.B.52.B	T-02	2	N/A	5 years
6	8.B.52.B	T-02	3	N/A	15 years
7	8.B.52.B	T-04	1	Female?	3 years
8	8.B.52.B	T-05	1	Male	Old adult
9	8.B.52.B	T-05	2	N/A	12-15 years
10	8.B.52.B	T-07	1	N/A	2.5 years
11	8.B.52.B	T-07	2	N/A	5 years
12	8.B.52.B	T-07	3	N/A	10 years
13	8.B.52.B	T-08	1	Female	Old adult
14	8.B.52.B	T-08	2	Male	Middle adult
15	8.B.52.B	T-08	3	Female	Middle adult
16	8.B.52.B	T-09	1	Male	Middle adult
17	8.B.52.B	T-09	4	Female	Middle adult
18	8.B.52.B	T-09	5	Female	Middle adult
19	8.B.52.B	T-09	7	N/A	1 month
20	8.B.52.B	T-09	8	N/A	7-8 years

#	Site	Tomb	Individual #	Sex	Age
21	8.B.52.B	T-09	9	N/A	1 year
22	8.B.52.B	T-09	10	N/A	1 month
23	8.B.52.B	T-09	11	N/A	40 weeks
24	8.B.52.B	T-10	1	N/A	6-7 years
25	8.B.52.B	T-10	2	N/A	4-5 years
26	8.B.52.B	T-10	3	N/A	1-3 months
27	8.B.52.B	T-11	1	N/A	9-11 years
28	8.B.52.B	T-11	5	Male	Middle adult
29	8.B.52.B	T-11	6	Female	Middle adult
30	8.B.52.B	T-11	16	N/A	40 weeks-1month
31	8.B.52.B	T-23	1	Female	Old adult
32	8.B.52.B	T-23	2	N/A	8-10 years
33	8.B.52.B	T-29	1	Male	Young adult
34	8.B.52.B	T-34	1	N/A	11-13 years
35	8.B.52.B	T-34	2	Male	Middle adult
36	8.B.52.B	T-34	3	Female	Old adult
37	8.B.52.B	T-34	4	Male	Young adult
38	8.B.52.B	T-35	1	Male	Middle adult
39	8.B.52.B	T-35	2	Female	Old adult
40	8.B.52.B	T-35	3	Female	16-17 years
41	8.B.52.B	T-35	4	N/A	12-13 years
42	8.B.52.B	Te-01	1	N/A	2-3 years
43	8.B.52.B	Te-01	2	N/A	1 month
44	8.B.52.B	Te-01	3	N/A	1 month
45	8.B.52.B	Te-01	4	N/A	1 month
46	8.B.52.B	Te-01	5	N/A	40 weeks
47	8.B.52.B	Te-01	6	N/A	1 year
48	8.B.52.B	Te-02	1	N/A	40 weeks
49	8.B.52.B	Te-03	1	N/A	1 year
50	8.B.52.B	Te-03	2	N/A	38-40 weeks
51	8.B.52.B	Te-04	1	N/A	40 weeks
52	8.B.52.B	Te-04	5	N/A	6 months
53	8.B.52.B	Te-04	6	N/A	40 weeks
54	8.B.52.B	Te-04	7	N/A	40 weeks
55	8.B.52.B	Te-04	8	N/A	40 weeks
56	8.B.52.B	Te-04	9	N/A	1 month
57	8.B.52.B	Te-04	10	N/A	40 weeks
58	8.B.52.B	Te-05	2	N/A	3 years
59	8.B.52.B	Te-07	1	N/A	3-6 months
60	8.B.52.B	Te-07	2	N/A	1 month
61	8.B.52.B	Te-07	3	N/A	40 weeks
62	8.B.52.B	Te-07	4	N/A	36 weeks
63	8.B.52.B	Te-08	1	N/A	1 month
64	8.B.52.B	Te-09	1	N/A	1 year

#	Site	Tomb	Individual #	Sex	Age
65	8.B.52.B	Te-09	2	N/A	38-40 weeks
66	8.B.52.B	Te-09	3	N/A	40 weeks
67	8.B.52.B	Te-09	4	N/A	40 weeks
68	8.B.52.B	Te-10	1	N/A	9 months
69	8.B.52.B	Te-12	1	N/A	3-4 years
70	8.B.52.B	Te-13	1	N/A	40 weeks
71	8.B.52.B	Te-14	1	N/A	1 year

Stable carbon and nitrogen isotopic analyses were conducted on the bone collagen of the skeletal samples, with the initial processing being completed at the University of Central Florida Laboratory for Bioarchaeological Sciences and the final mass spectrometry being conducted at the University of Florida's Department of Geological Sciences in Gainesville, Florida. The isotopic data will be used in conjunction with previously published literature on Meroitic period Sudan and stable isotope analysis of bone collagen to complete the research.

Methodology

This research was carried out using the bone collagen extraction protocol from UCF Bioarchaeology Lab Stable Isotope Tech Memo #01-02 (2012), adapted from Longin (1971). This protocol outlines the steps required to demineralize archaeological human bone, remove any humic and/or fulvic acids, and extract the collagen so it may be used in stable isotope analysis of carbon and nitrogen.

The first step in the process was to clean the bones using distilled water and an ultra-sonication device, which uses sonic vibrations to remove any adhered dirt, tissue, and/or other materials from the surface of the bone. The samples were placed in labeled beakers filled with enough distilled water to cover the bone and cleaned in ten-minute intervals. Between each cleaning, the water was replaced until it ran clear at the end of the next ten-minute cycle. Once clean, the samples were placed in a 60°C oven to dry overnight. Once dry, the bone samples

were further broken up into 1.0-2.0g samples, which were ground down using a mortar and pestle to fragments roughly 2-5mm in size. The fragments were made as uniform as possible—minimizing fine powder—in order to prevent uneven rates of demineralization. Once at a desirable size, the ground-up sample was placed into a labeled 50mL vial.

The next step in the collagen extraction process was the removal of lipids from the samples using 2:1 chloroform:methanol. Under the fume hood, approximately 10mL of the chloroform methanol solution was added to each vial and allowed to sit for 20 minutes. After this 20-minute period, if lipids were present in the sample there was a slight yellow color change and/or a floating or foggy substance in the liquid. The samples were then centrifuged at 2400rpm for 10 minutes, the liquid was decanted using a pipette, and the process was repeated two more times, or until no color change is apparent. After decanting the samples for the third time, the samples were left uncapped to dry overnight in the fume hood.

Once dry, the samples could undergo the demineralization process, which involves dissolving the inorganic portion of the bone in hydrochloric acid. Based on the young age of the individuals in the sample, 0.25M HCl was used for this process, though 0.5M HCl could have been used to speed up the process, if necessary. To begin, approximately 10mL of 0.25M was added to the vials, then the vials were agitated using the vortex machine. The vials were left for roughly 24 hours at room temperature, then the pH was tested. If the pH was above 2.0, the samples were centrifuged at 2400rpm for 10 minutes, and the liquid was decanted using a pipette. If the pH was below a 2.0, the samples were left until the appropriate pH was achieved. Once the liquid was removed, the samples' state of demineralization was checked using a glass rod by pressing the bone fragments against the vial. If all of the fragments were gelatinous, the sample was completely demineralized and could move on to the next step. If any fragments remained

that were still solid and resist squishing, new acid was added, and the process was repeated until full demineralization was achieved.

When the samples were completely demineralized, the next step was to rinse all of the hydrochloric acid from the vials. To do this, 10mL of distilled water was added to each vial, the samples were centrifuged at 2400rpm for 10 minutes, and the water was decanted using a pipette. This process was repeated two more times for a total of three rinses. After the third rinse, the pH of the samples was checked using pH strips and should have been between 2.5 and 3.0; if this pH was not obtained after three rinses, the rinsing process was continued until proper pH was achieved.

The next step in the process was to remove any humic acids, or contaminants found in soils, that may have been present in the sample, as they could have affected the integrity and isotopic composition of the sample. These acids are common in archaeological samples that have been exposed to burial environments for long periods of time and were removed using 0.1M NaOH, as the acids are base-soluble. Once any remaining rinse water was decanted, approximately 10mL of 0.1M NaOH was added to the vials and left to sit for 20 minutes. After 20 minutes, the samples were centrifuged at 2400rpm for 10 minutes, then observed for any visible color change. If the samples were clear, there was no humic acids present, and they could move on to the next step. If a color change was apparent, the liquid was decanted using a pipette, 10mL of fresh 0.1 M NaOH was added, and the samples were left to sit for another 20 minutes. The process was repeated until no color change was observed.

Once all samples showed no color change, the liquid was decanted with a pipette and the samples were rinsed 6 times with distilled water, centrifuging and decanting between each rinse, to remove all of the NaOH solution. After the 6^{th} rinse, the pH of each sample was tested using

pH strips and should have been between 6.0 and 8.0. If the pH of any sample was not in this range, some NaOH could still be present; this could have caused a salt to form in the sample resulting in a very sticky collagen extract. In this case, the samples continued to be rinsed with distilled water until the proper pH was obtained. When the pH of each sample was between 6.0 and 8.0, any remaining rinse water was decanted using a pipette.

The next step was to make the extracted collagen water-soluble using a weak hydrochloric acid so that it could gelatinize properly. Approximately 10mL of 0.25M HCl was added to each vial, centrifuged at 2400rpm for 10 minutes, and decanted using a pipette. After this, approximately 5mL of distilled water was added to each vial and the pH was checked using pH strips. The pH should have been between 2.5 and 3.0; if this was not the case, a buffer solution was added to each sample to obtain the proper pH. Once the suggested pH was reached, the vials were loosely-capped and placed into a 90°C oven for 16-24 hours to solubilize the collagen.

After the 16-24 hour period, the samples were removed from the oven, centrifuged at 2400rpm for 10 minutes, and the collagen solution was pipetted into weighed and labeled glass dram vials, avoiding any residue at the bottom of the 50ml vials. The dram vials were left uncapped and placed into the 90°C oven until they were completely dried, which took roughly 24-36 hours. Once the samples were completely dried, they were removed from the oven and weighed. This final weight allowed for the collagen yield to be calculated using the following formula:

$$\%\ collagen\ yield = \left(\frac{vial\ with\ collagen\ (g) - vial\ without\ collagen\ (g)}{sample\ dry\ weight\ (g)}\ \text{x}\ 100\right)$$

Once all calculations were completed and recorded, approximately 5mg of the collagen was weighed into 2ml vials to be sent to the Department of Geological Sciences at the University of Florida, Gainesville, for analysis via an isotope ratio mass spectrometer.

Mass Spectrometry

Within the field of bioarchaeology and within studies of light stable isotopes, the main goal of mass spectrometry (MS) is to precisely measure the mass of a sample and the masses of its component parts (Pollard et al., 2007). Because mass spectrometers are able to count individual ions, they present the most precise and most sensitive method for analyzing organic materials. As a technique, MS is based on the principle that electrically charged particles moving through a magnetic field can be controlled via their atomic masses; therefore, charged particles in a magnetic field can be separated and counted based on their atomic masses (Pollard et al., 2007). In order to do this, mass spectrometers have three main parts: an ion source, a magnetic deflection system, and an ion collector (Pollard et al., 2007). The ion source for light isotope mass spectrometers is generally an electron impact (EI) source consisting of a metal chamber through which the gaseous sample can flow. The chamber has a low-voltage heated filament which ionizes the sample via electron bombardment and, as it flows, a positively charged plate serves to focus and accelerate the now-ionized sample into a beam which is aimed into the magnetic deflection system (Pollard et al., 2007)

Once the ion beam has reached the mass analyzer, or magnetic deflection system, the ions are separated based on their individual atomic masses. This occurs due to the magnetic field created by two poles in the mass analyzer which allows each individual particle to follow its own path based on its mass and velocity. By manipulating the strength and voltage of the magnetic

poles, ions of specific masses can be manipulated into and captured by the ion detector(s) (Pollard et al., 2007). The ion detector varies from machine to machine and may include more than one individual detector, but generally acts to detect the voltage of the ion beam. The magnitude of the ion beam is directly proportional to the number of individual ions received by the detector, and this information provides a precise measurement of the abundance of different isotopes present in a sample (Pollard et al., 2007). Isotope ratio mass spectrometers (IRMS), those generally used to detect the ratios of light stable isotopes, tend to have two or three ion detectors for multiple isotopes of an element (Pollard et al., 2007).

Statistical Analysis

All statistical analyses were conducted using Microsoft Excel and SPSS software. All descriptive statistics—including the mean, standard deviation, and range of the entire sample as well as each age and biological sex cohort—were calculated in Microsoft Excel. In addition, all graphs, charts, and tables were created using Microsoft Excel. To determine if the differences between age cohorts, as well as differences between elite cemeteries, were significant, Mann-Whitney U statistical analyses were conducted in SPSS. The Mann-Whitney U test is a non-parametric statistical test that works well with small, independent samples. Once the differences in mean were calculated for each age cohort, the subsequently yielded p-values were determined to be significant at the level of $p < 0.05$. Results of all statistical analyses will be discussed further in the next chapter.

CHAPTER FOUR: RESULTS

The focus of this chapter centers on the isotopic results, including a discussion of the accuracy and precision of the analytic process, a discussion of the preservation of the samples, an examination of the isotopic data including general trends for the overall sample and each demographic group, and the presentation of the relevant statistical analyses conducted on these data. All isotope data presented are supported visually through graphs and tables and will coincide with the pertinent research questions on which this research is focused.

Accuracy and Precision

The samples for this research were analyzed at the University of Florida's Department of Geological Sciences in Gainesville, FL in three different batches. For this reason, the information on the precision of the mass spectrometer will be presented as three separate values. In order to calculate precision, two standards—USGS1 and USGS2—were analyzed with the mass spectrometer multiple times in each batch, and the standard deviation of each standard's isotopic values is presented as the instrument's precision. Batch one had precision values of ± 0.18 (n=6) for $\delta^{15}N$ and ± 0.08 (n=7) for $\delta^{13}C$, batch two had precision values of ± 0.05 (n=5) for $\delta^{15}N$ and ± 0.08 (n=6) for $\delta^{13}C$, and batch three had precision values of ± 0.09 (n=7) for $\delta^{15}N$ and ± 0.08 (n=7) for $\delta^{13}C$. In addition to assessing precision, seven samples were analyzed twice to assess the accuracy of the results. The difference between the $\delta^{15}N$ and $\delta^{13}C$ values for each duplicate sample were averaged to obtain a value for the accuracy of the results, which can be seen in Table 3. The average of the accuracy values was 0.05 for $\delta^{15}N$ and –0.03 for $\delta^{13}C$. These low values suggest the isotopic data presented in this study are both precise and accurate.

Table 3. Table showing the duplicated samples and their relative $\delta^{15}N$ and $\delta^{13}C$ differences used to test the accuracy of the measurements.

Sample ID	$\delta^{15}N$ Value 1 (‰)	$\delta^{15}N$ Value 2 (‰)	Difference in $\delta^{15}N$ (‰)	$\delta^{13}C$ Value 1 (‰)	$\delta^{13}C$ Value 2 (‰)	Difference in $\delta^{13}C$ (‰)
T-02 IND 3	11.53	11.58	0.05	–18.59	–18.57	–0.02
T-07 IND 2	12.56	12.54	0.02	–16.87	–16.84	–0.03
T-09 IND 4	12.05	12.02	0.03	–16.77	–16.70	–0.07
T-34 IND 1	11.41	11.53	0.12	–18.38	–18.42	–0.04
T-34 IND 4	12.33	12.28	0.05	–18.04	–18.01	–0.03
Te-05 IND 2	11.07	11.08	0.01	–17.00	–17.05	–0.05
Te-12 IND 1	12.55	12.60	0.05	–13.47	–13.47	–0.00
Accuracy	-------	-------	**0.05**	--------	--------	**–0.03**

Sample Preservation

In order for the results of stable isotopic studies to be valid, an assumption must be made that the bone collagen being analyzed has not been affected by any taphonomic factors in the postmortem environment and/or any diagenetic effects. This is not always the case, as bone collagen is susceptible to degradation under certain conditions (DeNiro, 1985). At site 8-B-52.B, because young non-adults were usually buried in the walls of pyramids or in shallow graves near the surface, these individuals were highly susceptible to environmental diagenetic effects. Frequent looting of the site also led to the exposure of remains on the surface and the subsequent degradation of the remains. For this reason, the preservation of the bone collagen in this study was carefully considered based on three main criteria: percent collagen yield, the atomic C:N ratio, and the percent weight of both carbon and nitrogen (Ambrose, 1990; DeNiro, 1985). Table 4 shows the values obtained for each of the three preservation factors for each sample, and Table 5 shows the sample-wide average values for each measure of preservation. Each sample was assessed based on these factors, and the results will be discussed below.

The first measure of the preservation of a sample to consider is the percent collage yield, which is calculated via the following formula:

$$\%\ collagen\ yield = \frac{Collagen\ weight\ (g)}{Sample\ dry\ weight\ (g)} x\ 100$$

This equation provides a measure of the amount of the original collagen still present in the bone after the collagen extraction process. Fresh bone has a collagen percentage ranging from 20% to 25% of the total bone weight, but diagenetic and/or taphonomic effects over time will result in the degradation of a percentage of the original collagen (DeNiro 1985; White et al., 2012). Researchers have conducted a number of studies testing the minimum percent collagen necessary for the resulting isotopic values to be considered valid. Some studies suggest collagen yields as high as 5%-6% are necessary to avoid the effects of diagenesis on the isotopic values (Schoeninger and DeNiro, 1982; Tuross et al., 1988), while other suggest values as low as 1% could yield acceptable isotopic values (White and Schwarcz, 1989; White et al., 1993). For this study, the value of 2% suggested by DeNiro and Weiner (1988) will be used as the value considered necessary to provide reliable results. Twenty of the 71 initial samples yielded below 2% collagen. However, this number is not wholly accurate, as the collagen yields for eight samples were unable to be calculated due to a human error in the process of weighing the vials before the collagen was put in. This is denoted in Table 4 by 'error'.

Table 4. Table showing the preservation measures for each sample analyzed. Samples highlighted in yellow were removed due to poor preservation.

Sample ID	% Collagen	$\delta^{15}N_{AIR}$ (‰)	$\delta^{13}C_{VPBD}$ (‰)	Wt % N	Wt % C	Wt ratio C:N	Atomic ratio C:N
T-01 IND 1	3.8	13.9	–17.7	13.1	40.7	3.1	3.6
T-01 IND 2	0.6	11.2	–19.0	9.9	37.9	3.8	4.5
T-01 IND 4	0.6	12.8	–20.0	6.2	31.0	5.0	5.8
T-01 IND 5	2.4	11.0	–17.5	13.5	42.2	3.1	3.6
T-02 IND 2	Error	10.9	–13.9	14.5	40.7	2.8	3.3
T-02 IND 3	17.2	11.5	–18.6	15.9	44.8	2.8	3.3
T-04 IND 1	3.5	14.7	–12.7	14.6	43.9	3.0	3.5
T-05 IND 1	14.6	12.2	–15.2	15.7	44.8	2.9	3.3
T-05 IND 2	13.9	11.3	–15.9	15.0	43.6	2.9	3.4
T-07 IND 1	2.0	12.8	–17.5	12.8	42.2	3.3	3.9
T-07 IND 2	12.5	12.6	–16.9	15.8	43.3	2.7	3.2
T-07 IND 3	Error	12.6	–16.7	15.6	42.6	2.7	3.2
T-08 IND 1	Error	10.8	–15.5	6.4	18.5	2.9	3.4
T-08 IND 2	1.9	13.4	–21.0	8.4	39.5	4.7	5.5
T-08 IND 3	9.3	10.0	–17.3	14.2	38.9	2.8	3.2
T-09 IND 1	9.2	12.8	–16.6	14.7	43.7	4.0	3.5
T-09 IND 4	12.5	12.1	–16.8	15.3	43.5	2.8	3.3
T-09 IND 5	6.7	11.1	–18.5	14.6	43.7	3.0	3.5
T-09 IND 7	1.3	13.8	–16.4	7.2	28.1	3.9	4.6
T-09 IND 8	12.9	11.6	–17.7	15.8	43.7	2.8	3.2
T-09 IND 9	4.6	12.9	–15.9	13.7	38.3	2.8	3.3
T-09 IND 10	0.7	13.5	–18.2	9.7	33.4	3.5	4.0
T-09 IND 11	0.8	14.6	–18.1	8.1	31.2	3.9	4.5
T-10 IND 1	6.1	11.5	–18.6	13.2	39.7	3.0	3.5
T-10 IND 2	2.5	11.7	–17.4	10.9	20.5	2.8	3.3
T-10 IND3	3.1	12.4	–18.6	10.0	28.3	2.8	3.3
T-11 IND 1	4.6	12.3	–13.5	13.0	37.1	2.8	3.3
T-11 IND 5	14.3	11.6	–16.7	16.6	46.3	2.8	3.3
T-11 IND 6	Error	11.2	–16.9	14.9	42.0	2.8	3.3
T-11 IND 16	2.9	13.4	–17.1	11.3	33.1	2.9	3.4
T-23 IND 1	13.6	11.8	–16.3	14.7	40.9	2.8	3.3
T-23 IND 2	5.6	11.9	–17.2	14.2	39.6	2.8	3.3
T-29 IND 1	Error	10.7	–15.6	14.6	40.2	2.8	3.2
T-34 IND 1	16.8	11.4	–18.4	16.7	34.4	2.8	3.2
T-34 IND 2	4.2	13.2	–15.8	15.0	43.5	2.9	3.4
T-34 IND 3	19.1	11.1	–15.9	15.4	42.8	2.8	3.2
T-34 IND 4	15.6	12.3	–18.0	16.0	46.3	2.9	3.4
T-35 IND 1	12.5	10.1	–17.2	16.4	46.6	2.8	3.3

Sample ID	% Collagen	$\delta^{15}N_{AIR}$ (‰)	$\delta^{13}C_{VPBD}$ (‰)	Wt % N	Wt % C	Wt ratio C:N	Atomic ratio C:N
T-35 IND 2	3.3	10.9	–17.8	13.3	37.5	2.8	3.3
T-35 IND 3	8.4	11.4	–15.8	14.6	41.1	2.8	3.3
T-35 IND 4	Error	11.2	–17.1	14.1	39.7	2.8	3.3
Te-01 IND 1	0.6	12.1	–17.6	11.5	33.4	2.9	3.4
Te-01 IND 2	Error	Not Analyzed					
Te-01 IND 3	1.8	13.2	–17.0	11.5	32.8	2.9	3.3
Te-01 IND 4	1.5	14.0	–15.5	13.0	36.6	2.8	3.3
Te-01 IND 5	2.5	13.1	–17.7	11.0	33.8	3.1	3.6
Te-01 IND 6	9.4	15.0	–11.4	16.7	35.9	2.8	3.2
Te-02 IND 1	2.0	13.4	–15.1	11.5	33.2	2.9	3.4
Te-03 IND 1	11.3	14.9	–11.4	15.3	42.9	2.8	3.3
Te-03 IND 2	2.1	12.9	–16.7	12.3	35.4	2.9	3.4
Te-04 IND 1	1.7	13.0	–17.8	12.6	38.2	3.0	3.5
Te-04 IND 5	12.9	15.5	–9.8	15.7	44.4	2.8	3.3
Te-04 IND 6	Error	12.5	–17.5	7.5	29.7	4.0	4.6
Te-04 IND 7	1.3	12.9	–14.6	11.9	38.6	3.3	3.8
Te-04 IND 8	3.0	12.7	–18.1	9.1	26.0	2.9	3.3
Te-04 IND 9	2.5	12.7	–15.1	12.7	37.9	3.0	3.5
Te-04 IND 10	0.6	13.2	–20.2	9.4	40.5	4.3	5.1
Te-05 IND 2	12.1	11.1	–17.0	16.0	45.3	2.8	3.3
Te-07 IND 1	1.43	14.7	–12.5	12.6	25.6	2.8	3.3
Te-07 IND 2	2.1	13.4	–13.9	9.4	26.9	2.9	3.4
Te-07 IND 3	2.2	11.6	–12.5	12.5	40.1	3.2	3.7
Te-07 IND 4	3.9	13.5	–17.3	11.3	34.6	3.1	3.6
Te-08 IND 1	4.4	11.6	–15.9	12.4	40.5	3.3	3.8
Te-09 IND 1	0.00	Not Analyzed					
Te-09 IND 2	0.5	12.5	–16.1	12.1	34.9	2.9	3.4
Te-09 IND 3	0.9	14.3	–17.8	9.5	31.6	3.4	3.9
Te-09 IND 4	0.2	Not Analyzed					
Te-10 IND 1	1.3	14.2	–12.1	11.9	33.8	2.9	3.3
Te-12 IND 1	12.6	12.6	–13.5	14.6	40.3	2.8	3.2
Te-13 IND 1	0.6	14.0	–16.1	6.2	26.0	4.2	4.9
Te-14 IND 1	2.1	14.2	–13.8	14.1	39.9	2.8	3.3

Percent collagen yield alone, however, is not a sufficient measure of sample preservation. After analysis of the samples via the mass spectrometer, two additional measures of the sample's preservation must be assessed. The first is the concentration (%) of carbon and nitrogen in the

sample. Ambrose (1990) determined that in order to be of sufficient quality, bone should contain between 15% and 47% carbon and between 5% and 17% nitrogen. These values for the current samples can be found in Tables 4 and 5. All 68 analyzed samples fit these standards, as can be seen in Figures 5 and 6.

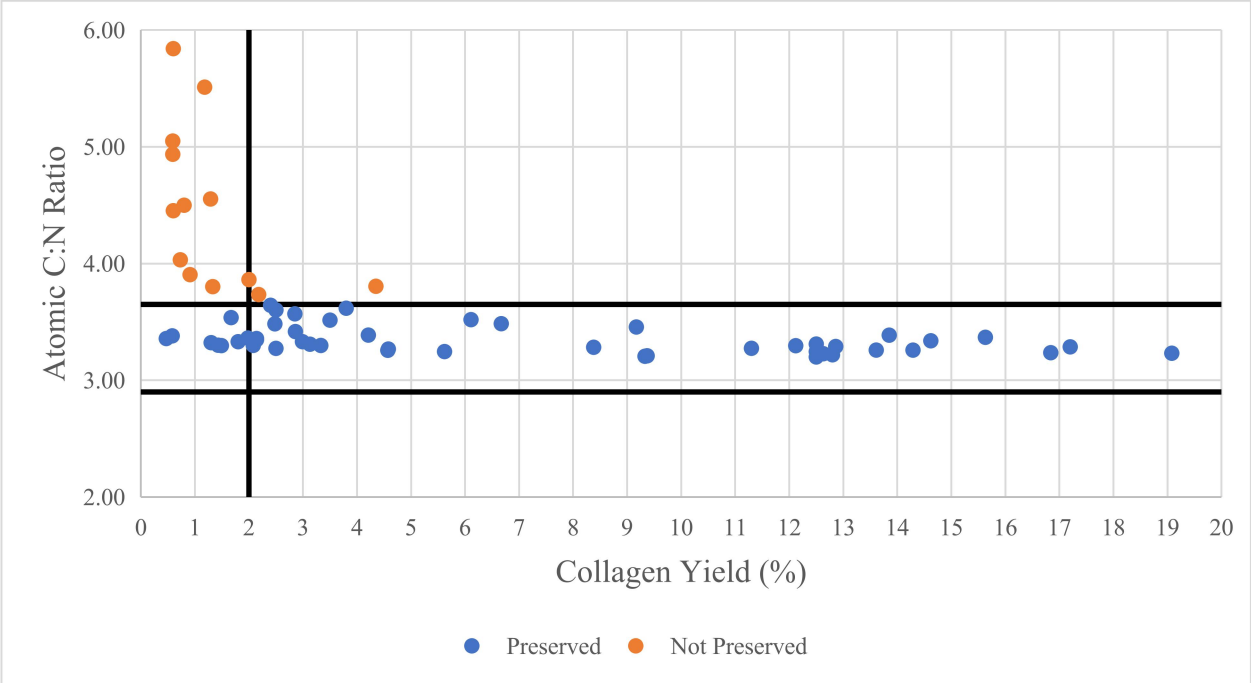

Figure 4. Graph plotting collagen yield against the atomic C:N ratio of each sample. The vertical line represents the 2% collagen yield threshold for preservation, and the two horizontal lines represent the atomic C:N ratio cutoff points for preservation.

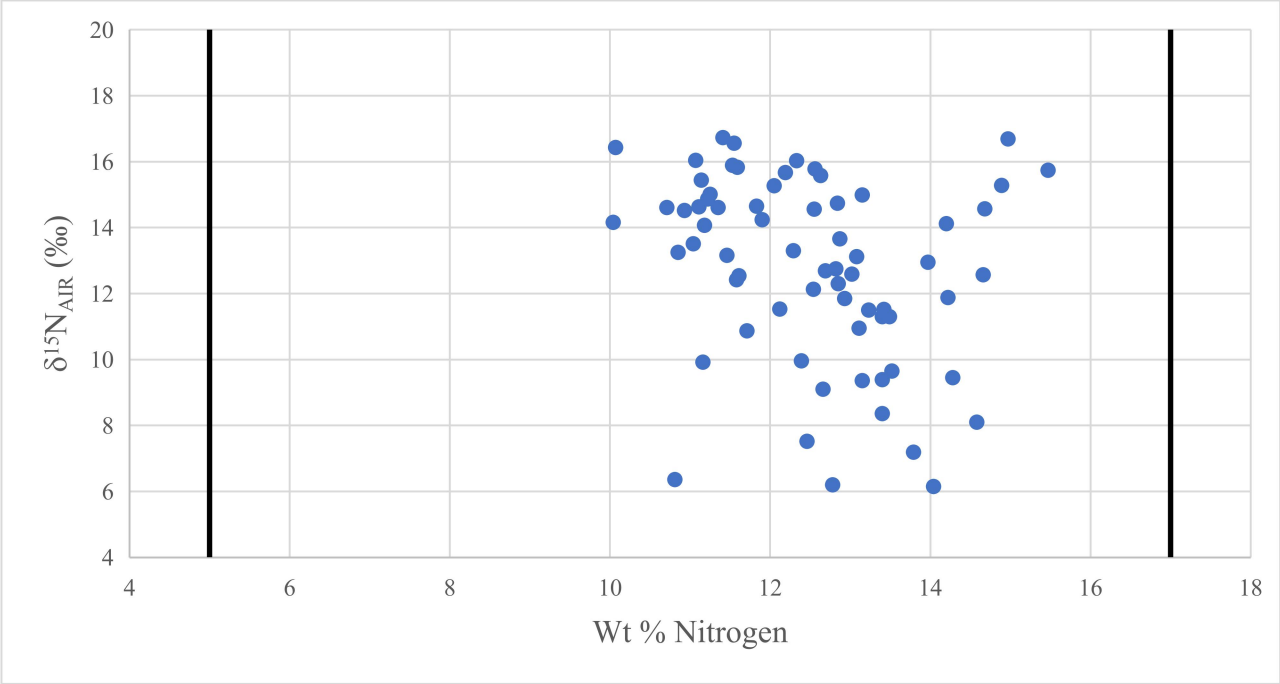

Figure 5. Graph plotting wt % N versus $\delta^{15}N$. Vertical lines represent preservation cutoffs for wt % N.

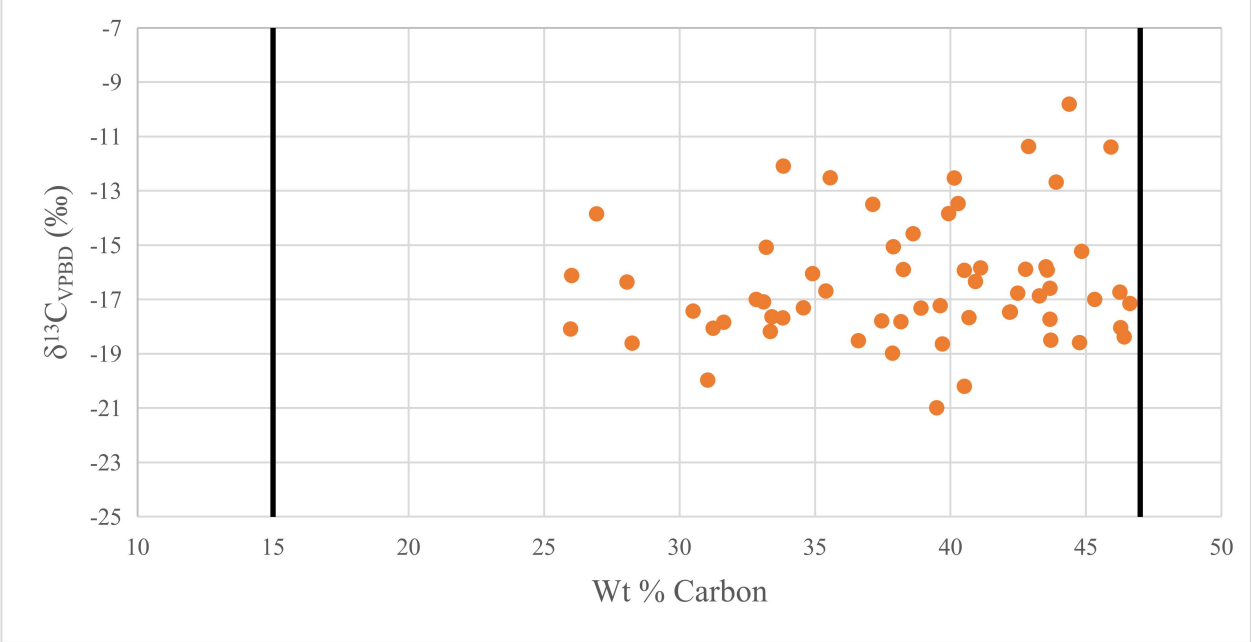

Figure 6. Graph plotting wt % C versus $\delta^{13}C$. Vertical lines represent preservation cut offs for wt % C.

The final measure of preservation assessed is the atomic ratio of carbon to nitrogen, which is calculated by taking the weight percent carbon to nitrogen ratio given by the mass spectrometer and plugging it into the following formula:

$$Atomic\ C{:}N\ ratio = \frac{14}{12}\ (weight\ \%\ C{:}N)$$

Because the sample preservation standards for atomic C:N ratios described by DeNiro (1985) were based on older mass spectrometry technology, the values given by modern mass spectrometers must be transformed by a factor of $\frac{14}{12}$ in order for the values to be assessed in a meaningful manner (Katzenberg, 2008). DeNiro (1985) determined that well-preserved archaeological bone should yield atomic C:N ratios between 2.9 and 3.6. The values for the samples in this study can be seen in Tables 4 and 5. Fourteen of the 68 samples analyzed had an atomic C:N ratio outside the acceptable range and were removed from further analysis. The atomic C:N ratios for all samples are visualized in Figure 4 as a function of percent collagen yield; samples that were determined to be well-preserved are in blue, while samples removed from further analysis based on their respective atomic C:N ratios are in orange.

Table 5. Table summarizing the sample-wide preservation statistics broken down by total number of samples analyzed and preserved samples.

	Collagen Yield (%)	Wt %N	Wt %C	Atomic C:N Ratio
All Analyzed Samples (n=68)	5.9 ± 5.4 (n=61)	12.8 ± 2.8	38.2 ± 5.0	3.6 ± 0.6
All Preserved Samples (n=54)	7.1 ± 5.5 (n=48)	13.7 ± 2.2	39.06 ± 5.9	3.3 ± 0.1

Examination of Isotopic Values

Stable isotopic analyses of carbon and nitrogen were conducted on a total of 68 bone samples. After assessing the preservation of these samples via analysis of percent collagen yield, weight percent carbon and nitrogen, and the atomic carbon to nitrogen ratio, a total of 54 samples remained viable for further analysis and interpretation—16 adults and 38 non-adults. The purpose of this analysis is to determine the diet and weaning patterns of the non-adults in this sample, and the adult values will be used as a comparative baseline. It's important to note that while the adult male values are used in the direct comparison of all adults to all non-adults, all other non-adult comparisons will be made to the adult female mean. A number of childhood diet and weaning studies (i.e. Dupras et al., 2001; Bourbou et al., 2019; Stantis et al., 2019) have used the adult female mean as a comparative baseline for non-adult weaning, as weaning is a physiological process which occurs between a non-adult and its mother. The stable carbon and nitrogen isotope values of each age group and their means and standard deviations, as well as their relative similarities and differences, will be discussed here.

Carbon and Nitrogen

To begin the analysis, the $\delta^{15}N$ and $\delta^{13}C$ values were organized in terms of the age cohorts previously described. Descriptive statistics were calculated for each group (Tables 6 and 7) and the data were graphed to reveal any underlying patterns or trends. The mean $\delta^{15}N$ and $\delta^{13}C$ values for all samples were 12.40 ± 1.29‰ and –16.10 ± 2.09‰, respectively. These values are plotted in Figure 7. When compared to the adult male and female values, the $\delta^{15}N$ and $\delta^{13}C$ values of the non-adults had higher ranges and standard deviations, as can be seen in Figures 8 and 9. The non-adult ranges for $\delta^{15}N$ and $\delta^{13}C$ are 10.9-15.5‰ and –18.6 - –9.8‰, while the

adult ranges are 10.0-13.2‰ and -18.5 - –15.2‰, respectively. To visually compare the $\delta^{15}N$ and $\delta^{13}C$ values of the non-adult samples to the adults, the non-adult values were plotted against the adult female mean in Figures 10, 11, and 12. In Figure 10, the adult female mean is presented as a red cross, while in Figures 11 and 12 the adult female mean is represented by a dashed line with the respective standard deviations represented by solid lines.

Table 6. Descriptive statistics for $\delta^{13}C$ for each age category.

CARBON					
Age Category	**Mean (‰)**	**Standard Deviation (‰)**	**Range (‰)**	**Minimum (‰)**	**Maximum (‰)**
All Samples	-16.1	2.09	8.8	-18.6	-9.8
All Adults	-16.7	0.97	3.3	-18.5	-15.2
Young Adults	-16.8	1.70	2.4	-18.0	-15.6
Middle Adults	-16.9	0.77	2.7	-18.5	-15.8
Old Adults	-16.4	1.10	2.6	-17.8	-15.2
Male Adults	-16.5	0.98	2.8	-18.0	-15.2
Female Adults	-16.9	0.97	3.0	-18.5	-15.5
All Non-Adults	-15.8	2.38	8.8	-18.6	-9.8
Perinatals	-16.9	1.09	3.0	-18.1	-15.1
Infants	-14.4	2.89	8.8	-18.6	-9.8
Young Children	-15.6	2.12	4.9	-17.6	-12.7
Old Children	-17.1	1.72	5.1	-18.6	-13.5
Adolescents	-16.9	1.29	2.8	-18.6	-15.8

Table 7. Descriptive statistics for $\delta^{15}N$ for each age category.

NITROGEN					
Age Category	**Mean (‰)**	**Standard Deviation (‰)**	**Range (‰)**	**Minimum (‰)**	**Maximum (‰)**
All Samples	12.4	1.29	5.5	10.0	15.5
All Adults	11.6	0.99	3.2	10.0	13.2
Young Adults	11.5	1.15	1.6	10.7	12.3
Middle Adults	11.5	1.15	3.2	10.0	13.2
Old Adults	11.7	0.89	2.3	10.8	13.1
Male Adults	11.8	1.12	3.1	10.1	13.2
Female Adults	11.4	0.87	3.1	10.0	13.1
All Non-Adults	12.8	1.24	4.6	10.9	15.5
Perinatals	13.0	0.36	1.0	12.5	13.5
Infants	13.9	0.96	3.1	12.4	15.5
Young Children	12.2	1.26	3.8	10.9	14.7
Old Children	11.8	0.55	1.6	11.0	12.6
Adolescents	11.3	0.15	0.4	11.2	11.5

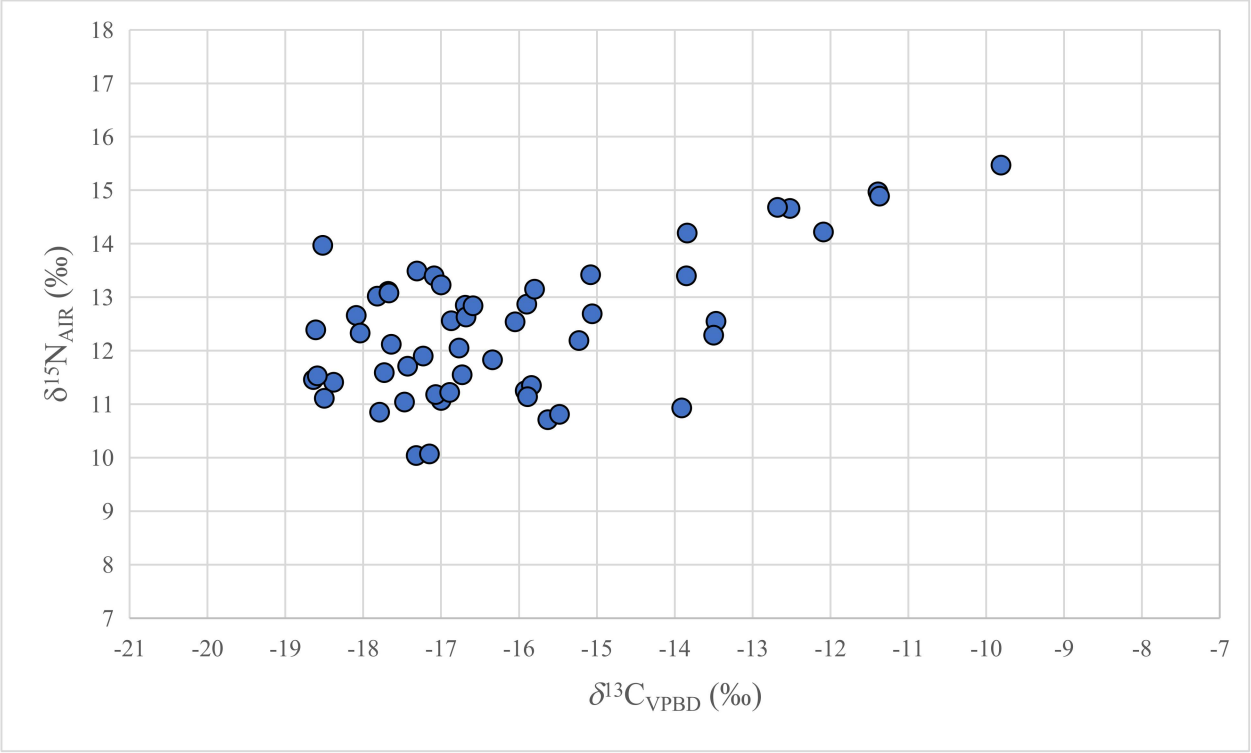

Figure 7. Graph plotting $\delta^{13}C$ versus $\delta^{15}N$ for all samples.

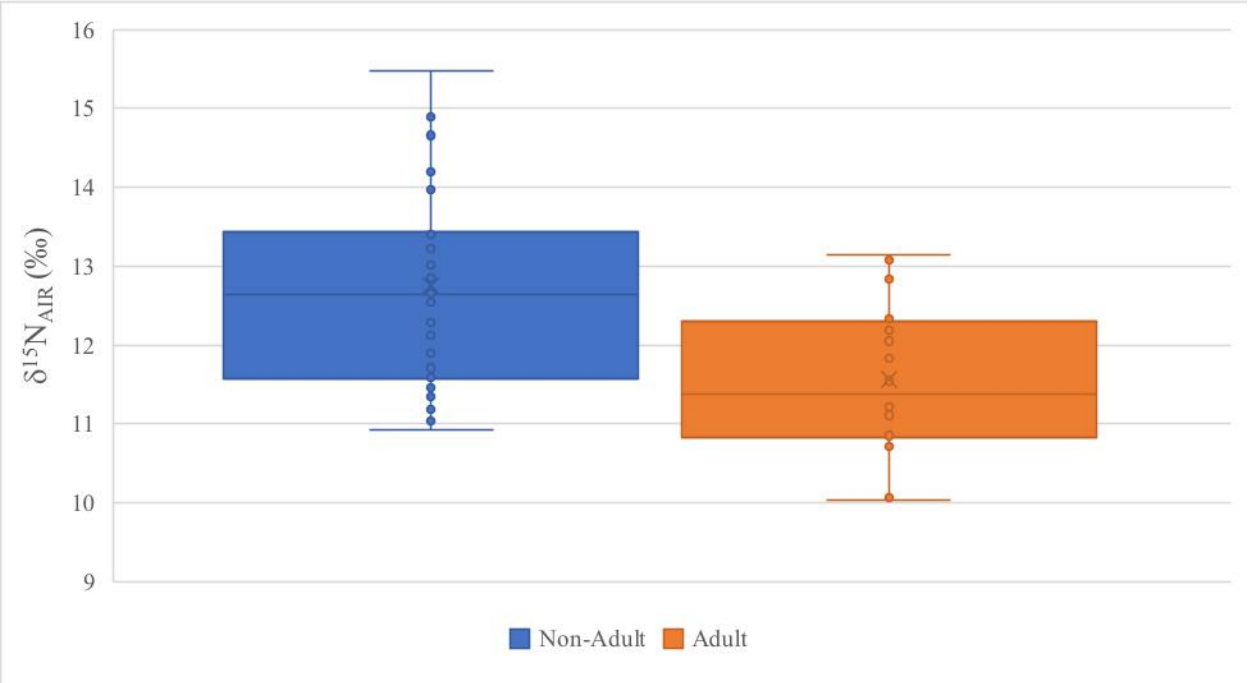

Figure 8. Box and whisker plot comparing the $\delta^{15}N$ values of the non-adults and the adults

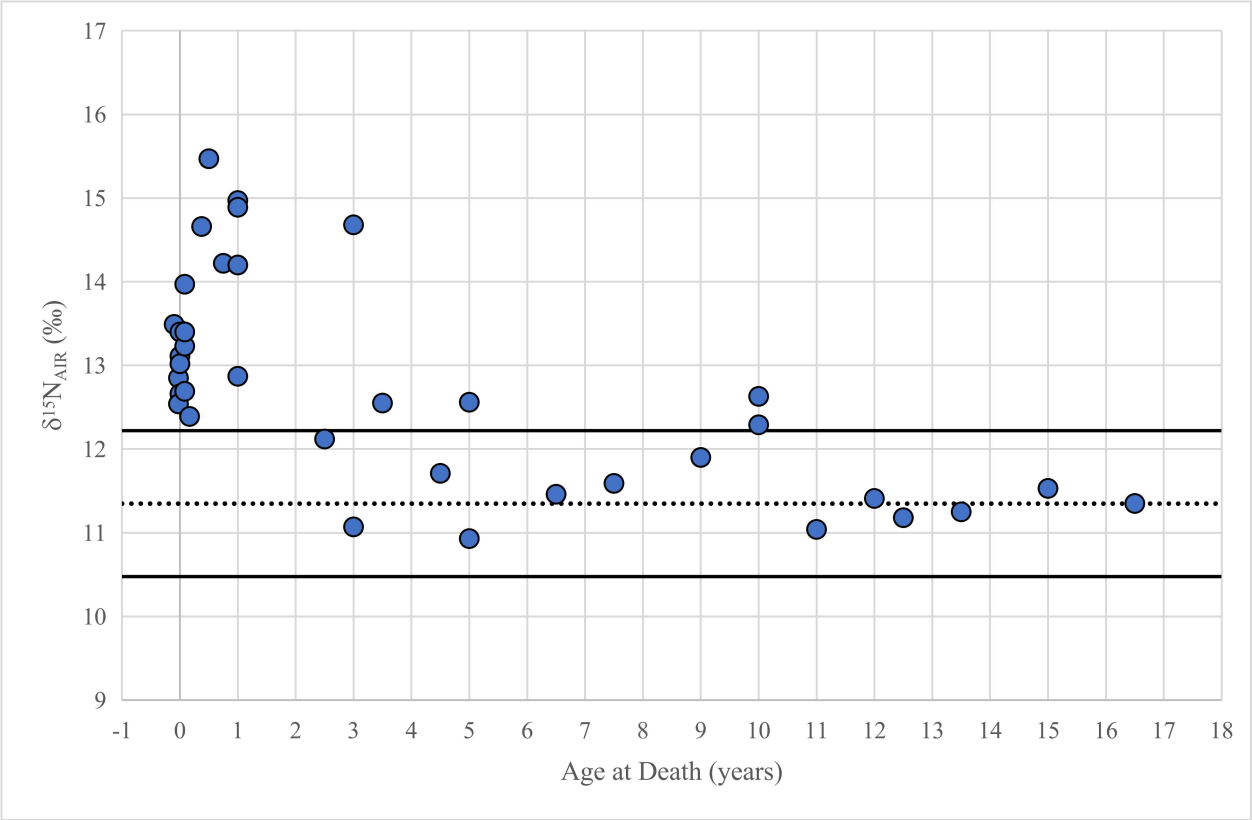

Figure 9. Graph plotting $\delta^{15}N$ versus age at death for all non-adult individuals. Dashed line represents adult female mean, and solid lines represent the standard deviations.

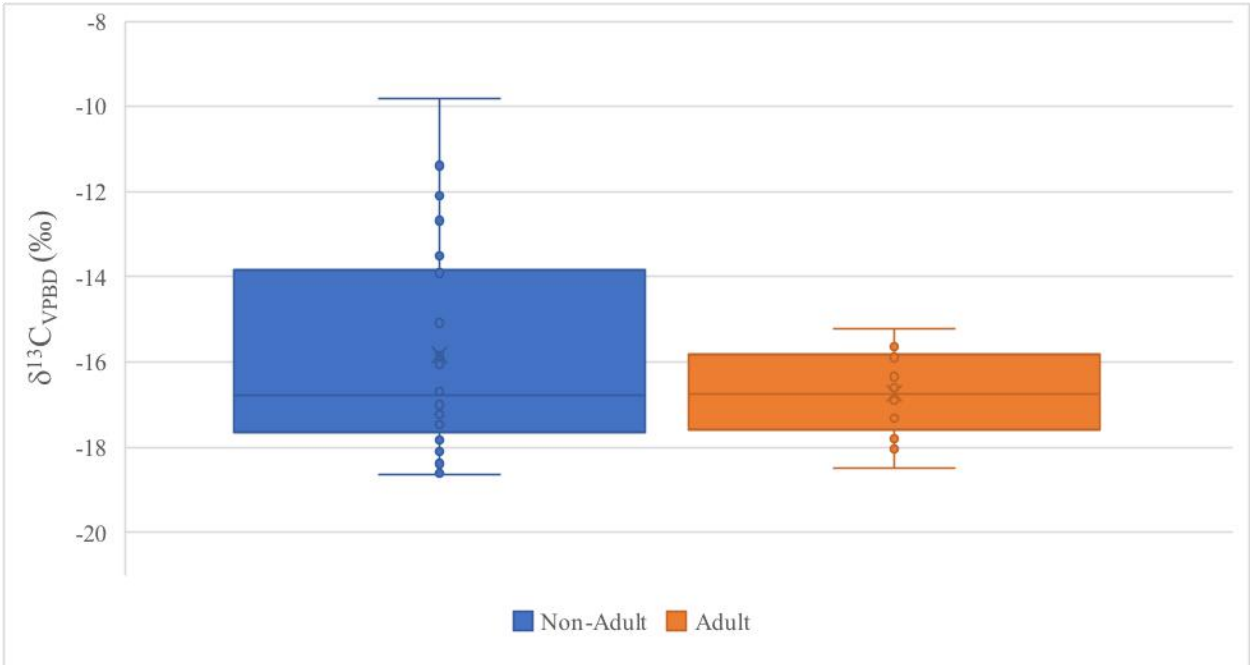

Figure 10. Box and whisker plot comparing the $\delta^{13}C$ values of the non-adults and adults.

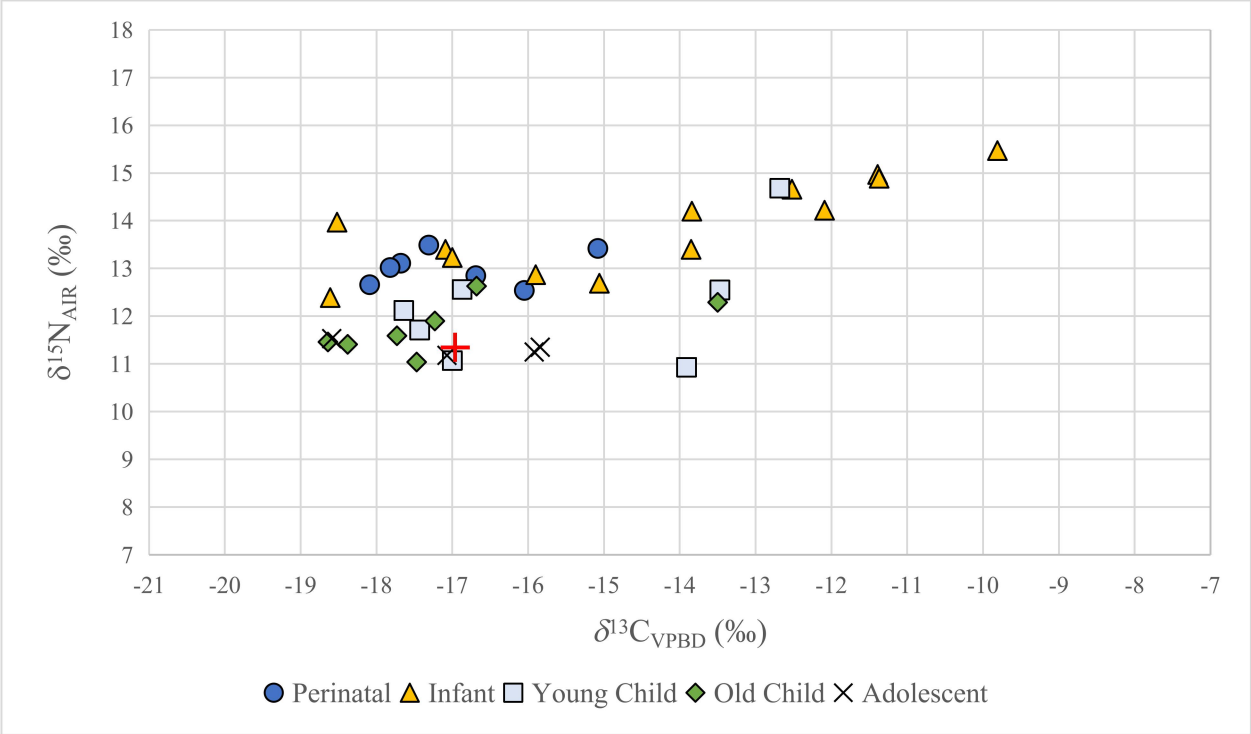

Figure 11. Graph plotting δ[15]N against δ[13]C for all non-adult individuals. The adult female mean is denoted by a red cross.

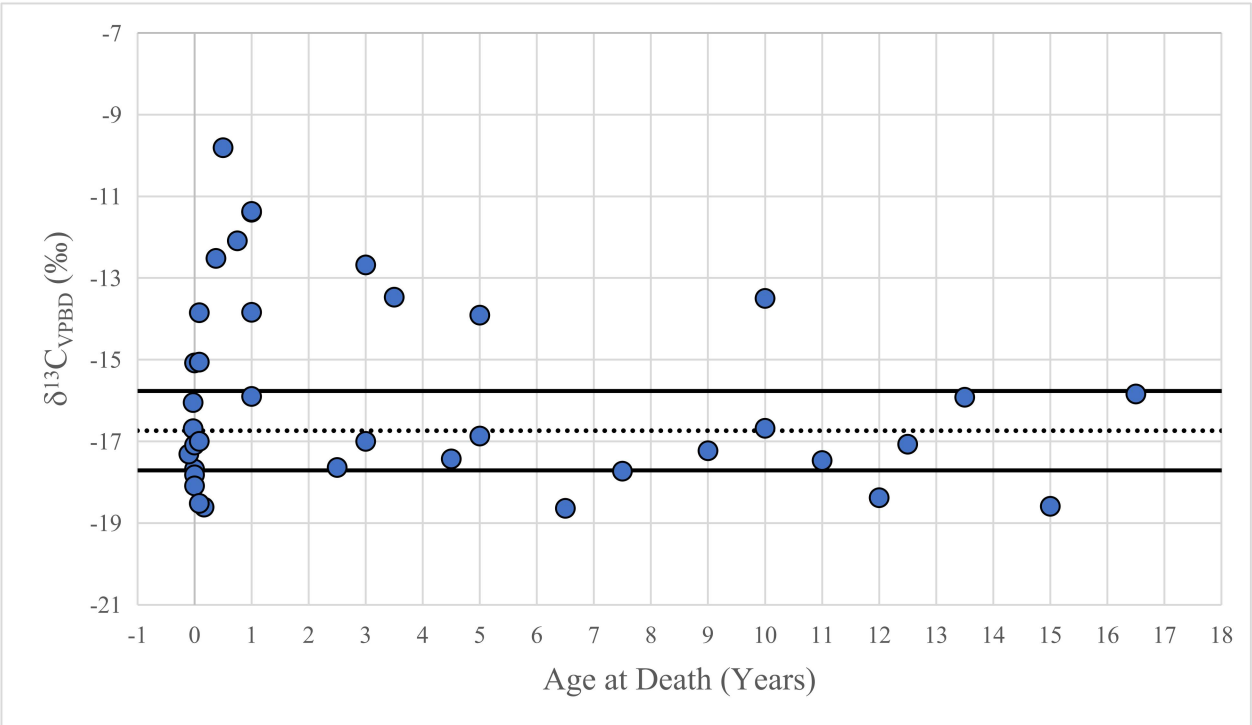

Figure 12. Graph plotting δ[13]C versus age at death for all non-adult individuals. Dashed line represents adult female mean, and solid lines represent the standard deviations.

The non-adult individuals were divided into five age cohorts: perinatal individuals (aged 36-40 weeks gestation) represented by seven individuals; infants (aged 0-1 year) represented by 13 individuals; young children (aged 1-6 years) represented by seven individuals; old children (aged 7-12 years) represented by seven individuals; and adolescents (aged 13-17 years) represented by four individuals. These ranges represent physiological milestones in an individual's life and, for this study, may provide the most insight into any patterns that may be present in diet and weaning along the life course.

Figure 11, which compares all non-adult $\delta^{15}N$ and $\delta^{13}C$ values, demonstrates a correlation between the age cohorts and $\delta^{15}N$ and $\delta^{13}C$ values. The old child and adolescent groups are clustered around the adult female mean, while the perinatal, infant, and young child values are enriched in one or both values. The perinatal individuals have a mean $\delta^{15}N$ value of 13.0‰, which is enriched in ^{15}N relative to ^{14}N compared to the adult female mean of 11.4‰. Their $\delta^{13}C$ values, however, are exactly the same with each group having a mean of –16.9‰. The $\delta^{15}N$ enrichment is likely due to exclusive breastfeeding, while the similar $\delta^{13}C$ values likely still represent in-utero or maternal values. The infant group exhibits the largest deviation from the adult female means for both $\delta^{15}N$ and $\delta^{13}C$, as can be seen in Figures 10, 11, and 12. The infant $\delta^{15}N$ and $\delta^{13}C$ means are 13.9‰ and –14.4‰, respectively, both of which are higher by more than 2‰ with regard to the adult female mean. This could indicate a continuation of breastfeeding with the introduction of plant-based foods. Finally, the young children exhibit increased $\delta^{15}N$ and $\delta^{13}C$ values, but not to the degree of the infant cohort. The young child $\delta^{15}N$ and $\delta^{13}C$ means are 12.2‰ and –15.6‰, respectively. As was previously mentioned, the old child and adolescent group $\delta^{15}N$ and $\delta^{13}C$ means are closer to the adult female mean.

Based on the previous data, it appears as though $\delta^{15}N$ values are higher beginning with the youngest individuals—the perinatals—and that this enrichment continues through the young child category. As the individuals reach the old child and adolescent stages, their $\delta^{15}N$ values become closer to the mean of the adult females. With regards to $\delta^{13}C$, it appears that the perinatal individuals may still be exhibiting maternal values, and that evidence of the consumption of alternative foods is not yet present. The infants and young children, though, begin exhibiting higher $\delta^{13}C$ values, indicating the consumption of C_4 based foods. As age increases past the young child phase, the $\delta^{13}C$ values deplete rapidly and become closer to the adult female mean.

In addition to general trends among these data, more clearly discernable patterns in the $\delta^{15}N$ and $\delta^{13}C$ values can be drawn between and among the different non-adult age cohorts discussed previously. Here, the $\delta^{15}N$ and $\delta^{13}C$ values for each of the five age categories will be discussed, comparisons between the groups will be made, and any patterns that exist outside the currently prescribed age cohorts will be discussed.

As can be seen in Figure 13—which compares the ranges in $\delta^{15}N$ for each non-adult age category as compared to the adult female mean—the range of $\delta^{15}N$ values for perinatal individuals is low (1.0‰,) when compared to the range of the infants (3.1‰,) and young children (3.8‰,). The mean, however, is higher than the adult females, showing enrichment in $\delta^{15}N$ and suggesting these individuals were exclusively breastfeeding. Further, as seen in Figure 10, all perinatal individuals are higher than one standard deviation above the adult female mean suggesting exclusive breastfeeding. This difference in values between the perinatal individuals and the adult females is statistically significant with a U-value of 4 and a p-value of 0.002 based on a Mann-Whitney U analysis (Table 8). One last line of evidence which may suggest exclusive breastfeeding can be seen in Figures 12 and 14: the perinatal individuals exhibit similar $\delta^{13}C$

values compared to the adult females in the sample. Based on the age of the individuals, it is likely these $\delta^{13}C$ values are reflective of the maternal or in-utero values and alternative foods have not been consumed.

Table 8. Table showing the results of Mann-Whitney U analyses used to compare the mean $\delta^{15}N$ values of different age categories.

Groups Compared	U-Value	p-Value	Statistically Significant at p=0.05?
Perinatal vs Adult Female $\delta^{15}N$	4	0.002	Yes
Infant vs Adult Female $\delta^{15}N$	3	0.0002	Yes
Young Child vs Adult Female $\delta^{15}N$	18	0.174	No
Old Child vs Adult Female $\delta^{15}N$	19	0.210	No
Perinatal vs Infant $\delta^{15}N$	22	0.067	No
Infant vs Young Child $\delta^{15}N$	12	0.006	Yes

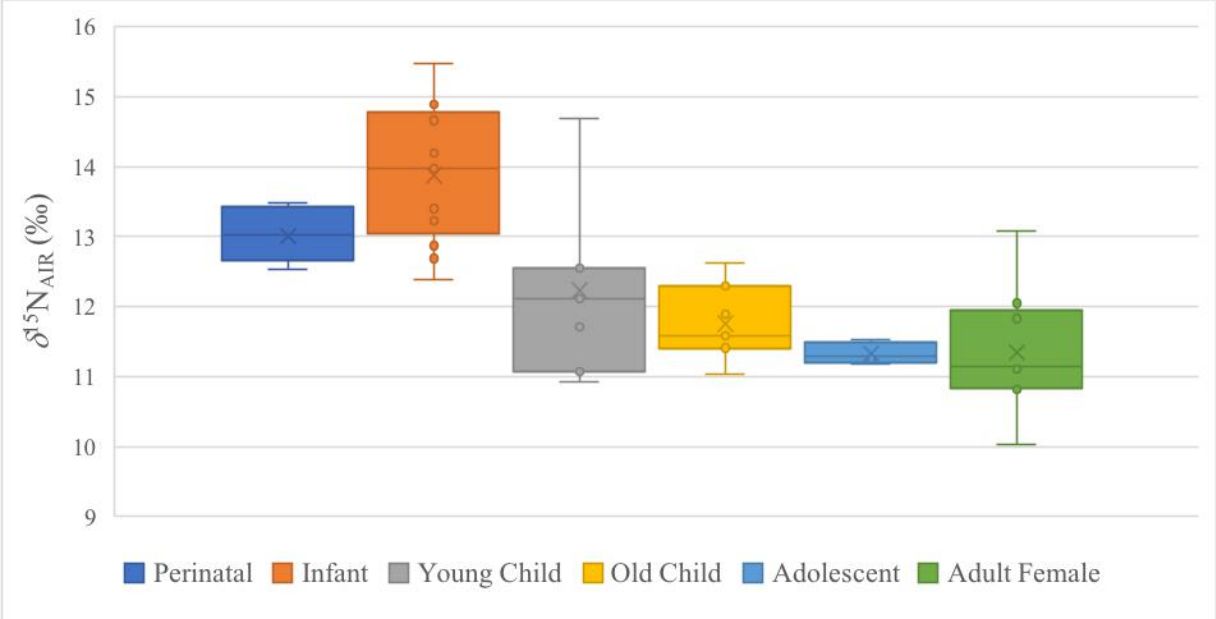

Figure 13. Box and whisker plot showing $\delta^{15}N$ ranges for each non-adult age category as compared to the adult female mean

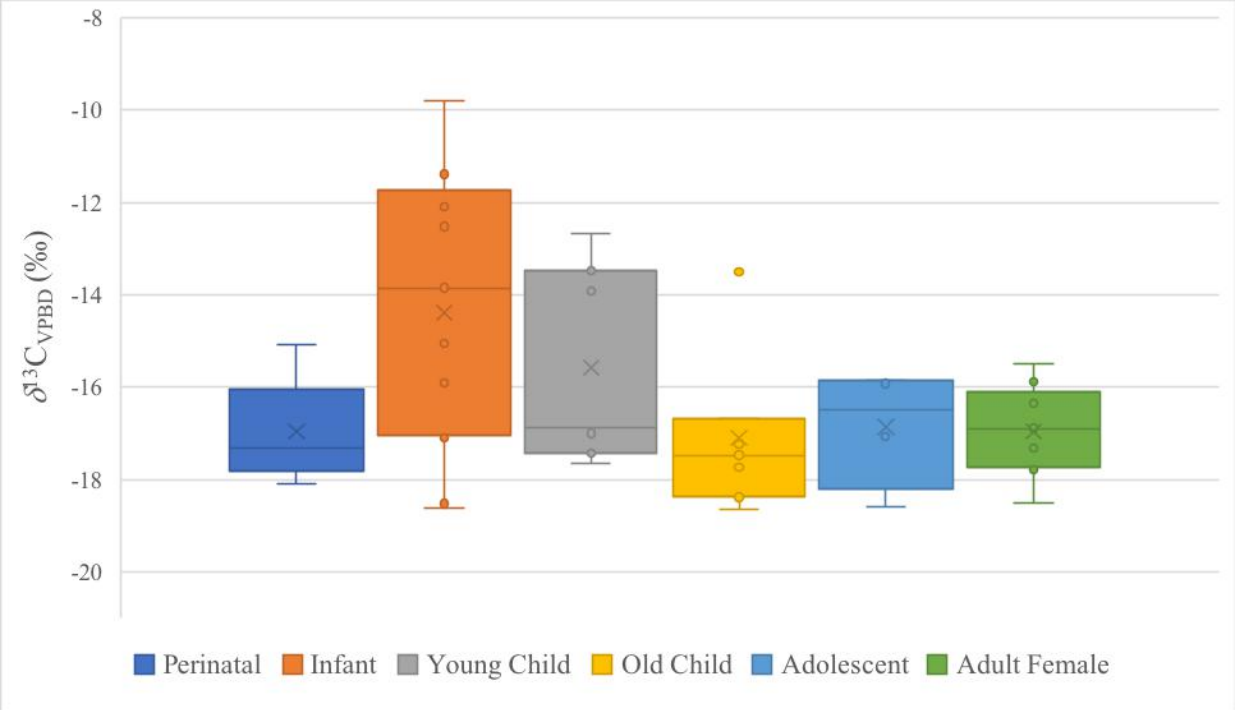

Figure 14. Box and whisker plot showing $\delta^{13}C$ ranges for each non-adult age category as compared to the adult female mean

Figures 11 and 13 demonstrate that the infants exhibit one of the highest levels of variation in $\delta^{15}N$ values of all the age cohorts. All of the infant individuals exhibit a $\delta^{15}N$ value higher than the female mean, suggesting that all infants were breastfeeding at the time of death. A Mann-Whitney U statistical analysis of the infant and adult female $\delta^{15}N$ values shows a statistically significant difference between the two groups with a U-value of 3 and a p-value of 0.0002 (Table 8). In contrast to the perinatal individuals, the $\delta^{13}C$ values for the infants are higher (Figures 12 and 14), suggesting the consumption of C_4 based foods. Figure 12 demonstrates that this enrichment in $\delta^{13}C$ increases with age. The younger infants—those around 1-2 months of age—exhibit $\delta^{13}C$ values closer to those of the adult females, while increasing age generally corresponds to increasing $\delta^{13}C$ values. This may represent differential patterns in the onset of weaning among individuals, or an increase in the consumption of C_4 foods during this time of development.

The young child category exhibits the highest range in $\delta^{15}N$ values as can be seen in Figures 11 and 13, but this is likely influenced by a single outlier (T-04 IND 1) with an unusually high $\delta^{15}N$ when compared to the rest of the young children in this sample. Of the young children, there are four individuals whose $\delta^{15}N$ values are within one standard deviation of the female mean, two individuals whose $\delta^{15}N$ values are just slightly higher than one standard deviation above the female mean, and the single outlier, whose $\delta^{15}N$ value is more than 3‰ higher than the adult female mean. When the outlier is not considered, the young children exhibit $\delta^{15}N$ values only slightly higher in comparison to the adult female mean, suggesting they may still be breastfeeding, but not exclusively. The outlier is likely still exclusively or nearly exclusively breastfeeding, though it is possible the individual is from another geographic region or that he or she was ill at the time of death. Based on the results of a Mann-Whitney U statistical

analysis, no statistical significance is found between the $\delta^{15}N$ values of the young children when compared to the adult females, though the difference between the young children and the infant cohorts is statistically significant with a U-value of 12 and a p-value of 0.006 (Table 8). The $\delta^{13}C$ values of the young children exhibit two groups of values which do not seem to correlate to age, which can be seen in Figure 12; there are three individuals aged 3, 3.5, and 5 years of age, which show $\delta^{13}C$ enrichment well above the adult female mean, and four samples aged 2.5, 3, 4.5, and 5 years of age, which fall right at or just under the adult female mean. This may suggest differential weaning patterns based on individual preference or differential access to C_4 based foods in the population.

When considering the older child category in terms of $\delta^{15}N$, there is less variation in values, the values are lower than the three previous age categories, and the mean is closer to that of the adult females (Figures 11 and 13). Six of the seven older children have $\delta^{15}N$ values within one standard deviation of the adult female mean, and the one individual who has a higher $\delta^{15}N$ value is only slightly higher than one standard deviation above the adult female mean. A similar pattern can be seen in Figures 6 and 8 regarding the $\delta^{13}C$ values of the older children: only one individual is higher than one standard deviation above the adult female mean, and two individuals are just slightly lower than one standard deviation below the adult female mean. These patterns may suggest a leveling-out of the $\delta^{15}N$ and $\delta^{13}C$ values for the older children.

The adolescent age category marks the point where all samples fall within one standard deviation of the adult female mean value for $\delta^{15}N$. In fact, all four samples are within 0.02‰ of the female mean, suggesting these individuals have assimilated completely to adult dietary patterns. The $\delta^{13}C$ values of these individuals is slightly more variable as one individual falls just under one standard deviation below the adult female mean, but the values average out to almost

the exact same mean $\delta^{13}C$ value. This is further evidence that by the adolescent stage, non-adults in this sample have completely assimilated to adult dietary patterns.

Percent C_4

Patterns of $\delta^{15}N$ and $\delta^{13}C$ values by age cohort allow for the interpretation of the patterns of breastfeeding and weaning for the sample, but it is also important to make inferences about what types of foods may have been used to during the weaning process. This type of information can be gained by determining how much of each individual's diet was composed of C_4 foods versus C_3 foods. As was previously discussed, the percent C_4 is calculated via the following equation developed by Schwarcz et al. (1985):

$$\%C4 = \frac{(\delta c - \delta 3 + \Delta dc)}{(\delta 4 - \delta 3)} x\ 100$$

The variables are as follows: δc = the $\delta^{13}C$ value of the sample, $\delta 3$ = the average $\delta^{13}C$ value of C_3 plants in the geographic region in question, Δdc = the fractionation factor between plants consumed and the body, and $\delta 4$ = the average $\delta^{13}C$ of C_4 plants in the geographic region in question. Based on the work of White and Schwarcz (1994) on materials from Northern Sudan, the values for $\delta 3$ and $\delta 4$ are –26.5‰ and –11.5‰, respectively. Due to the overlapping geographic regions and time periods, these values will be used for this research, as well. When these variables are inserted into the equation, it takes the following form:

$$\%C4 = \frac{(\delta 13C - (-26.5) + (-5)}{(-11.5) - (-26.5)}\ x\ 100$$

This formula was used to calculate percent C_4 for each individual; the non-adult values can be seen in Table 9 and Figure 15. The percent C_4 values for non-adults range from 19.1% to 77.9% with an average of 37.75%. The adult female mean, visualized by the black dashed line in Figure 15, is 30.3%.

Table 9. Table showing the ages and %C4 values for each non-adult sample.

Sample	Age	% C4
Te-07 IND 4	36 weeks	27.9
Te-03 IND 2	38-40 weeks	32.1
Te-09 IND 2	38-40 weeks	36.3
Te-01 IND 5	40 weeks	25.5
Te-02 IND 1	40 weeks	42.8
Te-04 IND 1	40 weeks	24.5
Te-04 IND 8	40 weeks	22.7
T-11 IND 16	40 weeks – 1 month	29.4
Te-01 IND 3	1 month	30.0
Te-01 IND 4	1 month	19.9
Te-04 IND 9	1 month	42.9
Te-07 IND 2	1 month	51.0
T-10 IND 3	1-3 months	19.3
Te-07 IND 1	3-6 months	59.9
Te-04 IND 5	6 months	77.9
Te-10 IND 1	9 months	62.7
T-09 IND 9	1 year	37.3
Te-01 IND 6	1 year	67.4
Te-03 IND 1	1 year	67.5
Te-14 IND 1	1 year	51.1
Te-01 IND 1	2-3 years	25.7
T-04 IND 1	3 years	58.8
Te-05 IND 2	3 years	30.0
Te-12 IND 1	3-4 years	53.5
T-10 IND 2	4-5 years	27.1
T-02 IND 2	5 years	50.6
T-07 IND 2	5 years	30.9

Sample	Age	% C4
T-10 IND 1	6-7 years	19.1
T-09 IND 8	7-8 years	25.1
T-23 IND 2	8-10 years	28.5
T-11 IND 1	9-11 years	53.3
T-07 IND 3	10 years	32.1
T-01 IND 5	10-12 years	26.9
T-34 IND 1	11-13 years	20.8
T-35 IND 4	12-13 years	29.5
T-05 IND 2	12-15 years	37.2
T-02 IND 3	15 years	19.4
T-35 IND 3	16-17 years	37.7

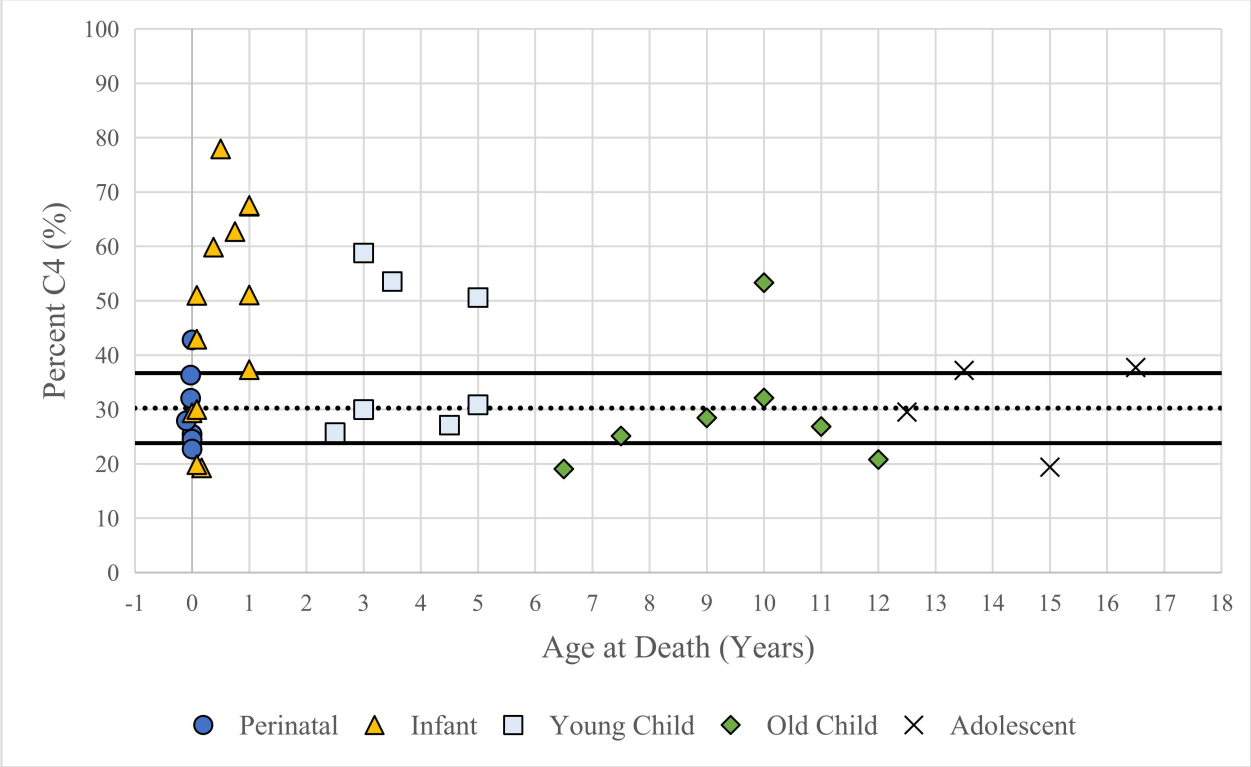

Figure 15. Graph plotting % C_4 against age at death for all non-adult individuals. Dashed line represents adult female mean, and the solid lines represent the standard deviations.

As is illustrated in Figures 15 and 16, the individuals with the most varied and wide-ranging values in percent C_4 are the infants, with values ranging from 19.3% to 77.9%. The young children exhibit varied percent C_4 values but are ultimately beginning the process of assimilation with the adult diet, as over 50% of the young children have percent C_4 values within one standard deviation of the adult female mean. Finally, the older children and adolescents exhibit percent C_4 values consistent and within one standard deviation of the adult female mean, suggesting near total assimilation with the adult diet.

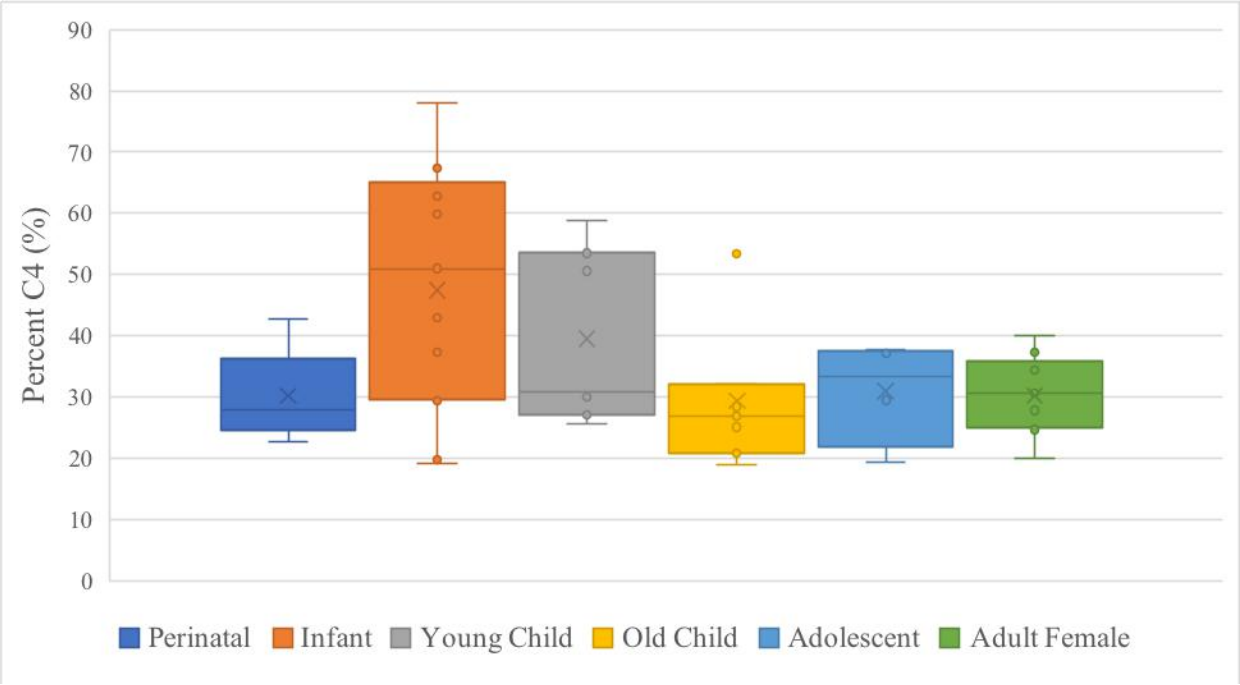

Figure 16. Box and whisker plot showing the % C_4 ranges for all non-adult age categories as compared to the adult female mean.

In addition to correlations with age at death, it appears that percent C_4 also shows a correlation with the $\delta^{15}N$ values of the non-adults. As can be seen in Figure 17—a graph plotting $\delta^{15}N$ against percent C_4 by age category— as percent C_4 increases, so does $\delta^{15}N$. Simply put, the

individuals with the highest percent C_4 values have the highest $\delta^{15}N$ values. Because the individuals with the highest $\delta^{15}N$ values are likely breastfeeding, this correlation could shed light on the types of foods being used to wean breastfeeding individuals.

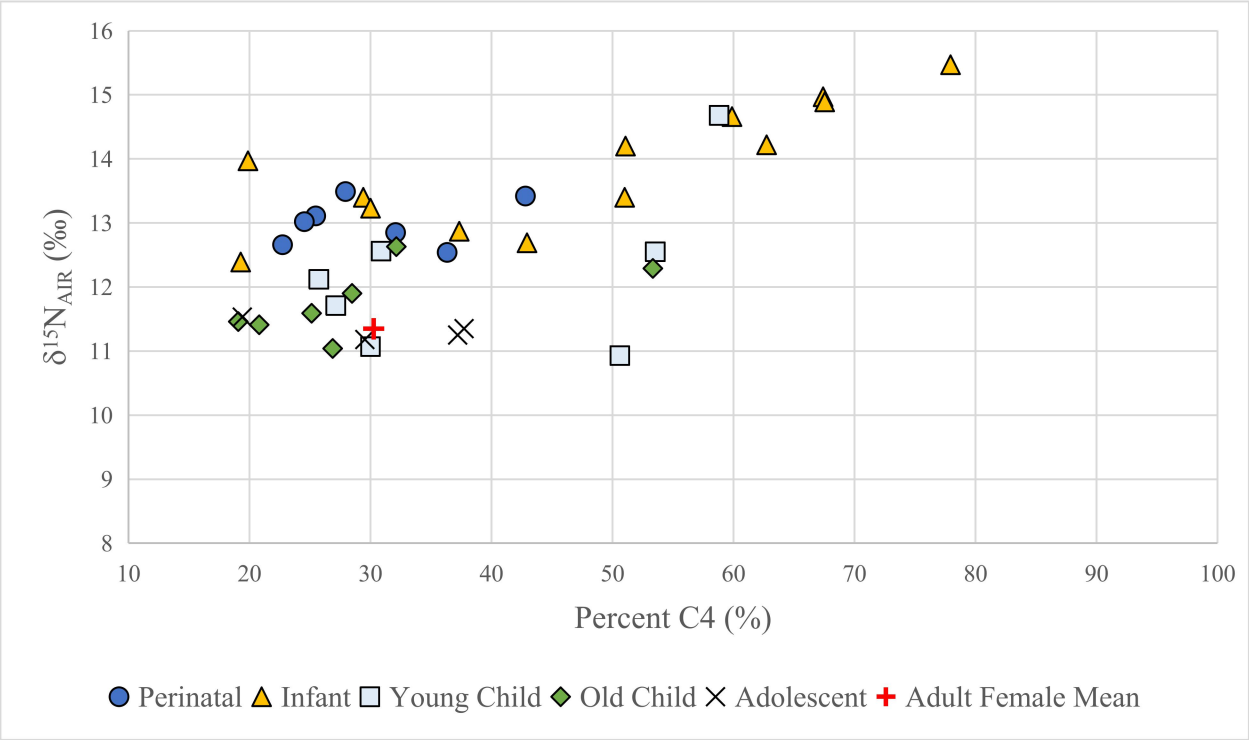

Figure 17. Graph plotting % C_4 against $\delta^{15}N$ for all non-adult individuals. The adult female mean is denoted by a red cross.

To test the significance of the patterns discussed, Mann-Whitney U statistical analyses were conducted to determine the difference between each age cohort and the adult female mean as well as the differences between the age cohorts themselves. In terms of percent C4, no statistically significant differences were found between the means of any of the age cohorts or the adult female mean.

CHAPTER FIVE: DISCUSSION

The following chapter presents an interpretation of the results in order to contextualize these data in terms of the background literature, theoretical approaches, and research questions. The goal of this research is to investigate the following questions through the lens of social identity and life history theories: Are there differences in dietary patterns between and/or among adults and non-adults in this sample? At what age are non-adults in this sample weaned? And are there intra-class diet and weaning differences between the elite groups on Sai Island? Each question will be addressed and supported by the isotopic, literary, and theoretical evidence available.

Differences in Adult and Non-Adult Diet

In this section, dietary differences between the adults and non-adults will be discussed based on the carbon and nitrogen isotopic values. In terms of $\delta^{13}C$ values, there are no significant differences in adults and non-adults in this sample based on Mann-Whitney U analyses of the means of each age cohort. Mann-Whitney U analysis suggests that no significant differences exist between the means of the adult and non-adult categories (U-value of 274; p-value of 0.574). In addition, no significant differences were found when all non-adult age cohorts were compared individually to the adult female $\delta^{13}C$ mean. Although not significant, the comparison between infants (0-1 years) and all adult females approaches significance (U-value of 30; p-value of 0.06), suggesting slight differences in the foods being fed to weaning infants compared to the diet of adults. In general, there are no significant differences in the $\delta^{13}C$ values or the C_4 based foods being consumed by adults and non-adults in this sample. This could be due to a lack of available

local C_4 foods, or it may suggest that the individuals in this sample were consuming similar foods due to their similar inferred elite status.

When $\delta^{15}N$ values are compared between adults and non-adults in this sample, significant differences do exist. When the means of all adults and all non-adults are compared using a Mann-Whitney U analysis, there is a statistically significant difference in the $\delta^{15}N$ values (U-value of 139; p-value of 0.002). This difference is most likely due to the large number of younger non-adults (aged 0-3; n=24) who may have been breastfeeding than those in the older non-adult age categories (aged 4-18; n=14), as non-adults who are breastfeeding exhibit enriched $\delta^{15}N$ values in comparison to non-breastfeeding individuals. To corroborate this, Mann-Whitney U analyses were conducted comparing the $\delta^{15}N$ values of the young child (1-6 years) and the old child (7-12 years) age cohorts to the $\delta^{15}N$ values of the adult females. No significant difference in the $\delta^{15}N$ values of children over the age of three and the adult females in this sample were found (p-values of 0.174 and 0.210, respectively). This further suggests that all individuals, with the exception of the very youngest non-adults in this sample, were consuming similar diets. As was previously mentioned, this homogeneity in diet could suggest a lack of variation in the foods available in the area and/or a homogeneity of C_4 foods related to the individuals' elite status.

Weaning Patterns of Non-Adults

In determining the weaning patterns of non-adults, it is important to first reiterate the mechanisms by which it is possible to detect weaning patterns in stable isotopic studies. Studies have found that when an infant is breastfeeding exclusively, their nitrogen isotope levels tend to be one trophic level—or about 2-3‰—above their mother's (Fogel et al., 1989; Fuller et al., 2004; Fuller et al., 2006). As the weaning process begins and foods other than breastmilk are

introduced into an infant's diet, their $\delta^{15}N$ values will begin to slowly equilibrate with that of their mother's (Fogel et al., 1989; Fuller et al., 2004; Fuller et al., 2006; Katzenberg, 2008). To analyze the weaning patterns of the non-adults in this sample, comparisons to the adult female mean of 11.4 ± 0.87‰ will be made for each age category. Due the limited number of adult female samples in each adult age category, all adult female samples were included here. The mean $\delta^{15}N$ values for the adult females and all non-adult age categories are listed in Table 10 and are illustrated in Figure 13.

Table 10. Table showing the descriptive statistics for $\delta^{15}N$ for the adult females and all non-adult age categories.

NITROGEN						
Age Category	**# of Samples**	**Mean (‰)**	**Standard Deviation (‰)**	**Range (‰)**	**Minimum (‰)**	**Maximum (‰)**
Adult Females	9	11.4	0.87	3.1	10.0	13.1
Perinatals	7	13.0	0.36	1.0	12.5	13.5
Infants	13	13.9	0.96	3.1	12.4	15.5
Young Children	7	12.2	1.26	3.8	10.9	14.7
Old Children	7	11.8	0.55	1.6	11.0	12.6
Adolescents	4	11.3	0.15	0.3	11.2	11.5

The average $\delta^{15}N$ value of the youngest age group—the perinates, aged 36-40 weeks gestation—is 13.0 ± 0.36‰. When compared to the adult female mean of 11.4 ± 0.87‰, the perinate $\delta^{15}N$ values are enriched by nearly 2‰. All individuals in this category are at least one standard deviation higher than the adult female $\delta^{15}N$ mean—an indicator of exclusive breastfeeding (Beaumont et al., 2015). Two of the seven individuals are enriched by more than 2‰. Based on these values, it would appear that all individuals in this sample aged 36 to 40 weeks are exclusively breastfeeding. It is important, however, to consider alternate

interpretations of the enriched $\delta^{15}N$ values of perinatal individuals, given their age, as several extrinsic factors may play a role in the $\delta^{15}N$ values of these individuals. One possibility is that the individuals were, in fact, exclusively breastfeeding. Due to their age, however, one must also consider that the $\delta^{15}N$ values are enriched for other reasons.

Even though fetal and perinatal individuals experience faster-than-average bone growth and turnover, it still takes time for the bone collagen to reflect the individual's dietary $\delta^{15}N$ values. Unless the perinates were born and began breastfeeding quite prematurely, it is unlikely that the individuals had been breastfeeding long enough for a chemical signature to be registered in the bone collagen. For this reason, it is likely that the enriched $\delta^{15}N$ values are in-utero values reflective of the $\delta^{15}N$ values of the individual's mothers (Beaumont et al., 2015). Studies by Katzenburg and Lovell (1999) and Fuller et al. (2004; 2005) found that both nutritional stress and pathological conditions can cause elevated $\delta^{15}N$ in adult individuals regardless of diet. Based on this, it is possible that the enriched $\delta^{15}N$ values in the perinatal individuals represents in-utero values of an ill or nutritionally stressed mother.

Another line of evidence which supports the possibility of the perinatal individuals showing in-utero $\delta^{15}N$ values can be found in their $\delta^{13}C$ values. The perinatal individuals have the exact same average $\delta^{13}C$ value of –16.96‰ as the adult females in this sample. While it must be taken into consideration that the adult females in this sample may have been passed their childbearing years and may be misrepresenting the actual average $\delta^{13}C$ values of the entire adult population, it is still meaningful to see no difference in the $\delta^{13}C$ values. In exclusively breastfeeding non-adults, a $\delta^{13}C$ enrichment of approximately 1‰ is generally present as a trophic level effect (Fuller et al., 2006). Because this $\delta^{13}C$ enrichment is not present in this

sample, it suggests even further that the perinatal $\delta^{15}N$ values represent in-utero values of an ill or nutritionally stressed mother.

The next age category to consider is the infants, aged 0-1 years. The average $\delta^{15}N$ value for this category is 13.9 ± 0.96‰,. When compared to the adult female $\delta^{15}N$ mean of 11.4 ± 0.87‰,, all infant individuals are at least one standard deviation above the mean, with five of the 13 individuals 2‰ above the mean, and four of the 13 individuals 3‰ above the mean. Based on this, it appears that all of the infants were breastfeeding at the time of death. Figure 18 shows the perinatal and infant individuals' $\delta^{15}N$ and $\delta^{13}C$ values with the adult female mean. This figure not only shows the changes which occur between the perinatal and infant individuals, but also demonstrates the beginning of the weaning process for several infant individuals.

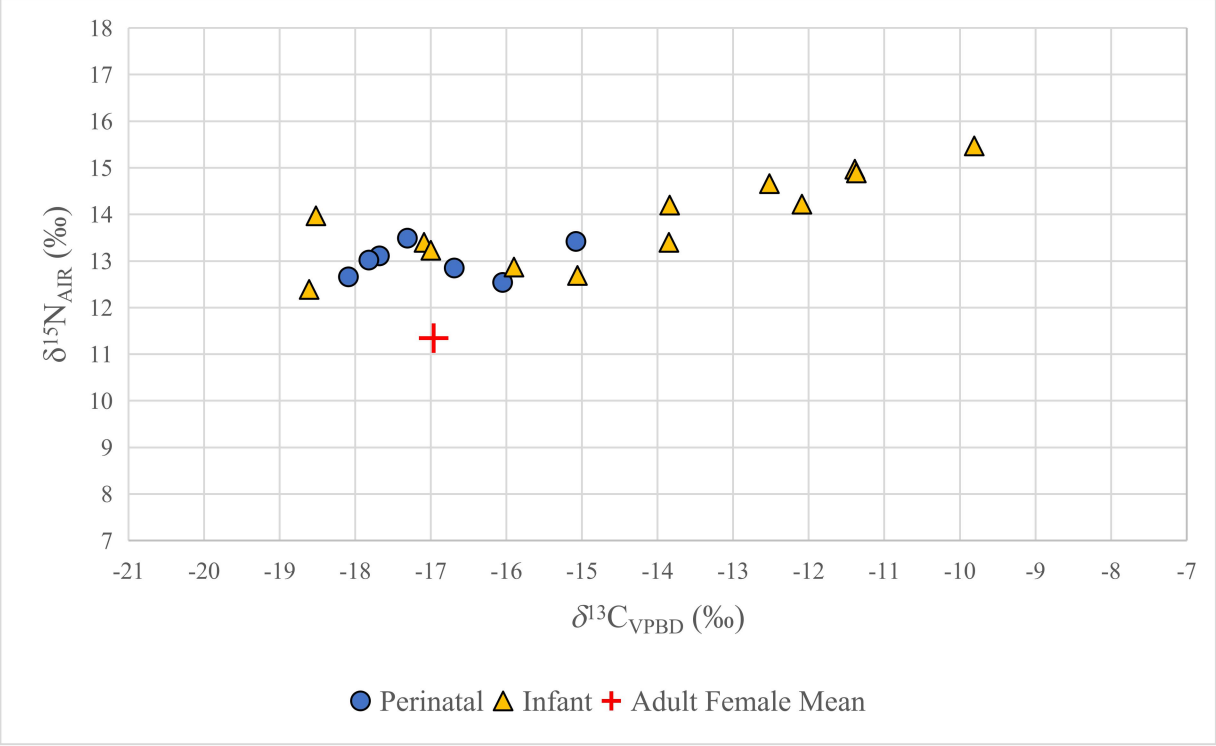

Figure 18. Graph plotting $\delta^{13}C$ versus $\delta^{15}N$ for perinatal and infant individuals. The adult female mean is denoted by a red cross.

When a non-adult is breastfeeding, there is slight enrichment in $\delta^{13}C$ values (Katzenberg et al., 1993; Fuller et al., 2006). While five of the infants have $\delta^{13}C$ values within or just below one standard deviation of the adult female mean, eight of the infants have enriched $\delta^{13}C$ values. As is shown in Figure 19, this trend of enrichment demonstrates a slight positive correlation with age—as age increases, $\delta^{13}C$ becomes more enriched, with the exception of three individuals who do not follow this trend. This suggests that the individuals with enriched $\delta^{13}C$ values have begun the process of weaning by introducing foods other than breastmilk; possible weaning foods will be discussed in the following section. The individuals with $\delta^{13}C$ values at or below the adult female mean are the youngest of the age category and likely still represent the $\delta^{13}C$ values of their mothers. It must be mentioned again, though, that the adult female mean used here may be misrepresentative of the adult females of reproductive age, as the adult female samples used are older adults.

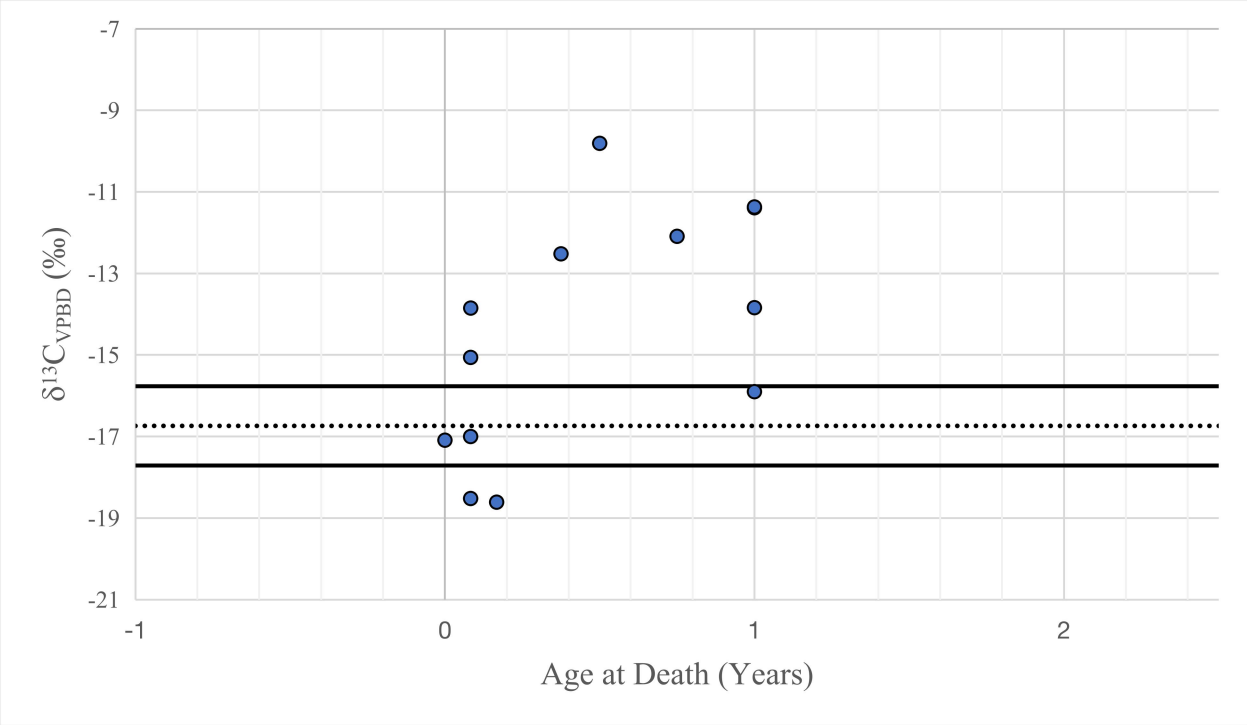

Figure 19. Graph plotting age at death versus $\delta^{13}C$ for infant individuals. Dashed line represents adult female mean, and solid lines represent the standard deviations.

By the time the individuals reach the young child category (1-6 years), the average $\delta^{15}N$ value is 12.2 ± 1.26‰. When compared to the adult female value of 11.4 ± 0.87‰, the young children are much less enriched in $\delta^{15}N$ than either of the previous two age categories. Mann-Whitney U tests show that the difference in means between the infants aged 0-1 years and the young children aged 1-6 years is statistically significant (U-value of 12; p-value of 0.006). As is demonstrated in Figure 20, four of the seven young children have $\delta^{15}N$ values within one standard deviation of the adult female mean, and there are three outliers. One of the outliers has a $\delta^{15}N$ value enriched by more than 3‰, while the other two are just slightly higher than one standard deviation above the adult female mean. If the three outliers, discussed later, are removed, the average of the $\delta^{15}N$ values becomes 11.5 ± 0.56‰, which is well within one standard deviation of the adult female mean; this suggests that these four individuals were likely completely weaned. The $\delta^{13}C$ data corroborates this, as is illustrated in Figure 21. The four individuals within one standard deviation of the adult female mean for $\delta^{13}C$ are the same four individuals within one standard deviation of the adult female mean for $\delta^{15}N$. Because there is no enrichment in $\delta^{15}N$ or $\delta^{13}C$, these data further support that by 2.5 years—the age of the youngest sample in this age category who shows no $\delta^{15}N$ or $\delta^{13}C$ enrichment—the individuals in this sample would likely be completely weaned. This value is rounded to a weaning age of approximately 3 years to provide room for error and standard deviation. This information is consistent with other weaning age estimations made on contemporaneous populations in the region (i.e. Eerkens et al., 2018).

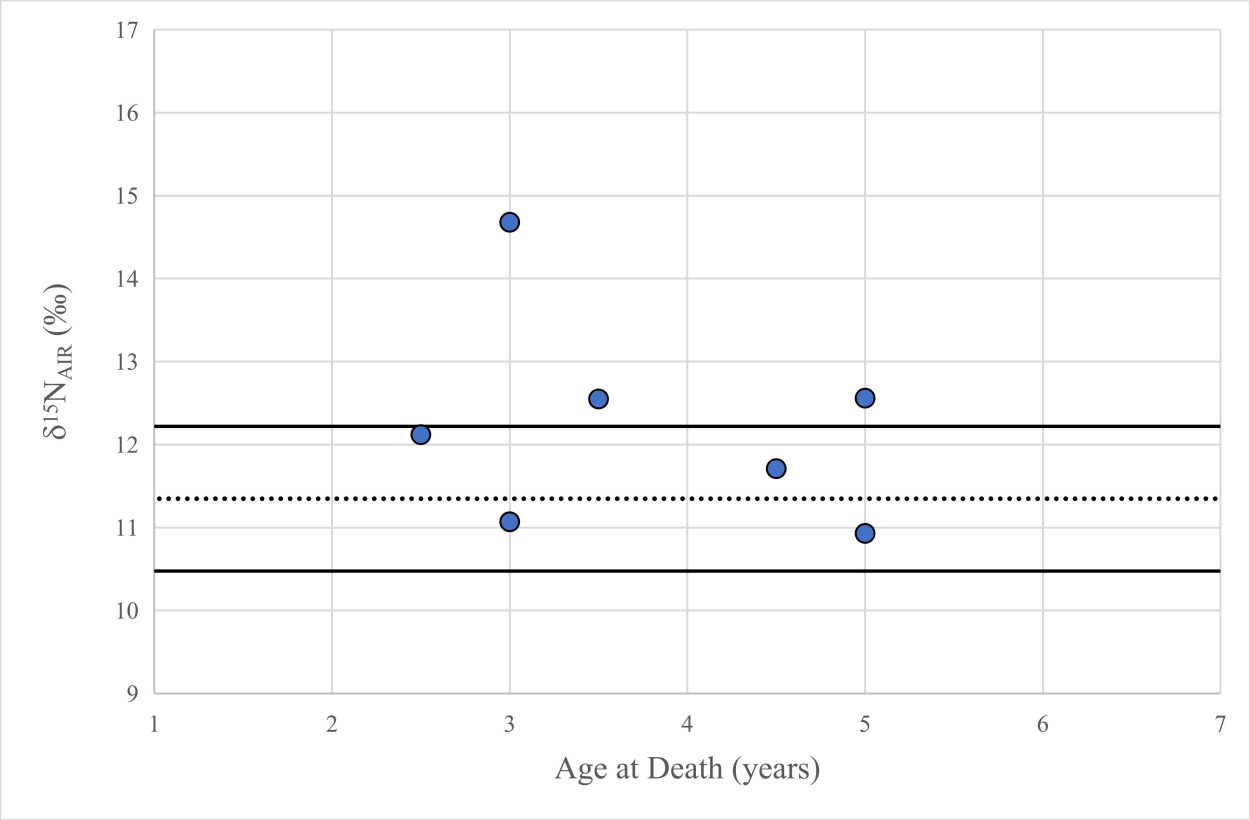

Figure 20. Graph plotting age at death versus $\delta^{15}N$ for all young child individuals. Dashed line represents adult female mean, and solid lines are the standard deviations.

The last two age categories—the older children (7-12 years) and the adolescents (13-17 years), both have $\delta^{15}N$ and $\delta^{13}C$ values mostly within one standard deviation of the adult female mean suggesting complete weaning and assimilation with the adult diet.

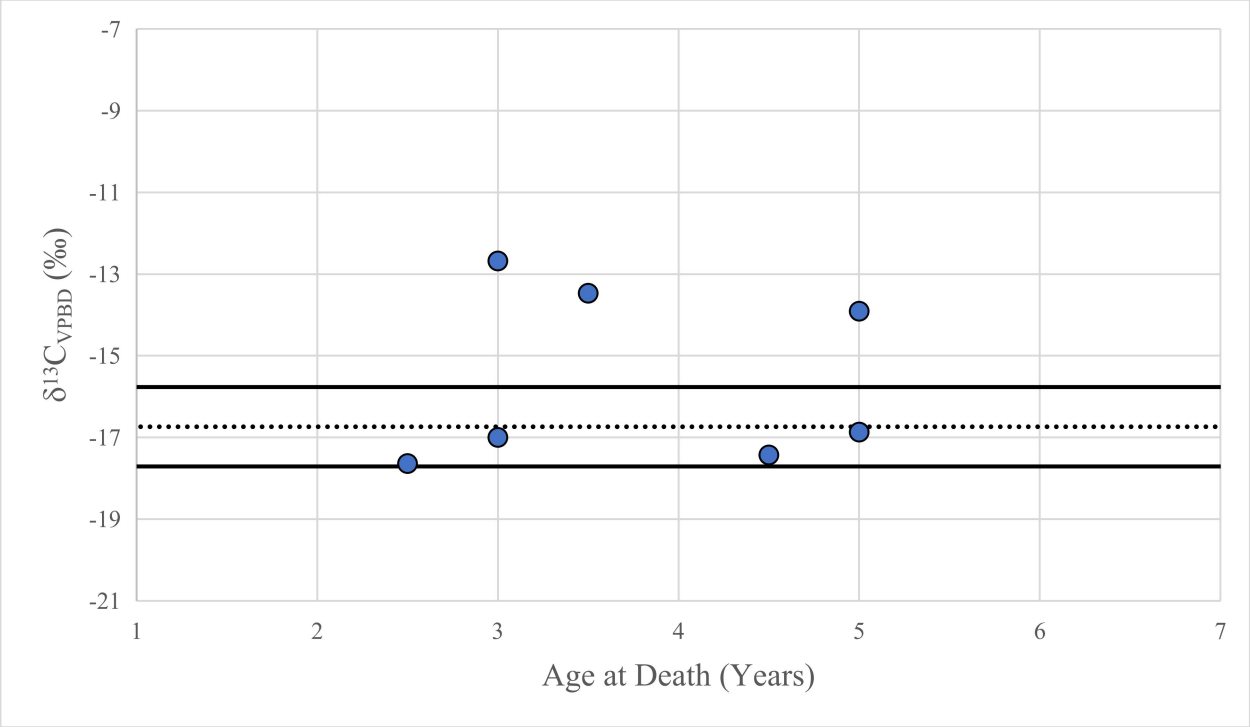

Figure 21. Graph plotting age at death versus $\delta^{13}C$ for all young child individuals. Dashed line represents adult female mean, and solid lines represent the standard deviations.

When it comes to the outliers in the young child category, it is necessary to note that the three outliers present in the $\delta^{15}N$ data are the same three outliers present in the $\delta^{13}C$ data. For this reason, it is important to consider these individuals separately from the rest of the samples and consider alternate interpretations for their elevated $\delta^{15}N$ and $\delta^{13}C$ values. The main consideration that must be made is that because these individuals died at a young age, it is unlikely they were thriving. Due to possible illness or other reasons leading to a failure to thrive, these individuals may have been fed different foods in order to promote wellness or soothing (Dupras et al., 2001). Based on the $\delta^{13}C$ enrichment in these individuals, it is likely these foods included C_4 plants such as millet and sorghum cereals, or the milk of livestock who consumed C_4 foods. In addition, it could be possible that these individuals and/or their mothers were non-local. To determine this, analysis of stable oxygen and/or strontium isotopes would be necessary. Finally, it could be that these individuals simply breastfed longer than the average length of time. Both an individual and

his or her mother are direct agents in the breastfeeding and weaning process (Lozoff et al., 1977; Winberg, 2005; Palmquist, 2020). If the individual rejected solid foods, the mother may have not had a choice but to continue breastfeeding. Conversely, if the mother did not have access to any alternative foods or made a conscious decision to continue breastfeeding for any number of other reasons, the individual's $\delta^{15}N$ and $\delta^{13}C$ values would continue to be higher than the adult female mean.

Weaning Foods

To determine the types of foods which may have been used as a weaning food in this sample, the $\delta^{13}C$ and percent C_4 values of each individual in the infant and young child age categories, as well as the values of the adult females, was analyzed. Based on the isotopic data discussed earlier, the weaning process likely began around six months of age and was completed by around 3 years of age, making the infant (0-1 years) and young child (1-6 years) age categories the most relevant for understanding the types of foods these individuals may have been weaned on. In addition, the adult females will be used as the baseline for comparing the non-adult $\delta^{13}C$ and percent C_4 values.

Table 11 lists the average $\delta^{13}C$ and percent C_4 values for all non-adults, the infant and young child age categories, the individuals aged 0.5-1 year, and the adult females in this study. When comparing the mean $\delta^{13}C$ value of all non-adults (–15.8‰) to that of the adult females (–16.9‰) in this sample, the non-adults are only slightly enriched, supporting the idea that the adults and non-adults were eating a relatively homogenous diet. When the adult females are compared to the individuals who were likely in the process of weaning (the infants and young children), however, the differences are more noteworthy. The average infant $\delta^{13}C$ value is –

14.4‰, which is enriched by 2.5‰ compared to the adult females (Table 11). This amounts to a mean difference of 17.1% in percent C_4 between these groups, with infants eating a mean of 47.4% C_4 and the adult females eating a mean of 30.3% C_4. In addition, when only infants aged 0.5-1 year (those at the beginning of the weaning process) are compared to the adult females, the difference is even more drastic, with those individuals exhibiting a 4.5‰ enrichment in $\delta^{13}C$ and eating an average of 60.7% C_4 plants. When the young child category is considered, the $\delta^{13}C$ values are enriched by only 1.3‰ when compared to the adult females, and the difference in percent C_4 consumption is 9.2%. While these individuals are still enriched in $\delta^{13}C$ with regards to the adult females, they are not as enriched as the infant groups, further suggesting that complete weaning is occurring during this stage.

Table 11. Table showing average $\delta^{13}C$ and percent C_4 values for different age categories.

Age Category	$\delta^{13}C$ (‰)	% C_4
All Non-Adults	-15.8	37.8
Infants	-14.4	47.4
0.5-1 year	-12.4	60.7
Young Child	-15.6	39.5
Adult Female	-16.9	30.3

Based on the $\delta^{13}C$ and percent C_4 values of these groups, the general types of foods used to wean these individuals can be deduced. As was discussed in the Meroitic Period Sudan section of the literature review, the important agricultural crops in this region during the Meroitic period consisted of sesame, date palms, wheat, millet, barley, and sorghum, while domesticated livestock included oxen, sheep, goats, and horses (Edwards, 2004; Haaland, 2014). Because the individuals in the process of weaning have enriched $\delta^{13}C$ values and higher percent C_4 values when compared to the adult females, it can be assumed that they were being weaned on C_4 foods. These C_4 foods could include millet and sorghum, as well as the milk of any livestock who may

have been consuming C_4 plants. This is consistent with the results of studies conducted by Eerkens et al. (2018) and Gregoire (2019) on Sai Island, as well as with the information presented in Martin et al. (1989), which suggested that Sudanese Nubian non-adults were likely weaned on millet and/or sorghum-based gruels.

It must also be considered that these individuals were of wealthy elite status and that this social identity may have influenced the variety and quality of foods they would have available for weaning. Eerkens et al. (2018) found that the religious elite non-adults at site 8-B-5.A on Sai Island exhibited greater variation in $\delta^{13}C$ values when compared to contemporaneous sites in Egypt. The authors argue that this variation is due to the higher status of these individuals, as well as their greater access to a wide variety of foods. Because weaning places a heavy pathological load on an individual, access to a wider variety of higher quality foods could have provided the individuals in this sample with a greater chance of survival compared to lower status individuals.

Inter-Cemetery Differences between Sites 8.B.52.B and 8.B.5A at Sai Island, Sudan

In this section, comparisons will be made between the isotopic data from site 8-B-52.B presented in this study and the isotopic data from site 8-B-5.A as presented by Gregoire (2019). Gregoire (2019) used the same methods as the current study, allowing for direct comparisons to be made between the two data sets. Both 8-B-5.A and 8-B-52.B are contemporaneous elite Meroitic period cemeteries located at Sai Island, Sudan. As can be seen in Figure 22, these sites are located in close proximity to one another in the Northern portion of Sai Island. Site 8-B-5.A is believe to be a necropolis used for the burial of the religious elite (Francigny, 2009), while it is suggested that site 8-B-52.B was used as a cemetery for wealthy elite (Dupras, pers. comm.).

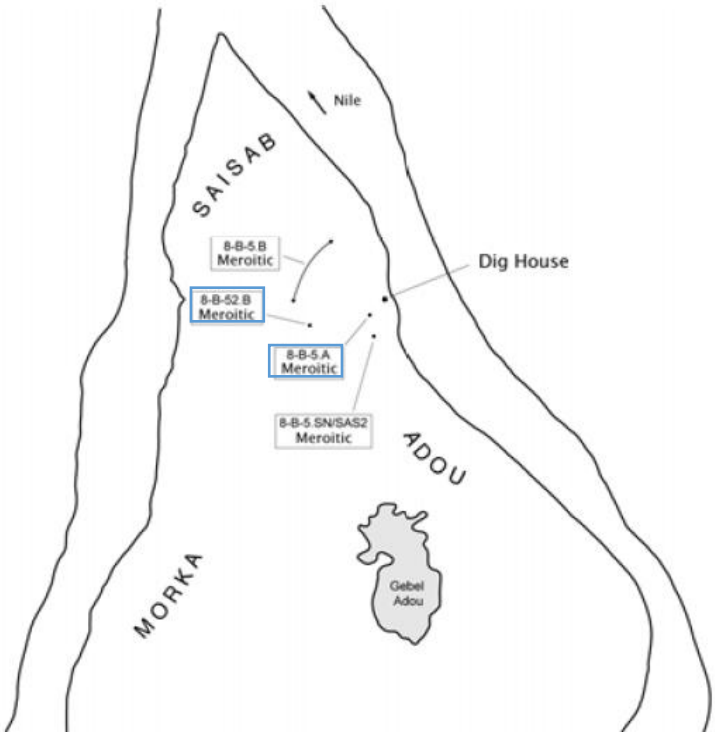

Figure 22. Map of the Northern portion of Sai Island, Sudan showing the locations of four necropolises on the island. Sites 8-B-5.A and 8-B-52.B can be seen in the blue rectangles Adapted from Francigny (2016).

Comparisons will be made between age categories and supported by statistical analyses to determine if any differences or similarities can be seen between the two elite cemeteries. In addition, the approximate weaning ages for each site will be compared to determine if any differences and/or similarities in the isotopic values of the age categories corresponds to any differences and/or similarities in average weaning age. To accomplish this, the isotopic data presented by Gregoire (2019) was reorganized into the age categories used in this study. These data were input into SPSS, and Mann-Whitney U analyses were conducted to compare the difference between the means of each age category for each site. All non-adult age categories were compared with the exception of the adolescent category, as there were not enough samples

to conduct the analysis. The results of the Mann-Whitney U statistical analyses will be discussed below.

Table 12 shows the p-values for the Mann-Whitney U analyses conducted to compare the isotopic values for each age category between sites 8-B-5.A and 8-B-52.B. As can be seen in Table 12, only one of the Mann-Whitney U analyses showed a significant difference in the mean—the comparison between the infants from each site. The infants from site 8-B-5.A had a mean $\delta^{15}N$ value of 12.3‰ (n=7) (Gregoire, 2019), while the infants from site 8-B-52.B had a mean $\delta^{15}N$ value of 13.9‰ (n=13)—significantly higher than the infants from the contemporaneous elite cemetery at Sai Island. Several possibilities exist which could explain why only one age category shows any statistically significant difference in the mean. This may mean that the wealthy elite adult females were consuming a diet higher in ^{15}N and that this was reflected in the $\delta^{15}N$ values of the breastfeeding infants. When statistical comparisons were made between the adults from sites 8-B-5.A and 8-B-52.B, no statistically significant differences were present between the $\delta^{15}N$ values.

Table 12. Results of Mann-Whitney U analyses comparing the mean $\delta^{15}N$ and $\delta^{13}C$ values for each age category between sites 8-B-5.A and 8-B-52.B

Age Category	$\delta^{15}N$ 8.B.5.A (‰)	$\delta^{15}N$ 8.B.52.B (‰)	U-Value	p-Value	$\delta^{13}C$ 8.B.5.A (‰)	$\delta^{13}C$ 8.B.52.B (‰)	U-Value	p-Value
Perinatal	13.4	13.0	16	0.189	–16.4	–16.9	24	0.694
Infant	12.3	13.9	11	***0.005***	–12.1	–14.4	29	0.211
Young Child	11.4	12.2	14	0.639	–16.8	–15.6	11	0.343
Old Child	11.3	11.8	11	0.181	–17.2	–17.1	17	0.628
All Non-Adults	12.0	12.8	404	0.063	–15.6	–15.8	485.5	0.407

It is more likely that the difference in the $\delta^{15}N$ values of the infants from each site is either reflective of sampling and/or age bias. The sample of infants from site 8-B-5.A consists of seven individuals, all of whom are aged between one and three months (Gregoire, 2019). The sample of infants from site 8-B-52.B used in this study, however, consists of 13 individuals ranging in age from birth to one year. It must be considered that the younger average age of the infant individuals from 8-B-5.A resulted in lower $\delta^{15}N$ values because the bone had not fully incorporated the infants' diets and is still presenting the mothers' $\delta^{15}N$ values. To test this, the infants aged birth to three months from site 8-B-52.B (n=6) were separated from the other individuals in the infant category and compared to the infants aged birth to three months from site 8-B-5.A. The $\delta^{15}N$ averages for the two groups are 13.2‰ and 12.3‰, respectively. When analyzed with a Mann-Whitney U test, these two groups yield a U-value of 9 and a p-value of 0.101, indicating a difference in means that is not significant. Based on this, it seems as though the older infant individuals in the sample from site 8-B-52.B are skewing the mean and causing the difference in means between the infant categories from the two sites to be significantly different; therefore, it appears as if the two sites do not have different feeding and weaning practices, but that the issue is one of sampling bias.

Based on the information presented, it appears as if the infant feeding and weaning practices for different age categories between and among the elite Meroitic cemeteries on Sai Island do not differ significantly. For site 8-B-52.B, weaning seems to begin around six months of age and is completed by around 3 years of age based on the combination of $\delta^{15}N$ and $\delta^{13}C$ enrichment patterns. While a lack of appropriately-aged samples limited the determination of a specific weaning age at site 8-B-5.A, Gregoire (2019) determined that it was likely individuals were weaned between the ages of two and four. This is consistent with the weaning age of site 8-

B-52.B, further corroborating the possibility that the non-adults at the two elite sites were fed and weaned in very similar manners. In 2018, Eerkens et al. conducted a stable isotopic study on serial sections of teeth from non-adult individuals from site 8-B-5.A at Sai Island, Sudan. The authors found that the average weaning age was approximately 2.7 ± 0.95 years, suggesting that individuals from the site were weaned by three years of age—a determination consistent with those of this study and of Gregoire (2019) from elite Meroitic cemeteries at Sai Island, Sudan. These results are summarized in Table 13.

While the nominal and mortuary distinctions between the religious and wealthy elite interred at Sai Island suggest differing social identities between the two groups, the lack of difference in the diet and weaning patterns of non-adults between the two may suggest that these populations shared similar access to dietary resources and/or had similar views on the feeding and weaning of children.

Table 13. Table summarizing different weaning studies that have been conducted on contemporaneous sites in Northern Africa and the Mediterranean.

Author(s)	Site	Time Period	Non-Adult Sample Size	Weaning Completed
Raisor, 2020 (current study)	8-B-52.B Sai Island, Sudan	Meroitic	38	3 years
Gregoire, 2019	8-B-5.A Sai Island, Sudan	Meroitic	31	2-4 years
Eerkens et al., 2018	8-B-5.A Sai Island, Sudan	Meroitic	11	2.7 ± 0.95 years
Dupras, 1999	Kellis 2 Dakhleh Oasis, Egpyt	Roman	51	3 years
Dupras and Tocheri, 2007	Kellis 2 Dakhleh Oasis, Egypt	Roman	102	3 years
Dupras et al., 2001	Kellis 2 Dakhleh Oasis, Egypt	Roman	49	3 years
Keenleyside et al., 2009	Leptiminus, Tunisia	Roman/Late Roman	35	3 years
Prowse et al., 2008	Isola Sacra Rome, Italy	Roman	37	2-2.5 years

Regional Comparisons of Weaning Patterns

As can be seen in Table 13, when the geographic scope is widened to include Egypt and the Mediterranean, the weaning age of approximately three years is consistent across the Roman (27-395CE) and Meroitic (300BCE-350CE) periods. Three studies conducted on Roman-period non-adult individuals from the Kellis 2 Cemetery at Dakhleh Oasis, Egypt suggest a very similar pattern—weaning begins at around six months of age and is complete by three years of age (Dupras, 1999; Dupras et al., 2001; Dupras and Tocheri, 2007). While different in culture, diet, and geography, it appears as if the individuals from site 8-B-52.B and those from Kellis 2 cemetery followed similar patterns of weaning. Further, studies conducted by Keeleyside et al. (2009) and Prowse et al. (2008) in Leptiminus, Tunisia and Rome, Italy, respectively, found similar results (Table 13). While Prowse et al. (2008) found a slightly earlier weaning age of 2-2.5 years, it is still consistent with the weaning age of around 3 years found for site 8-B-52.B in this study. Based on these findings, it appears as though during the Meroitic (300BCE – 350 CE) and Roman periods (27-395CE), the Northern African/Mediterranean regions practiced consistent patterns of weaning and that the weaning patterns found at sites 8-B-5.A and 8-B-52.B on Sai Island do not differ from the greater geographic region.

Summary – Theoretical Considerations

This chapter discussed the differences in adult and non-adult diet, the weaning patterns of non-adults, the types of foods individuals may have been weaned on, intra-cemetery differences between sites 8-B-52.B and 8-B-5.A, and comparisons of weaning patterns across the Northern African and Mediterranean regions. The data suggest that all individuals except the youngest

non-adults in this sample were consuming a relatively homogenous diet. The youngest individuals were likely breastfeeding exclusively for the first six months of their lives, then were weaned by the age of 3 years. $\delta^{13}C$ enrichment in the individuals who were likely weaning suggests that C_4 foods like millet and sorghum may have been used to supplement the weaning process. No significant differences existed in the non-adult diet and weaning patterns between sites 8-B-52.B and 8-B-5.A, nor between any contemporaneous sites in the surrounding geographic regions.

Additional factors must be taken into account when interpreting these data, though, including the social identities of these individuals and the impact this may have had on their life histories, health, and wellness. As was previously discussed, this research used two main theoretical approaches when interpreting results: social identity theory and life history theory. Social identity theory is based on the idea that people categorize themselves as belonging to various social groups, and that these groups represent one's social identity; this approach aims to explain individual thoughts and behaviors through their associated group processes (Tajfel and Turner, 1979; Trepte, 2006). For the purposes of this research, a social identity approach was used in regard to the social status and age of individuals. The individuals interred at site 8-B-52.B were wealthy elite. Based on information from Haaland (2014), Eerkens et al. (2018), and Edwards (2004), elite groups in Meroitic culture not only had access to greater resources, but to different foods and trade items that could have allowed for greater variation in the diet of these individuals. In turn, greater dietary variation may have been a physiological benefit to the non-adult individuals being weaned.

Life history theory is concerned with variations in energy and resource allocation strategies in the body (McDade, 2003; Roksandic and Armstrong, 2011). Here, this approach is

used to explain the effect of dietary resource availability on the health of breastfeeding and weaning children. The process of weaning places a high pathological load on an individual—especially those receiving nutritionally poor supplementary foods—and trade-offs must be made to account for this. These trade-offs can include stunted body growth to allow for strengthening of the immune system, as well as reduced immune strength to allow for body growth, each of which places stress on the overall health of an individual (McDade, 2003). If a wider variety of higher quality foods were available to the mothers of weaning children, however, these children may have had to make fewer physiological trade-offs during the weaning process and could have had a greater chance of survival compared to individuals of lower status. Further comparative studies with larger samples sizes, as well as samples from lower status individuals, would allow for better understanding of the impact social status may have had on the diet and weaning patterns at Sai Island.

Ultimately, this study demonstrated the relationship between status, age, and dietary patterns during the Meroitic period, but more specifically illustrated the patterns of early life feeding and weaning behaviors that influence the relationship between a mother and her infant. The study of the mother-infant dynamic and how it varies through time is essential to understanding the lived experiences of mothers and children in both the past and the present; this includes aspects of human care, agency, reproduction, division of labor, and resource availability, among a number of other important facets of the human experience (Halcrow, 2020). To understand the actions and motivations of mothers and their children is to understand the most natural and intimate roles humans can play.

CHAPTER SIX: CONCLUSION

The goal of this research was to analyze and compare childhood dietary patterns of a sample of elite Meroitic individuals to better understand childhood diet and weaning. This section will be used to revisit the original research questions and hypotheses to discuss the results of each question. The first research question was "are the dietary differences between adults and non-adults in this sample?" The hypothesis was that there would be statistically significant differences in the diets of the adults and non-adults, especially between breastfeeding individuals and the adults. The results found that in regard to $\delta^{15}N$ there were statistically significant differences in the diets of the perinatal individuals and infants when compared to the adults in the sample, but no statistical differences between the young children, old children, and adults. No differences were found between non-adults and adults with regards to $\delta^{13}C$. This suggests that with the exception of breastfeeding individuals, all individuals in this sample were consuming similar diets, likely due to their elite status.

The second research question was "at what age are non-adults in this sample weaned?" Based on other research in the area, the hypothesis was that the non-adults in this sample would be weaned by the age of 2.5 years. Isotopic analyses found that by the age of 3 years, no consistent $\delta^{13}C$ and $\delta^{15}N$ enrichment was present, suggesting the completion of weaning. Three individuals aged 3 years or older (ages 3, 3.5, and 5 years) showed $\delta^{15}N$ enrichment consistent with the continuation of breastfeeding. It could be that these individuals and/or their mothers chose to breastfeed for a longer period of time than average; however, based on corroborating factors, these outliers most likely represent individuals facing an illness who were consuming different diets.

The final research question was "are there dietary differences within the elite social class in on Sai Island?" It was hypothesized that there would be differences in the weaning patterns of those from the wealthy elite 8-B-52.B cemetery compared to the contemporaneous religious elite cemetery on Sai Island (8-B-5.A), but results found no significant differences in the isotopic values of individuals in the two cemeteries. This finding is consistent with the homogeneity of the adult and child diet at site 8-B-52.B, which may suggest even broader dietary homogeneity among the elites interred at Sai Island, Sudan. Dietary homogeneity among the wealthy elite and the religious elite non-adults may suggest that these two groups shared similar access to resources and/or had similar practices for the diet and weaning patterns of children.

Limitations

The main limitations of this study are the sample size per age cohort for non-adults and the lack of child-bearing age adult females. While the perinatal and infant age cohorts were relatively well-represented by samples which ranged from the earliest to the latest ages of the category, the young child, old child, and adolescent categories were not as well-represented. More samples in the young child category—particularly those aged 2-4 years—would allow for a more well-supported conclusion to be made regarding the weaning age of the population. In addition, more adult female samples in the young adult category (those who would likely be childbearing) would provide more accurate values for comparing breastfeeding non-adults to the adult females in the population.

In addition to the lack of samples in certain age and sex categories, preservation issues were a limitation in this study. While 71 samples were initially collected for this research, only 54 samples were preserved well enough to be included in the analyses. Eight of the 17 poorly

preserved samples were from the perinatal age category, five were from the infant category, and three were from the young child category. If these samples had been preserved, their inclusion in the study could have allowed for more robust conclusions to be made about the diet and weaning patterns of non-adults in this population.

Lastly, it must be noted that the individuals analyzed in this study—particularly the children—died for a reason. If the individuals were sick, they could have been consuming different diets or have been treated differently, and this could have affected their isotopic values. Additionally, the lack of more detailed background information on the site and/or culture in question makes it difficult to understand any differences in treatment that may have been given to sick individuals. These limitations were taken into consideration when analyzing and interpreting the results of the study and caution was taken to not overstep or make any claims that could not be substantiated.

Future Research

To better answer the research questions posed in this thesis on a great population-level, a larger sample size is necessary. In addition to being larger, it would be highly beneficial for the sample to be more representative of each age category—especially the young children and young and middle adult females—in order to obtain the isotopic values necessary to conduct a more comprehensive weaning study. Further, it would be highly interesting to conduct similar research using the teeth of the individuals from 8-B-52.B to obtain a deeper understanding of each individual's life history. Because teeth form at different rates throughout one's lifetime, isotopic values could be obtained for each developmental stage of an individual's life (Beaumont et al., 2015; Eerkens et al., 2018). Further, by thin sectioning the deciduous dentition of non-adults and

analyzing the presence or absence of a neonatal line and the height of postnatal enamel formation, it is possible to determine the survivability of perinatal individuals (Smith and Avishai, 2005). This would allow for the isotopic values of the youngest individuals in a population to be interpreted more accurately based on whether they died at birth or survived for a period before dying. One last factor to consider for future studies would be the inclusion of a comparative lower-status population. This would provide the research with a more nuanced understanding of dynamics that existed within the diet and weaning patterns of different social classes in Meroitic period Sudan.

In addition, it would be beneficial to include animal and plant isotopic data in future research. Because very little zooarchaeological and paleobotanical work has been conducted at Sai Island, little is known about the extent of the dietary variation the individuals in this area would have had access to. A better understanding of the plants and animals that would have been available in this area at the time would allow for much more detailed analyses of individuals' isotopic values, but would also allow for a food web to be created which describes what types of foods an individual or a population was consuming.

APPENDIX: RAW DATA

Sample ID	Age	Sex	% Collagen	$\delta^{15}N_{AIR}$ (‰)	$\delta^{13}C_{VPBD}$ (‰)	Wt %N	Wt %C	Wt ratio C:N	Atomic ratio C:N
T-01 IND 1	Old adult	Female	3.8	13.9	-17.7	13.1	40.7	3.1	3.6
T-01 IND 2	10-11 years	N/A	0.6	11.2	-19.0	9.9	37.9	3.8	4.5
T-01 IND 4	2-3 years	N/A	0.6	12.8	-20.0	6.2	31.0	5.0	5.8
T-01 IND 5	10-12 years	N/A	2.4	11.0	-17.5	13.5	42.2	3.1	3.6
T-02 IND 2	5 years	N/A	Error	10.9	-13.9	14.5	40.7	2.8	3.3
T-02 IND 3	15 years	N/A	17.2	11.5	-18.6	15.9	44.8	2.8	3.3
T-02 IND 3	15 years	N/A	17.2	11.6	-18.6	15.7	44.4	2.8	3.3
T-04 IND 1	3 years	Female?	3.5	14.7	-12.7	14.6	43.9	3.0	3.5
T-05 IND 1	Old adult	Male	14.6	12.2	-15.2	15.7	44.8	2.9	3.3
T-05 IND 2	12-15 years	N/A	13.9	11.3	-15.9	15.0	43.6	2.9	3.4
T-07 IND 1	2.5 years	N/A	2.0	12.8	-17.5	12.8	42.2	3.3	3.9
T-07 IND 2	5 years	N/A	12.5	12.6	-16.9	15.8	43.3	2.7	3.2
T-07 IND 2	5 years	N/A	12.5	12.5	-16.8	15.8	43.2	2.7	3.2
T-07 IND 3	10 years	N/A	Error	12.6	-16.7	15.6	42.6	2.7	3.2
T-08 IND 1	Old adult	Female	Error	10.8	-15.5	6.4	18.5	2.9	3.4
T-08 IND 2	Middle adult	Male	1.9	13.4	-21.0	8.4	39.5	4.7	5.5
T-08 IND 3	45-50 years	Female	9.3	10.0	-17.3	14.2	38.9	2.8	3.2
T-09 IND 1	40-50 years	Male	9.2	12.8	-16.6	14.7	43.7	4.0	3.5
T-09 IND 4	Middle adult	Female	12.5	12.1	-16.8	15.3	42.5	2.8	3.3
T-09 IND 4	Middle adult	Female	12.5	12.0	-16.7	15.1	41.8	2.8	3.2
T-09 IND 5	40-45 years	Female	6.7	11.1	-18.5	14.6	43.7	3.0	3.5
T-09 IND 7	1 month	N/A	1.3	13.8	-16.4	7.2	28.1	3.9	4.6
T-09 IND 8	7-8 years	N/A	12.9	11.6	-17.7	15.8	43.7	2.8	3.2
T-09 IND 9	1 year	N/A	4.6	12.9	-15.9	13.7	38.3	2.8	3.3
T-09 IND 10	1 month	N/A	0.7	13.5	-18.2	9.7	33.4	3.5	4.0
T-09 IND 11	40 weeks	N/A	0.8	14.6	-18.1	8.1	31.2	3.9	4.5
T-10 IND 1	6-7 years	N/A	6.1	11.5	-18.6	13.2	39.7	3.0	3.5
T-10 IND 2	4-5 years	N/A	2.5	11.7	-17.4	10.9	20.5	2.8	3.3
T-10 IND 3	1-3 years	N/A	3.1	12.4	-18.6	10.0	28.3	2.8	3.3

Sample ID	Age	Sex	% Collagen	$\delta^{15}N_{AIR}$ (‰)	$\delta^{13}C_{VPBD}$ (‰)	Wt %N	Wt %C	Wt ratio C:N	Atomic ratio C:N
T-11 IND 1	9-11 years	N/A	4.6	12.3	-13.5	13.0	37.1	2.8	3.3
T-11 IND 5	45-50 years	Male	14.3	11.6	-16.7	16.6	46.3	2.8	3.3
T-11 IND 6	45-50 years	Female	Error	11.2	-16.9	14.9	42.0	2.8	3.3
T-11 IND 16	40 weeks-1 month	N/A	2.9	13.4	-17.1	11.3	33.1	2.9	3.4
T-23 IND 1	50-60 years	Female	13.6	11.8	-16.3	14.7	40.9	2.8	3.3
T-23 IND 2	8-10 years	N/A	5.6	11.9	-17.2	14.2	39.6	2.8	3.3
T-29 IND 1	20-25 years	Male	Error	10.7	-15.6	14.6	40.2	2.8	3.2
T-34 IND 1	11-13 years	N/A	16.8	11.4	-18.4	16.7	46.4	2.8	3.2
T-34 IND 1	11-13 years	N/A	16.8	11.5	-18.4	16.6	46.3	2.8	3.3
T-34 IND 2	40-50 years	Male	4.2	13.2	-15.8	15.0	43.5	2.9	3.4
T-34 IND 3	Old adult	Female	19.1	11.1	-15.9	15.4	42.8	2.8	3.2
T-34 IND 4	Young adult	Male	15.6	12.3	-18.0	16.0	46.3	2.9	3.4
T-34 IND 4	Young adult	Male	15.6	12.2	-18.0	16.1	46.2	2.9	3.4
T-35 IND 1	40-45 years	Male	12.5	10.1	-17.2	16.4	46.6	2.8	3.3
T-35 IND 2	50-60 years	Female	3.3	10.9	-17.8	13.3	37.5	2.8	3.3
T-35 IND 3	16-17 years	Female	8.4	11.4	-15.8	14.6	41.1	2.8	3.3
T-35 IND 4	12-13 years	N/A	Error	11.2	-17.1	14.1	39.7	2.8	3.3
Te-01 IND 1	2-3 years	N/A	0.6	12.1	-17.6	11.5	33.4	2.9	3.4
Te-01 IND 2	1 month	N/A	Error	Not Analyzed					
Te-01 IND 3	1 month	N/A	1.8	13.2	-17.0	11.5	32.8	2.9	3.3
Te-01 IND 4	1 month	N/A	1.5	14.0	-15.5	13.0	36.6	2.8	3.3
Te-01 IND 5	40 weeks	N/A	2.5	13.1	-17.7	11.0	33.8	3.1	3.6
Te-01 IND 6	1 year	N/A	9.4	15.0	-11.4	16.7	35.9	2.8	3.2
Te-02 IND 1	40 weeks	N/A	2.0	13.4	-15.1	11.5	33.2	2.9	3.4
Te-03 IND 1	1 year	N/A	11.3	14.9	-11.4	15.3	42.9	2.8	3.3
Te-03 IND 2	40 weeks	N/A	2.1	12.9	-16.7	12.3	35.4	2.9	3.4
Te-04 IND 1	40 weeks	N/A	1.7	13.0	-17.8	12.6	38.2	3.0	3.5
Te-04 IND 5	6 months	N/A	12.9	15.5	-9.8	15.7	44.4	2.8	3.3
Te-04 IND 6	40 weeks	N/A	Error	12.5	-17.5	7.5	29.7	4.0	4.6

Sample ID	Age	Sex	% Collagen	$\delta^{15}N_{AIR}$ (‰)	$\delta^{13}C_{VPBD}$ (‰)	Wt %N	Wt %C	Wt ratio C:N	Atomic ratio C:N
Te-04 IND 7	40 weeks	N/A	1.3	12.9	-14.6	11.9	38.6	3.3	3.8
Te-04 IND 8	40 weeks	N/A	3.0	12.7	-18.1	9.1	26.0	2.9	3.3
Te-04 IND 9	1 month	N/A	2.5	12.7	-15.1	12.7	37.9	3.0	3.5
Te-04 IND 10	40 weeks	N/A	0.6	13.2	-20.2	9.4	40.5	4.3	5.1
Te-05 IND 2	3 years	N/A	12.1	11.1	-17.0	16.0	45.3	2.8	3.3
Te-05 IND 2	3 years	N/A	12.1	11.1	-17.1	15.9	44.9	2.8	3.3
Te-07 IND 1	3-6 months	N/A	1.4	14.7	-12.5	12.6	25.6	2.8	3.3
Te-07 IND 2	1 month	N/A	2.1	13.4	-13.9	9.4	26.9	2.9	3.4
Te-07 IND 3	40 weeks	N/A	2.2	11.6	-12.5	12.5	40.1	3.2	3.7
Te-07 IND 4	36 weeks	N/A	3.9	13.5	-17.3	11.3	34.6	3.1	3.6
Te-08 IND 1	1 month	N/A	4.4	11.6	-15.9	12.4	40.5	3.3	3.8
Te-09 IND 1	1 year	N/A	0.0	Not Analyzed					
Te-09 IND 2	38-40 weeks	N/A	0.5	12.5	-16.1	12.1	34.9	2.9	3.4
Te-09 IND 3	40 weeks	N/A	0.9	14.3	-17.8	9.5	31.6	3.4	3.9
Te-09 IND 4	40 weeks	N/A	0.2	Not Analyzed					
Te-10 IND 1	9 months	N/A	1.3	14.2	-12.1	11.9	33.8	2.9	3.3
Te-12 IND 1	3-4 years	N/A	12.6	12.6	-13.5	14.6	40.3	2.8	3.2
Te-12 IND 1	3-4 years	N/A	12.6	12.6	-13.5	14.9	41.2	2.8	3.2
Te-13 IND 1	40 weeks	N/A	0.6	14.0	-16.1	6.2	26.0	4.2	4.9
Te-14 IND 1	1 year	N/A	2.1	14.2	-13.8	14.1	39.9	2.8	3.3

*yellow indicates samples that were not preserved
**green indicates duplicate samples

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