Taking a Bite out of History: Hellenistic Dietary Reconstruction and Population Mobility at the Site of New Halos, Thessaly, Greece

by

Hillary Anne Sparkes

A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

Department of Anthropology
University of Alberta

Abstract

The Hellenistic site of New Halos in Thessaly Greece was founded around 302 BC and was occupied for a short period of time until it was destroyed by an earthquake. The short occupation makes New Halos an ideal site for study because it represents a snapshot of rural Hellenistic life. Both the site of New Halos and an associated Hellenistic cemetery were excavated prior to this research. Skeletal remains from 98 individuals were collected for stable isotope analysis. Stable carbon and nitrogen isotopes from bone collagen and enamel carbonate were used to analyze diet composition. Mobility patterns were studied using strontium and oxygen isotopes from enamel apatite. The goals of this study were to investigate dietary habits at New Halos and understand dietary preferences. This study evaluated the importance of marine resources at New Halos. New Halos is situated close to the coast and during the excavations many marine shellfish were recovered suggesting they were an important dietary resource. The majority of the individuals at New Halos were consuming a C_3 terrestrial based diet. Some individuals showed signs of marine input while others appear to have consumed a diet whose protein was drawn primarily from domesticated animal products.

A second thread of investigation involved examining migration patterns and population composition. During the Hellenistic period many new settlements were established, but it is unclear where the population of these new settlements came from. The strontium and oxygen isotope results were able to identify that the population of New Halos was a mixture of both local and non-local individuals. It appears that the majority of non-local individuals were from areas to the west of New Halos towards the Othris mountain chain; others could have come from further afield. The isotopic investigation at New Halos has provided exciting results about this population.

Preface

This thesis is an original work by Hillary A. Sparkes. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board. “Taking a Bite out of History: Dietary Reconstruction and Population Mobility at the site of New Halos, Thessaly, Greece. No. 18071, 5 June 2012.

Acknowledgements

This PhD has been a long time coming and I would like to sincerely thank my primary supervisor Dr. Sandra Garvie-Lok for her patience, generosity, support, and guidance over the years. Dr. Margriet Haagsma, my co-supervisor, thank you for your guidance with the Hellenistic period and your archaeological expertise about New Halos. I have truly enjoyed working on this project and learning about this population.

My supervisory committee, Dr. Lesley Harrington and Dr. Robert Losey have been wonderful mentors during my time at the University of Alberta. I was a teaching assistant for both and I learned a great deal from them. Additionally, I appreciated their comments and help with this research project. Their experience and understanding greatly improved this work. Thank you to Dr. A. Keenleyside for being my external reader and for taking the time to provide excellent detailed comments. I would like to express my gratitude to Dr. Rupp, Director of the Canadian Institute in Greece, and Dr. V. Rondiri. They were both instrumental in acquiring the skeletal samples for this projects and for getting them to Canada. I would like to recognize the work done by Dr. R. Creaser and Dr. M. Ma. Their Laboratories analyzed my samples and provided the data for this research.

I would also like to acknowledge the Department of Anthropology at the University of Alberta. This department provided me with many opportunities to refine my teaching skills and develop a wide network of colleagues. To Jennifer Miller, Stephanie Brown, Erin Jessup, Lacey Flemming, and Thea Luig thank you for the many lunch and coffee breaks, constant friendship, and support during this degree. These incredible women are fantastic colleagues, but more importantly friends. A special acknowledgment goes out to my friends and family. To Marcy, Alana, Lucy, Thomas, and Pam thank you for the many years of friendship and all the support you have given me. Mom, Dad, Ainsley, and Rowan thank you for not letting me give up and for always offering to listen and offer words of encouragement. Ainsley and Rowan, thank you for the constant stream of Maeve photos, they really got me through some long days of writing and editing. Lastly, to my husband and best friend Kyle, thank you for your patience, support, and love. I am very proud of this accomplishment and I truly could not have done it without you.

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Chapter 1 Introduction

During the Hellenistic Period, Macedonian and Greek culture spread outward from Greece as a consequence of the areas Alexander the Great (356-323 BC) had conquered, especially the former Persian empire. His passing left behind a rich but vulnerable kingdom without an obvious leader (Billows 1995). The *diadochoi*, generals in Alexander's army who rose to power after his death, scrambled for control creating years of conflict, unrest, and turmoil. They each attempted to gain and maintain control over vast portions of Alexander's territory and rule the previously independent Greek city-states within their borders (Chamoux 2003). Toward the end of the 4th century BC, the *diadochoi* had eventually set up three empires: the Antigonid empire in Macedonia and Greece, the Ptolemaic empire in Egypt, Libya, and Palestine, and the Seleukid empire in Western Asia (Billows 1995; Boardman et al., 1988; Chamoux 2003; Habicht 2006). The *diadochoi* established many new cities in order to solidify and protect their new kingdoms (Cohen 1996).

The Hellenistic site of New Halos in Thessaly, Greece was a short-lived settlement that was established during this dynamic period. Previous archaeological work done at the site investigated how the town was laid out, what the occupation layers contained, if there was any evidence of social stratification, and what kinds of resources existed at New Halos (Reinders 1983; Reinders 2009; Reinders 1988). Faunal material, ceramic pieces, coins, and other artifacts have been analysed to understand this settlement (Prummel 2003; Reinders 2003b; Beestman-Kruyshaar 2003). The domestic economy and social organization were also explored through the analysis of houses at New Halos and the cultural material they contained (Haagsma 2010). Excavation of the Southeast gate at New Halos was completed to understand how and when this structure was used and how it related to the city of New Halos (Reinders 2014).

This dissertation will build upon the research mentioned above by investigating questions of food resource use at the Hellenistic city of New Halos using stable isotope analysis of human skeletal samples found in the cemeteries belonging to this city. Previous studies have looked at what resources and foods were available in Greece, what kinds of preparation methods were used, how foods were consumed, and what symbolic value they held (Chamoux, 2003; Errington, 2008; Haagsma, 2010; Mee, 2011;

Reinders & Prummel, 2003). In addition, food processing tools and other remains found in archaeological contexts provide valuable general and site-specific information about the choices populations made about available foods (Garnsey, 1999; Haagsma, 2010). Stable isotope studies provide an extra dimension to the existing historical and environmental research by adding direct evidence about diet and food choices of the inhabitants of Halos. This research method has the potential to support or challenge what the archaeological record and ancient written sources mention about the Hellenistic period (Ambrose, 1986; Bocherens et al., 1995). A cemetery associated with New Halos was excavated and produced approximately 100 graves and a large skeletal sample (Malakasioti 1985; Malakasioti and Rondiri 1990). In this study, bone and teeth from the New Halos skeletal population will be sampled and their stable isotope profiles will be analyzed to learn about dietary habits at New Halos.

The landscape around New Halos was not conducive to large scale intensive agriculture (Haagsma 2010); therefore this dissertation will examine diet at New Halos to understand what overall subsistence strategies were in place. Age, sex, and grave date will also be examined to identify if there are any dietary trends associated with these variables. Previous isotopic studies in Greece have shown that many past populations do not show a marine signature in their isotopic profiles (Petroutsa and Manolis 2010; Bourbou et al. 2011; Vika 2011; Panagiotopoulou et al. 2016). The archaeological record at New Halos reflects an abundance of marine shellfish. The various types of mollusks collected at New Halos would have required a high level of energy to collect enough shellfish to feed a single family. In contrast, terrestrial protein sources would have been more easily accessible at this site (Reinders & Prummel, 2003). This study will attempt to understand how reliant the people of New Halos were on marine resources (Prummel 2003). An attempt will also be made to understand if marine resources were equally accessible to the entire population or if they were only available to certain segments of the population.

A second thread of investigation will look at population composition. The available literature informs us about the establishment of new cities during the Hellenistic period (Archibald 2001; Aperghis 2005; Boardman et al., 1988; Boehm 2011; Chamoux 2003; Errington 2008; Kravaritou 2011; Migeotte 2009; Shipley 2000). New cities were often

built by means of s*ynoikismos. Synoikismos* literally means the "founding or establishing of a living space for people together" (Boehm 2011). When this term is used in reference to city-states it indicates that a resettlement, rebuilding, reoccupation, or repopulating had occurred (Boehm 2011). A *synoikismos* could mean the abandonment of an existing city and the construction of a new settlement; alternatively populations could be absorbed into an existing settlement. The policies of the Hellenistic kings had a dramatic effect on the landscape as cities were destroyed or evacuated to populate new cities (Boehm 2011). Often independent communities would be merged together into a new centralized area. This was beneficial for military strategy and was politically advantageous (Boehm 2011).

The foundation of Demetrias is an example of a *synoikismos* that occurred in Thessaly. Fifteen communities were drawn upon to populate the new city of Demetrias (Strabo 9.5.15). The people from these 15 communities had different political and linguistic preferences and these populations now found themselves within a new large urban settlement (Boehm 2011). Demetrias was founded as a royal city that controlled the Pagasitic Gulf and was dominant in Thessaly (Boehm 2011). Hellenistic kings created cities and moved populations regularly in order to concentrate their power and secure control in specific areas (Boehm, 2011). Merging and creating new cities was not a new phenomenon but the forced movement of populations was new in the Hellenistic period (Boehm, 2011). Other evidence that supports the forced movement of populations comes from a letter by Antigonos Monophthalmos who ordered the *synoikismos* of Teos and Lebedos. This letter can be found in a compilation of royal correspondence that survives from the Hellenistic period (Welles, 1934). The letter outlines that the population of Lebedos was forced to move and be absorbed by the city of Teos (Cohen, 1996).

The fact that New Halos was moved further inland to a more strategic location suggests that this was a calculated placement for a new settlement. It is unclear where the population of New Halos was derived, however if Demetrias and Teos can be used as examples it is reasonable to suggest that the population of New Halos was forced or at least coerced to move into the area. The stable isotope analysis of the New Halos remains will provide an important independent line of evidence about population

composition during the Hellenistic period. The site of New Halos was built during the Hellenistic period but it is unclear who lived at New Halos and where they originated. Based on an analysis of archaeological remains found in the houses of Hellenistic Halos, contextualized with epigraphic historical evidence from other Hellenistic cities, Haagsma (2010) suggests that the population that eventually occupied the Hellenistic city may have largely come from the immediate *chora* (surrounding area).

Strontium and oxygen isotope analysis of dental enamel will offer insights about where the New Halos individuals came from and can identify whether individuals were local or non-local to the area. If a *synoikismos* did occur at New Halos it would be expected that the isotopic data would show distinct groups from different geographic locations. Other considerations will be if age or sex reveal any pattern of population movement at New Halos. Understanding the population composition of New Halos can also be used as evidence for how the Hellenistic kings populated the many new cities that were established during this time period. This dissertation will add to the growing research in Thessaly and help progress our understanding of this region and the Hellenistic time period.

Below is a brief outline of the chapters in this dissertation.

Chapter 2 focuses on a brief historical background of Greece, tracing changing economic strategies and settlement patterns over time. A review of the Classical period and the rise of Macedonian power is covered to explain events that occurred leading up to the Hellenistic period. The Hellenistic period begins after the death of Alexander the Great in 323 BC and it is this period that is given most attention. The focus narrows to Thessaly during the Hellenistic period as this is where the site of New Halos is located. Political and cultural landscapes during the Hellenistic are investigated in this chapter along with information about daily lives of urban and rural Greeks. This chapter concludes with a discussion about diet, health, and subsistence in the Hellenistic period.

Chapter 3 introduces the archaeological site of New Halos. The history of New Halos is outlined along with a description of the location of the settlement and how the city was organized. Using excavation reports, evidence for diet and food at New Halos is presented and some questions about the subsistence patterns at New Halos are raised.

Lastly, this chapter discusses the associated cemetery where the skeletal collection for this study was recovered.

Chapter 4 focuses on stable isotope analysis. It provides a brief introduction to isotopes and how they are measured in different samples. An in-depth look at each of the four isotopes (carbon, nitrogen, strontium, oxygen) used in this study is then presented to provide the reader with an understanding of how the isotopes function within different ecosystems and body tissues. Lastly, examples of isotopic studies already performed in Greece are outlined; these will be used as comparisons to the New Halos data.

Chapter 5 presents the methods and materials used to conduct this study. It focuses on the site and how human and faunal samples were selected. Sample preparation for collagen analysis from bone is presented followed by enamel apatite preparation methods for strontium analysis and enamel carbonate preparation methods for oxygen analysis. A model to interpret collagen and carbonate $\delta^{13}C$ values is presented and explained in this chapter along with methods to interpret the strontium and oxygen data. This chapter also discusses diagenetic indicators and how to assess sample quality.

Chapter 6 outlines the results of this research. It begins with a discussion of quality indicators for bone collagen from human and faunal samples. This is followed by the results for dietary analysis based on the stable carbon and nitrogen isotope results from bone collagen. Enamel carbonate carbon results representing whole diet are compared to bone collagen carbon results reflecting dietary protein. Oxygen and strontium results are also presented in this chapter; they indicate individual movement patterns for people from New Halos. Differences in diet and place of origin are considered by separating the data by age, sex, and grave date. Lastly, this chapter examines whether diet was different for individuals who were identified isotopically as local or non-local.

Chapter 7 discusses and interprets the results from the previous chapter. It begins by comparing the $\delta^{13}C$ and $\delta^{15}N$ values from human and faunal collagen samples. The isotope values from bone collagen are also analyzed in terms of age and sex to determine if there are any variations in diet for different segments of the population. Chapter 7 also compares the isotope values from New Halos to previously reconstructed food values and to other isotope studies in Greece. The bulk dietary values from enamel

carbonate are then compared to the isotopic values from bone collagen, representing dietary protein. Following this discussion, oxygen and strontium values are interpreted to consider movement patterns for the population of New Halos. A discussion of local and non-local individuals is presented in the last section of this chapter.

Chapter 8 is a concluding chapter that summarizes the important findings of this study. It also presents possible avenues for future work. Although this is a robust study there is more work to be done to provide further information about the people of New Halos and more broadly on the Hellenistic period.

Chapter 2 Historical Background

2.1 Before the Hellenistic Period

This chapter will begin with a brief synopsis of the Greek Prehistoric and Historic periods. It will focus on economic strategies and settlement patterns during each period. Following this, a more detailed description of the Hellenistic Period will be given to provide the necessary historical context to answer questions about dietary habits and population composition of new settlements during this time period.

The Paleolithic period reaches back to approximately 2.5 million years ago and lasted until approximately 10 000 years ago. For this study we will consider a section of the Paleolithic starting around 55 000 years ago when modern humans were making their way to the Levant and Greece (Runnels & Murray, 2001). Stone, bone and other organic material like wood were used for constructing tools and weapons during this time period (Runnels & Murray, 2001). This was a time in Greece when early humans formed small, mobile, hunter-gatherer kin-based groups of around 20 to 50 people (Runnels & Murray, 2001).

The majority of Palaeolithic sites in Greece were along the coast; few have been found inland. The archaeological record shows short, interrupted habitation phases at Palaeolithic cave sites throughout Greece (Runnels & Murray, 2001). Franchthi Cave, a site in the Argolid, is the only known large Palaeolithic site that could accommodate a large number of people and it has been suggested that it was a possible home base for this population (Runnels & Murray, 2001). There was no evidence of graves, artwork or permanent construction associated with the Palaeolithic occupation of Franchthi Cave. Although the majority of known Palaeolithic sites in Greece were along the coast, all of the known Palaeolithic sites in Thessaly are inland sites found along the Peneios river (Adam, 1999). Palaeolithic sites in northern Greece can be found near Thessaloniki at Petralona cave and at Theopetra cave in western Thessaly. Theopetra Cave is an archaeological site that produced artifacts representing the Middle Palaeolithic through to the Neolithic period (Adam, 1999). Surface surveys in Thessaly conducted in the 1980s identified 32 additional spots that contained lithic artifacts associated with the Palaeolithic (Runnels, 1988).The majority of the 32 sites were in western Thessaly. A

survey in eastern Thessaly failed to yield any Upper Palaeolithic or Mesolithic sites (Runnels & Murray, 2001).

The transition from the Palaeolithic to the Mesolithic (10 000 – 9000 BC) is reflected in the environmental and archaeological records. The climate got warmer in the Mesolithic and large plains were replaced with forests. The forests pushed large animals further north while other species went extinct opening up habitats for new types of fauna (Runnels & Murray, 2001). Elk, deer, and pig replaced the larger Palaeolithic fauna creating a need for new types of stone tools and hunting methods (Runnels & Murray, 2001). Mesolithic sites are found inland and at higher elevations; this was likely in response to the warmer climate and rising ocean levels (Runnels & Murray, 2001). The people of the Mesolithic still chose to live in caves; however, this may not have been the only occupation pattern as the rising ocean levels could have submerged and erased Mesolithic coastal sites, altering our understanding of this time period (Runnels & Murray, 2001). At cave sites during this period grinding stones and the first evidence of burials are found. Hunting was still an important part of the subsistence strategy during the Mesolithic, though there is also evidence of wild plant and marine resource use (Runnels & Murray, 2001). Theopetra Cave, mentioned above, has a continuous occupation record that includes the Mesolithic Period (Kyparissi-Apostolika, 2003). Not only does this site prove that there was a Mesolithic occupation in Thessaly, it is also an important site that contains evidence for the transition between the Mesolithic and Neolithic Periods in the region (Kyparissi-Apostolika, 2003).

Agriculture, animal husbandry, and permanent architecture are some of the major changes seen in the area during the Neolithic Period (9000 BC- 5000 BC) (Runnels & Murray, 2001). The Greek Neolithic economy was based on agriculture and small permanent villages. Examples of Neolithic sites found in the Almiros plain include Magoula Zerelia and Magoula Ambelia-Almirou (Reinders, 2004).

There are different theories on how the Neolithic subsistence strategy developed in Greece. The first theory suggests that a new subsistence pattern did not develop gradually in Greece; instead the Neolithic began abruptly with the appearance of fully domesticated species of plants and animals imported from the Near East (Runnels & Murray, 2001). By 10 000 BC permanent villages and farming techniques had developed

in the Levant and the Near East. This theory holds that these techniques were brought with people as they migrated to Greece (Runnels & Murray, 2001). The Neolithic settlement at Franchthi Cave begins abruptly with the introduction of domesticated sheep/goats along with domesticated cereals (Runnels & Murray, 2001). Outside the cave entrance are small houses with stone foundations and mudbrick walls built on virgin soil (Runnels & Murray, 2001). These permanent structures are a major difference from the previous time periods. In addition to architectural changes during the Neolithic the material culture at the site also shows a transition from flaked stone tools to ground stone tools, and the introduction of textiles, pottery, and art (Runnels & Murray, 2001).

A second theory proposes that indigenous Greek populations developed techniques for domestication and Neolithic subsistence strategies, possibly through cultural and technological exchange and contact but not through direct colonization (Zeder, 2008). However, recent genetic studies have provided new insight into this discussion suggesting that the transition into the Neolithic is more complex and is perhaps a combination of both theories mentioned above (Zeder, 2008). Although this topic isbeyond the scope of this research, it is important to mention because animals and plants that were heavily relied upon by the population of New Halos were domesticated around the time of the Neolithic transition.

Thessaly, with its vast agricultural plains, was the centre of Neolithic society in Greece (Andreou et al., 1996; Preziosi & Hitchock, 1999). There are hundreds of mounds recorded in Thessaly that reflect a successful Neolithic culture (Alexakis et al., 2011). The mound settlements had small populations of 100-400 people (Runnels & Murray, 2001). Andreou et al. (1996) composed a review of Aegean prehistory that included a summary of important Neolithic sites in Thessaly. Among the Thessalian sites mentioned were Sesklo, Dimini, and Theopetra Cave. Theopetra Cave is an interesting site because the long occupation history begins in the Middle Palaeolithic and continues through all phases of the Neolithic (Andreou et al., 1996). Early pioneering research was conducted at Sesklo by Christos Tsountas in 1908. The rich Neolithic record in Thessaly along with research in the 1970s at Dimini by Georgos Hourmouziadis and again at Sesklo by Demitris Theocharis was responsible for making this region the centre of Neolithic research in Greece (Andreou et al., 1996; Demoule & Perlès, 1993). I would direct

readers seeking more information about the Neolithic period in Greece to the review by Andreou *et al.* (1996) and the sources they cite therein.

The Helladic or Bronze Age period in Greece covers a large spatial and temporal range. This term is used to discuss what was happening on mainland Greece, on Crete, and on the Cycladic Islands between approximately 3000 BC and 1100 BC (Runnels & Murray, 2001). It can be broken down into three periods: Early Helladic (3200 BC-2000 BC), Middle Helladic (2000 BC-1550 BC), and Late Helladic/Mycenaean Period (1550 BC-1100 BC). Additionally, the civilization that was developing at this time in Greece was a network of politically independent, organized, and stratified societies (Runnels & Murray, 2001). Large buildings, fortified walls, and valuable copper objects support the interpretation of a growing stratified society (Runnels & Murray, 2001).

Many innovations occurred during the Early Helladic period including the plow, long boats, and improved textiles (Runnels & Murray, 2001). The plow made cultivation more efficient and as a result trees were cut down to increase the usable land. This in turn was one reason the landscape changed and soil erosion occurred. Destruction of forests, drier climates, and grazing animals also contributed to changing the landscape (Butzer, 2005). People were encouraged, as the landscape changed, to move down into valleys where farming could still take place (Runnels & Murray, 2001). Jahns (1993) recorded a pollen profile from a core sample taken from Lake Lerna in the Argive Plain. The pollen analysis determined that during the Early Bronze Age there was a decrease in deciduous oak trees and a partial clearance of the vegetation. This suggests that a modest amount of upland grazing of livestock was occurring at this time (Jahns, 1993). As time progressed an increase of olive cultivation was recorded and the Late Bronze Age reflected intensive agriculture in the pollen profile. During the Hellenistic period it was suggested that olive groves and vineyards were well established, and upland areas continued to be deforested and changed into open shrub-land suitable for grazing animals (Jahns, 1993).

Similarly, a core from New Halos was examined to recreate the area's environment (Bottema, 1988). In this pollen profile a similar deforestation of deciduous oak trees occurred at the same time as in the Argive Plain, as indicated by the core analysed by Jahns (1993). Also, increases in tree species that are better resistant to grazing thrived.

According to Bottema (1988) the change to grazing resistant tree species was the result of increased amounts of grazing animals in the area. It also indicated human interference through deforestation because otherwise a deciduous oak or fir tree forest would have had equal chance for regeneration. The Early Helladic period ended with site abandonment and/or destruction throughout the Greek mainland (Runnels & Murray, 2001).

The archaeological record for the Middle Helladic period suggests that Early Helladic mainland settlements and population numbers decreased significantly while the Minoan and Mycenean civilizations reached their high points. Knossos on Crete is an example of a large palatial structure built by the Minoans (Runnels & Murray, 2001). The destruction of Knossos is attributed to an attack by the Myceneans in 1450 BC (Preziosi & Hitchock, 1999; Runnels & Murray, 2001). At the peak of Mycenean civilization they set up networks of mini-kingdoms that had centralized administrations and a military force (Preziosi & Hitchock, 1999; Runnels & Murray, 2001).The Mycenean population grew in numbers quickly; their territory began in the southern Peloponnese and Argolid and reached as far north as modern Thessaloniki (Runnels & Murray, 2001). Magoula Pavlina is a Middle Bronze Age site located in the Sourpi plain. The excavations at this site recovered thousands of mollusk shells, which, as will be seen below, is similar to the archaeological record from New Halos. It is approximately 2.5 km southeast of New Halos. As at New Halos, the residents of Magoula Pavlina would have gathered shellfish from Sourpi bay (Reinders, 2004).

The final stage of the Mycenean civilization occurred in the Late Helladic period. Towards the end of that period (ca. 1250 BC), the archaeological record shows signs of war and preparation for war at many sites. Fortification walls were erected around cities, large gates controlled the flow of people, and increased storage facilities were built within city walls to sustain a population for long periods of time (Runnels & Murray, 2001). Starting around 1200 BC waves of destruction moved throughout Greece. The Mycenean civilization collapsed and it eventually disappeared completely by 1100 BC along with all their technologies (Runnels & Murray, 2001).

After the collapse of the Mycenean and Minoan civilizations the archaeological record indicates that there was a decrease in the number of settlements and they become

scattered and unorganized during the 11th century BC (Whitley, 2001). It has been proposed that the individuals living at this time switched from a cereal based agricultural economy to herding cattle and other animals (Whitley, 2001). It is also assumed that there was a lack of political structure within or between the settlements at this time. It is most likely that settlements were composed of a ranked society of kin-based groups (Whitley, 2001).

In the 8th century BC the population of Greece began to increase and evidence of contact with the Near East and Egypt emerged. It was also at this point that the concept of 'citizen' developed (Whitley, 2001). The concept of citizenship arose within Greek city-states and was seen as a way to connect an individual (male) to his city-state. Artifacts from Athens have provided evidence about citizenship within that community. Citizenship linked men to each other beyond kin-based relationships which deepened their loyalty to their city-state (Heater, 2004; Manville, 2014). Citizenship meant that citizens could participate in cults and festivals, vote and speak in political assemblies, and own land (Manville, 2014). Aristotle believed citizenship was established to encourage political participation which was an integral part of culture (Heater, 2004). Citizens were also required to fulfill military duties and pay taxes (Manville, 2014). Failure to abide by these laws would result in the loss of rights and privileges (Manville, 2014).

The *poleis* (city-states) arose at the beginning of the Archaic period (700 BC); small settlements were abandoned and larger settlements were formed creating urban environments (Whitley, 2001). By the end of the 6th century these new city-states had fortified walls, temples, public buildings and a public water supply along with specific ideas about how to treat the dead (Whitley, 2001). Urban environments also had people who began to specialize in various trades like pottery or metal work. As settlements evolved a social stratification and political structure emerged as there was a need for a political system that could facilitate decision making for the population (Whitley, 2001).

It is important to this study that the Classical period be well understood as events during this period influenced how the Hellenistic period unfolded. The Classical Period (480-323 BC) saw the height of the Greek city-state (*polis*). The Classical *polis* was a system of urban and rural areas that were economically interdependent (Alcock, 1996; Migeotte,

2009). Aristotle and Plato shared an opinion that the appropriate management of individual agricultural estates by citizens was the backbone of a healthy *polis* economy (Miller, 2012). This belief was the basis for many conflicts between *poleis* because agricultural land was limited and conflict would arise when ownership was questioned or challenged. Sanctuaries were an important part of the landscape and were used as forums where social and political status could be negotiated (Alcock, 1996). The Classical Period was also a time marked by internal instability and rivalry between Greek city-states. During this time city-states remained separate political communities but they shared similar ideas about the Greek world. Struggles were continuous as city-states fought wars and attacked each other to maintain control of a region.

The Peloponnesian War (431-404) saw Sparta pitted against Athens, one of many examples of how instability in the Greek world manifested itself. A result of the Peloponnesian War was a change in fighting methods and the development of paid (mercenary) soldiers (Boardman et al., 1988). Prior to the Peloponnesian War soldiers were often local men defending their *polis* and the surrounding area. Mercenary soldiers weakened the link between a *polis* and the men fighting for it because they were mobile and went where they were needed.

The late Classical period was also characterized by the increasing power of the kingdom of Macedonia in Northern Greece. Philip II of Macedonia recognized that Greek city-states were preoccupied with internal, intraregional, and interregional power struggles. Philip II capitalized on the Greeks' distraction and seized control of Macedonia and Thessaly in the 350s BC (Boardman et al., 1988; Morris & Powell, 2010). Philip II was a charismatic leader with innovative military tactics. Much of his military success was based on the changes he made to the Greek phalanx. The Greek phalanx was traditionally a group of 100 men in a ten by ten formation. The soldiers wore heavy armor and carried spears (Freeman, 2011). In contrast to the traditional Greek hoplites who carried expensive shields and heavy body armor, his soldiers had a 16-foot *sarissa* (spear) and much lighter body armor allowing for more flexible movement (Billows, 1995; Freeman, 2011). The lighter armor was less costly, and therefore the military was no longer an expensive elite career (Billows, 1995;

Freeman, 2011). Men of all backgrounds and wealth could now make a career out of being a soldier.

With this new military structure Philip II won battles against the Phokians, Thebans, Illyrians and the Chalkidian League (Billows, 1995). He was able to hold these gains in part by directing the Greeks against a common enemy, Persia. The so-called Corinthian League, a consolidation of a large number of Greek *poleis* determined to undermine the Persian Empire, was founded shortly after Philip's decisive victory against the Greeks at the Battle at Chaironea in 338 BC. Another successful tactic Philip II employed was to give land in Macedonia to Macedonians or those who wanted to become Macedonian. This was a strategic move which provided long term stability to people who were loyal to the Macedonian rulers (Errington, 2008).

Philip II was assassinated in 336 BC, allowing his 19-year-old son Alexander to assume the leadership role. Alexander the Great, as he was later known, was able to raise funds for an army consisting of Macedonians and mercenaries. This army went on to conquer the Persian Empire, Asia Minor, Northern Syria, and Egypt using his father's military strategy (Billows, 1995; Boardman et al., 1988). As Alexander and his army entered new territory they brought with them a thoroughly Hellenized culture. The dissemination of Greek culture throughout Alexander's empire laid down the foundation for what is now known as the Hellenistic period, a time when the Greek world expanded its borders and the Eastern Mediterranean area became a multicultural society (Shipley, 2000).

In 323 BC Alexander The Great died in Babylon at the age of 32 (Boardman et al., 1988). Alexander's death left his army and his *diadochoi* (generals) divided. The infantry was loyal to Alexander and supported the Argead bloodline. The infantry wanted either Alexander's young half brother Arrhidaeus or Alexander's unborn child being carried by his wife Roxanne as heir to the empire. However, Alexander's *diadochoi* saw this void as an opportunity to rise to power. A conference was held in Babylon and after a week's negotiation a compromise was reached: Arrhidaeus would reign as King Philippos III and would be co-king if Roxanne's child was a boy (Billows, 1997). Roxanne did have a son named Alexander IV. In the interim while the two boy-kings reached maturity Alexander's *diadochoi* would rule in their stead. This compromise led to many years of

conflict and struggle as Alexander's large empire was broken down into three distinct kingdoms.

2.2 The Hellenistic Period

Although the Hellenistic was a rich period of Greek history we are left with incomplete records of this time period (Chamoux, 2003). There were many historians writing during the Hellenistic period – examples of major 3rd century BC historians include Hieronymos, Phylarchos and Aratos (Shipley, 2000) – but few of their works survive. The surviving fragments of work from Hellenistic historians tend to concentrate on war and Rome's eventual conquest of Greece, obscuring the daily lives of individuals. More complete surviving texts are not often from contemporary accounts but rather were written by philosophers looking back in time (Chamoux, 2003; Shipley, 2000). Thus, modern research into the Hellenistic period has had to rely mainly on inscriptions, papyri, and coins for information about social and economic conditions. These items provide information about specific scenarios but do not lend themselves easily to generalizations about the period (Habicht, 2006). Scripts do not always mean what they say and their meaning can prove difficult for modern researchers to interpret. A contemporary audience would easily understand subtle jokes and ironic scenes that were described by an author. Because cultural references are often specific to a time period, modern researchers can easily miss their meaning as they attempt to interpret written sources. Although complete contemporary sources are lacking there is still a great deal known about the Hellenistic. The following section will offer a brief outline of how events unfolded after Alexander the Great's death and how the cultural, social, and economic landscape in Greece changed during the Hellenistic period.

As described previously, Alexander the Great's sudden death in 323 BC left his empire without a clear successor. The result was that Alexander's generals were entrusted to rule in the place of his heirs until the boy-kings came of age (Austin, 1986). However, the young kings never got the opportunity to rule because the ambitious generals took control for themselves. In 311 BC the tenuous peace that had been established between the generals failed. Alexander's empire was broken into parts, and three kingdoms took root (Bengston, 1988). Macedonia fell to the rule of Antigonos Gonatas, whose Antigonid dynasty would rule Macedonia and southern Greece until the Roman

conquest at the end of the 2nd century BC (Shipley, 2000). Egypt was ruled from that point onward by the Ptolemaic dynasty (Shipley, 2000), and Persia and Central Asia were ruled by the Seleucid dynasty (Billows, 1997; Boardman et al., 1988; Chamoux, 2003).

The new rulers foresaw difficulties with maintaining control as Alexander's heirs approached adulthood, and they were unwilling to relinquish their power after many years of war (Billows, 1997). In order to avoid any problems both young kings were murdered (Bengston, 1988; Billows, 1997; Chamoux, 2003). With the Argead heirs dead, fighting amongst the three territories continued as each ruler attempted to extend his reach; this fighting continued through later generations until approximately 280 BC (Chamoux, 2003). As these conflicts went on the ruling castes developed into monarchies. All three rulers took the title of king. Antigonos the-One-Eyed was the first to adopt the royal title in 306 BC (Bengston, 1988; Shipley, 2000). The necessary qualities of a king included divine ancestry, controlling a large territory, and having substantial wealth and military success (Shipley, 2000).

As time went on the Macedonian rulers protected their territory by keeping power securely in Macedonian hands, beyond the reach of the Greeks (Errington, 2008). They accomplished this by endogamous marriage with other elite Macedonians. However, the Macedonian kings still faced problems ruling over the Greeks. They encountered resistance and had to strike a delicate balance that gave Greek cities some autonomy while keeping them loyal to the Macedonian king (Austin, 1986). The kings needed the support of the cities, so could not treat the population harshly or with force; likewise the populations needed the protection of the kings, so could not resist too much or risk being vulnerable to another ruler (Shipley, 2000). A goal of the kings was to create a system whereby cities could continue to practice their own way of life, avoid conflict, and still be loyal to the king (Errington, 2008). In addition, as the regionalized dynastic structure developed, the kings knew they must find a way to connect armies to themselves and earn their loyalty (Errington, 2008). They knew that without military strength they would not be able to maintain power or their territory against the other kings (Billows, 1995).

Warfare was second nature to the Hellenistic kings, as they knew power rested in military prowess. There was constant fighting between the kings, especially between the

Ptolemies and the Seleucids (Biers, 1996). Many new cities were founded in order to appease the armies and to provide land to reward soldiers, all the while being built in strategic locations (Boardman et al., 1988). Within the Seleucid realm military colonies were established, and the Ptolemies granted land to their soldiers across their territory (Boardman et al., 1988). Antigonos also established cities to settle his troops in permanent locations in exchange for loyalty (Billows, 1995). Hellenistic military expenses were high because many of the soldiers were mercenaries. In order to cover costs, the Kingdoms relied on taxes from their cities (Billows, 1995; Migeotte, 2009).

2.2.1 The Greek Political Landscape During the Hellenistic Period

The Greek ruling class in the Hellenistic period consisted of the monarchs, their immediate family, close friends, and the military elite (Habicht, 2006; Nielsen, 1994; Ogden, 2002). The duties of a king were to dispense justice, create new laws, and lead the military (Austin, 1986; Nielsen, 1994). A king's court became the centre of intellectual life because the Hellenistic kings competed to recruit the best talent in all fields of study (Habicht, 2006). Science made significant advances as a result of this competition (Habicht, 2006). The elite class surrounding the kings enjoyed economic and political benefits and helped to rule the kingdoms (Habicht, 2006). The majority of the king's ruling class were "Hellenes"; this included Macedonians because they shared the language and because Alexander the Great improved the Macedonian image (Habicht, 2006). In contrast, Egyptians, Syrians, Jews, and Persians were not granted membership into a king's entourage because they were seen as 'others' or non-Greek (Habicht, 2006).

It was common for new kings to replace their father's council with their own trusted friends as advisors to ensure loyalty and protection (Habicht, 2006). Cities would follow the laws set out by the king, and these laws would be implemented by the king's family and friends (Chamoux, 2003). Many cities had their own laws, judicial systems and currency. In many instances cities could continue to function as they had before by implementing small changes to comply with new laws (Billows, 1995; Chamoux, 2003). Cities generally consisted of an urban centre which acted as a main gathering place and a rural agricultural area that produced food to support the urban area (Migeotte, 2009).

In many instances the urban and rural areas were interdependent and one did not control the other; rather, both were necessary for the success and well-being of the joint population (Migeotte, 2009).

Citizenship within the Greek world was a very important status to hold. Possessing Greek citizenship allowed men to participate in government, own land, and have legitimate Greek children who could inherit property (Migeotte, 2009). Both mother and father had to be Greek citizens for their children to be recognized as Greek (Manville, 2014; Migeotte, 2009). Beyond this core benefit, wives who held citizenship were not given many more rights than children. They lived under the control of their husbands, sons, or other male relatives and were only allowed to carry the same amount of money as children (Manville, 2014). Women's intelligence was considered similar to that of a child (Migeotte, 2009). The ideal was for women to exist within the private family sphere.

Given the far-reaching boundaries of Greek territory, many native people in newly established Greek city-states were never given Greek citizenship in either the city-state where they lived or in the wider Greek world. However, non-Greeks did gradually adopt certain aspects of Greek culture (Boardman et al., 1988; Shipley, 2000). Greeks were determined to maintain their identity no matter where they settled, hence the restrictions placed on citizenship that did not allow non-Greeks to attain Greek citizenship. Greeks feared that their culture would be threatened and changed if non-Greeks were given citizenship. Many scholars are now of the opinion that the Near East did not fully adopt Greek culture but instead co-existed and functioned within the Greek way of life (Shipley, 2000).

Specific details about non-citizens are limited. It is known that individuals who did not possess Greek citizenship were part of the lower social classes and had limited rights. Foreigners could not hold political office, own land, or marry a citizen woman (Manville, 2014). If a foreigner wanted to sell goods in the public market they had to pay a special tax for that privilege (Manville, 2014). Foreigners could be tenant farmers or paid employees of full citizens (Migeotte, 2009). Slaves on the other hand did not own land and were considered the property of their citizen master (Migeotte, 2009). Often people captured from conquered cities were forced into slavery (Haagsma, 2010).

Near the end of the Hellenistic period citizenship became easier to achieve as Romans moved into the Greek world and populations became more fluid (Migeotte, 2009). Alexander the Great understood the importance of recruiting non-Greek men during his crusades to replenish his numbers and to appease the local populations (Habicht, 2006). He was met with strong resistance from his council, advisors, and his army in response to his willingness to accept foreigners. After his death, even if the kings had wanted to continue with Alexander's plan of including foreigners in Greece they were not able. The resistance from the army and Greek citizens was so strong that the kings were forced to reverse what Alexander had done and exclude non-Greeks once again (Habicht, 2006). It is clear that the kings were constantly under threat not only from invading armies but also from the populations within their territory. As a result, finding a balance and establishing long-lasting peace during the Hellenistic period eluded them.

2.2.2 Hellenistic Economy

Defining 'The Hellenistic Economy' is difficult as the Hellenistic world was complex and covered a vast area. Each Hellenistic king controlled and ruled over his territory differently. Based on political changes and the increase in new settlements across the Hellenistic world it is common to assume that major economic changes did occur (Archibald, 2001). Davies (2001) argues that the Hellenistic economy on mainland Greece did not change from Classical times despite the political turmoil of this period. Additionally, Davies claims that in Asia Minor, Egypt, and Mesopotamia the political rulers may have changed but the social and economic systems did not change as drastically as some believe (Davies, 2001). Davies is arguing that one unified Hellenistic economy did not exist; instead, there were changes to existing economic patterns throughout the Greek world.

An economic driver during the Hellenistic was the large professional army employed by the Hellenistic kings (Davies, 2001). Armies required payment and weapons had to be manufactured. The military fleet needed to be built and maintained and cities had to be fortified. Soldiers were sometimes given land in order to guarantee their loyalty to the King (Davies, 2001; Erskine, 2005). Garrisons were both a positive and negative force on a local economy because they put a great deal of stress on the system. They required food, lodging, skilled trades people, and many city resources (Archibald, 2001; Davies,

2001). *Katoikiai* were military settlements that were similar to a garrisoned town except that the majority of the population was military personnel. *Katoikiai* were established to control vulnerable regions in a king's territory (Aperghis, 2005). While many towns existed before a garrison was stationed there the *Katoikiai* were strategic settlements founded specifically for military purposes.

New settlements were not founded solely for military support or political control. The majority of new settlements during the Hellenistic were the result of royal intervention, and historians have used city development over time to assess cultural and economic changes (Archibald, 2001). The Seleukid kings developed new settlements in areas with large agricultural potential in order to generate economic activity and produce revenue through the cultivation of food crops (Archibald et al., 2005; Erskine, 2005). A fundamental feature of the Hellenistic economy was the production of food. The *poleis* would have had connections to agricultural land through citizen owned or city owned land (Erskine, 2005). Most people during the Hellenistic period would have been small scale farmers, either as owners or tenants (Erskine, 2005). New urban settlements would have needed to import a diverse population to fill all jobs associated with food production. Skilled trade workers, not normally found in rural environments, would have been brought to the new settlement, often from neighboring urban centres (Aperghis, 2005). The trade workers would develop goods and provide services that added to a city's economy. Developing or maintaining a network of cities to buy and sell goods produced in these new settlements would be important for a population to survive. Over-land trade was often done over short distances between closely connected communities.

Large scale trade networks did exist, but were controlled by the Hellenistic kings. Timber for example was a resource controlled by the kings and it was sold based on a supply and demand model (Davies, 2001). Similarly, salt was an important resource traded on a large scale. Salt was not a local resource in all areas; inland settlements would have had to exchange goods or buy it directly (Davies, 2001). These two examples indicate that the movement of some goods was regulated and controlled by the kings or other wealthy individuals while market places would have existed to trade all types of local resources.

It is unlikely that every settlement had similar access to goods. Being close to trade routes or having a desirable commodity to sell or trade would provide a settlement with access to the goods they required. Without an established network that could supply a settlement with resources it lacked, it would be very difficult to support and maintain a population.

2.2.3 The Thessalian Landscape

There is an incomplete picture of the culture in Hellenistic Thessaly because – as for the Hellenistic world in general – reliable firsthand accounts of the area do not exist (Westlake, 1969). Westlake (1969) describes how the topography of Thessaly influenced its regional cultual development and explains why it differed slightly from cities like Athens in the south; the summary in this section follows that source. Thessaly is surrounded by mountain ranges that separate the land into two large upper and lower plains. The natural geographical division of the Thessalian plains led to the creation of four districts of Thessaly: Thessaliotis, Hestiaeotis, Pelasgiotis and Phthiotis. These eventually developed beyond geographical regions into political organizations within Thessaly. Eventually a Thessalian league developed that united these four areas, primarily for military defense. Near the end of the 4th century BC a fully united Thessaly emerged. After this unification and prior to the Hellenistic Period, Philip II became the president of the Thessalian League. Philip II was eager to acquire access to Thessaly because of their superior cavalry and better harbour access (Westlake, 1969). He achieved this access through diplomatic strategies and did not draw unwanted attention to himself. Presidency of the Thessalian League granted a Macedonian leader unprecedented access to Greek military power, and played a role in Phillip's rise to power (Ashley, 2004). Most large Thessalian cities were in the lower plain, although overall Thessaly had a relatively small population. In order to grow the population of Thessaly the region accepted outsiders, and population growth and urbanization began in the 4th century BC. During the Hellenistic period Thessalians lived in the northern areas of the mainland world, but they were still considered Hellenes, if just a bit different from the southern Greeks (Westlake, 1969).

2.3 Evidence for Daily Life in the Hellenistic Period

As discussed in section 2.2, the Hellenistic is a period which lacks a large number of documentary resources (Errington, 2008). The available sources are mainly from periods before and after the Hellenistic. A rare Hellenistic source, 'The Histories', written by Polybius, covers the period of 264-146 BC. Polybius wrote about 100 years of struggle and change in Greece, focusing on the elite upper class. There are also sources from the 1st century BC by Artemidoros, but his work focuses on sailing and cartography and offers little about the daily lives of people (Palagia, 1992). Manuscripts from 5th century BC writers and historians such as Herodotus, Sophokles, Ephorus, Thucydides and Xenophon provide a wide selection of information about daily life in earlier Greece (Boardman et al., 1988; Pomeroy, 1997). These are among some of the best sources we have considering the lack of Hellenistic sources. The Classical and Hellenistic eras differed in many ways and we must be aware of the possibility that daily life was also different.

Our understanding of the Hellenistic period is incomplete for other reasons. The Classical texts available for extrapolation about Greek lives in the Hellenistic period were written by elite men, which may bias the information provided (Nardo, 2000; Nevett, 1995; Pomeroy, 1997). The rural population, women and children, and the poor are largely absent, ignored or undervalued in these documents (Chaniotis, 2005). When men in antiquity were writing about women they were doing so in relation to their own experiences and place in society. Thus, modern authors using these sources may believe they are writing about men, women and children of all social classes when they are in fact focusing on elite individuals and emphasizing men and boys because that is who the literature represents (Brulé, 2003; Pomeroy, 1997).

Another limitation when using the Classical sources is that most of their evidence is focused on Athens and Sparta (Nardo, 2000; Nevett, 1995; Pomeroy, 1997). It is important to recognize that the sources do not reflect life in Greece generally. They may allow us to infer how the rest of Greece may have lived, but these sources provide information about daily life specifically in Athens and in Sparta. Athens in particular is the subject of many ancient sources, but this does not necessarily make it representative of Greece as a whole. Unfortunately it is difficult to determine what

types of regional differences existed because there are so few sources that comment on cities or regions other than Athens (Nevett, 1999).

In conjunction with ancient written sources researchers have often chosen to work with other sources of evidence. Information about the period can be gleaned from archaeological data, including iconographic evidence from sources such as funeral stelae, coins, and paintings (Andrianou, 2006; Edward et al., 1984; Haagsma, 2010; Pemberton, 1985). Archaeological data can support or refute what the ancient written texts describe. It can add to areas in the Hellenistic record that would otherwise be blank, like the daily lives of rural or non-Athenian and non-Spartan territories. Archaeology can also expose aspects of life obscured by the written sources, such as how women, children, and the poor lived. The archaeological record can increase our knowledge about sections of the population that remain invisible in the ancient writings. Archaeologists conceive, interpret, and influence our understanding of domestic space in past cultures, providing another window into daily life (Haagsma, 2010).

2.4 Daily Life in Hellenistic Greece

The daily lives of Greeks varied depending on sex, age, and social class. Cities were essentially male organizations where politics were a city's central focus. Men would publicly gather daily to discuss and debate political matters (Boardman et al., 1988). Male citizens spent much of their time outdoors and in the public sphere (Boardman et al., 1988). In addition to a man's public role he was also head of his household, or *oikos*. The Greek family in Athens was a monogamous arrangement between husband and wife, which existed in the private sphere to support children, dependent relatives, and slaves (Boardman et al., 1988). Aristotle promoted the idea of the *oikos* as a very important part of daily life (Haagsma, 2010).

For the wealthy, marriages were unions to link families together and to create new alliances (Pomeroy, 1997). Marriage in Greek culture was seen as fulfilling one's responsibility to produce an heir who would inherit family property and to produce strong warriors for the city (Nevett, 1995). Often a family would raise multiple children, especially boys, because although only one heir was needed, many children and men died (Pomeroy, 1995). It has been estimated that families would have on average four

children (Migeotte, 2009). Adoption was also practiced, as families without sons could adopt a boy; females were rarely adopted (Pomeroy, 1995).

In Athens men had to serve as soldiers for 10 years, so their marriages were sometimes later in life (Pomeroy, 1995). Pomeroy indicates that on average elite women married around 15 years of age while males married later, around 30 years of age (Pomeroy, 1997). Most Greeks practiced patrilocal marriages where the bride would go to live in the husband's home.

Life expectancy for women was less than 40 year of age. Poor nutrition and childbirth were contributing factors to a low life expectancy for females. Men lived slightly longer, but few people of either sex lived to an old age (Migeotte, 2009). It was not uncommon for the husband to pass away first (around 45 years of age) leaving a young widow (Pomeroy, 1997). If a woman were to remarry, the children from the first marriage would be left with the father's family (Pomeroy, 1997). A widow could not inherit from her husband (unless she had no other male relatives), nor could a daughter inherit from a father. If a family only had daughters they were considered to be part of the family property, which would go with them when they married. In order to prevent a family with only daughters from losing their wealth through marriage wealthy Athenians would practice endogamous marriages between uncles and nieces (Nevett, 1995; Pomeroy, 1997). Marriage taboos did exist, though. For example, siblings could not marry, parents and children could not marry, and children who shared the same mother but different fathers could not marry (Pomeroy, 1997). Little is known about marriage in the lower classes; however, theories speculate that the lower class would have followed similar practices of marrying close family relatives (Pomeroy, 1997).

Women were expected to be faithful to their husbands but husbands could have relations with other women, mainly prostitutes. There were three classes of women recognized in Greek culture: married women, concubines and *hetaerae*. Concubines were prostitutes, while *hetaerae* were educated women who served as companions to elite men. Both the concubines and *hetaerae* were able to function in the public sphere with men. Children born to a man by prostitutes would be free individuals but of lower status than his legitimate children (Pomeroy, 1997). This created yet another level of status within a complex social organization. The women of the married class were

expected to stay within their homes to remain proper and pure. Visiting with a female neighbor or family member was one of the few appropriate reasons for a married woman to be outside the home (Pomeroy, 1997). Most Athenian women and children attempted to spend the majority of their time at home away from the public eye (Boardman et al., 1988; Pomeroy, 1997). It was the women's responsibility to cook, maintain the house, spin wool and create textiles, all the while conforming to the expectation of being quiet and respectful (Boardman et al., 1988).

An important aspect of Greek life was the separation between public and private realms. It is evident from both written and archaeological sources that the Greeks used physical space to separate private and public aspects of their daily routines. Within a home there are many ways space can be used; those uses both reflect and influence how relationships are created and managed. Athens and other large urban centres had similar architectural patterns for the home, to control how its occupants and guests used the space (Boardman et al., 1988; Pomeroy, 1997; Spencer, 1995). Typical Greek houses in Athens had one entrance from the street that opened into a small hallway (Spencer, 1995). The entrance was designed to restrict visual access into the rest of the home (Spencer, 1995). Often a house would have an interior courtyard only accessible through the house where many of the female tasks, like cooking and textile creation, would take place. Spaces within the home were often conceptually labeled as male or female. The women's quarters were traditionally on the second floor, accessed from the courtyard (Nevett, 1995; Pomeroy, 1997). Men occupied the main floor of the house, controlling access in and out. There was some flexibility to these physical spaces. The female spaces may not have been rigid physical spaces but more fluid concepts that were enforced when unrelated males entered the home (Nevett, 1995).

To ensure and protect a woman's and family's purity and modesty, these architectural features were put in place so visitors would not infringe upon the private lives of the family (Haagsma, 2010; Pomeroy, 1997; Spencer, 1995). A man could not enter a family home with women present unless invited in by the head of the house (Boardman et al., 1988). When a male came to visit the house he was most likely escorted to the *andron* (male quarters for entertaining) (Nevett, 1995). The *andron* was a highly

decorated room with raised platforms used for reclining during meals (Boardman et al., 1988; Haagsma, 2010). Houses in both urban and rural settings have similar architectural elements separating different activities that take place in the home. In smaller, less affluent homes, where physical walls were not in place to separate males and females, sight lines would often be obstructed using curtains or wooden partitions (Nevett, 1995). The fluidity of domestic space was also dependent on many other variables. For example, time of year, phase of household development and social status would influence how space was negotiated (Haagsma, 2010). Another example of the shifting division of domestic space occurred when a baby was born. This information comes from a speech by Lysias where he mentions that the male and female spaces would temporarily switch, and women would move down to the main floor to provide easier access to food and remove hazards like stairs from the daily routine of the mother (Lysias I, 9-11; Jameson, 1990).

Our knowledge about households focuses heavily on the Athenian home because little is known about houses in areas outside Athens (Spencer, 1995). There is some evidence for regional variation. One archaeological study excavated the site of Olynthos in Northern Greece and completed an in depth look at domestic and social organization. The study found that there were no obvious female spaces and that objects generally associated with females were scattered throughout the houses (Nevett, 1995). Another important observation made during this study was that placement of the objects did not necessarily reflect where the objects would have been used, suggesting some objects were found in storage spaces (Nevett, 1995). Domestic space was proved to be more complex than initially thought. In many of the houses at Olynthos there was not a strict division between male and female space, but instead there was an attempt to control access and movement in the house (Nevett, 1995).

Although Athenian women would spend the majority of their time in the privacy of their homes, there were public festivals devoted to and accessible to women. These festivals would be a time when women would enter the public sphere together. The Thesmophoria is an example of a women's festival that worshipped the goddesses Demeter and Persephone. This festival was a rare occasion when respectable

married women would leave Athens together to participate in their religion. Women also participated publically in weddings, funerals, and state religious celebrations (Pomeroy, 1997).

In contrast to Athenian women, Spartan women were expected to be physically fit like men. Being a warrior was the ultimate goal for young Spartan men. It was believed that two fit parents would produce stronger offspring (Morris & Powell, 2010). Sparta allowed more flexibility for the sexes to interact. Women were not restricted to their homes and were often out in public with men around. However, in Sparta strict gender roles existed which encouraged women to eat a different diet than men (Pomeroy, 1997).

The public and private spheres of Greek culture played a large role in the daily lives of women and men in Athens and Sparta. It seems likely that this division between the sexes would have applied in the rest of the Greek world, but without evidence to support this assumption it remains unclear.

2.5 The Expansion of Cities in the Hellenistic Era

A significant migratory movement began during the Hellenistic period because of the new possibilities Alexander's empire offered (Migeotte, 2009). The Hellenistic kings founded approximately one hundred new cities in areas such as southern Russia, North Africa, Turkey, and along the shores of the Black Sea and the Mediterranean. Most new cities were formed in Asia Minor, suggesting a continuous movement of people during the 3rd century BC (Boardman et al., 1988; Migeotte, 2009). All of the new cities were modeled on the Greek *polis* which was considered to be the only civilized way of life and in which Greek culture was rooted (Morris & Powell, 2010). The lavish city of Alexandria was founded in Egypt and was said to have been the greatest Hellenistic city (Morris & Powell, 2010). The library of Alexandria contained over 700,000 books, making it a popular location for scholars and drawing many migrants to this city (Morris & Powell, 2010).

When new cities were first settled their inhabitants were mainly soldiers, mercenaries, and immigrants from Greece (Alcock, 1996). Merchants, scholars, artisans, and labourers were among those who eventually chose to relocate in search of new

opportunities and greater fortunes (Shipley, 2000). It is unknown how large the movement east would have been but it is suggested that a similar flow of people would have been coming into Greece from the West (Alcock, 1996). The individuals who moved often had occupations that involved manufacture or commerce which in turn may have contributed to the rise in urbanization and increased populations because the cities were hubs for buying and selling (Biers, 1996). In previous time periods owning land was associated with wealth, and while this was still true in the Hellenistic Period it was now also possible to amass a fortune by trade and transportation of moveable goods (Chamoux, 2003). Having a tangible skill also became increasingly important during the Hellenistic as new cities and new opportunities arose. There is little known about the proletariat and slaves because this portion of a population is not represented by writers or philosophers in surviving texts (Habicht, 2006).

The dramatic urbanization which occurred during the Hellenistic period may have been responsible for the decrease in rural habitation which is also seen during this period (Ogden, 2002). In addition to numerous newly built cities, existing cities were often merged together by moving part of one city's population and leaving behind a smaller village in its place (Chamoux, 2003; Tarn & Griffith, 1961). An example of this population movement is the city of Seleukia, whose population was forced to move to a newly established nearby city called Antiocheia (Errington, 2008).

A review of archeological surveys in mainland Greece by Alcock and colleagues (2005) looked at population settlement patterns across Hellenistic Greece. This study found that during the Hellenistic there were fewer archaeological sites in rural areas compared to earlier times. Between the Archaic period and the Hellenistic period there is archaeological evidence that indicates a heavy rural occupation (Alcock, 1996). In the past it was believed that rural farmsteads began to decrease in number at the start of the Hellenistic indicating that fewer people were living on cultivable land. A single generalized explanation for settlement patterns across all of Greece during the Hellenistic is improbable (Alcock et al., 2005). Other surface survey research in Greece had proposed that interpretations of site distribution based on material culture, specifically ceramic sherds, could be misleading. Older material can be worn and degraded to the point of being unrecognizable and artifacts made of organic material

do not always remain in the archaeological record. This can bias the record leading to a decreased reporting of the older time periods (Bintliff, 2005). It is possible that Hellenistic sites were overlooked or misinterpreted because of such preservation factors. The study by Alcock was largely based on surface survey, which can be difficult to interpret. For example, how closely do surface finds reflect what is below ground and how do changes in practices affect the interpretation of finds? Clay, glass, and metal were common materials used to make vessels and other objects; a change in frequency of these materials can influence interpretation if a survey is heavily relying on ceramics to date a site and to assess a population size (Alcock, 1996; Shipley, 2000).

It appears that urbanization was on an upward trend during the Hellenistic and cities were getting steadily larger (Alcock, 1996). Literary sources are of little help in assessing the residential pattern because they tend to carry an urban bias and write little about rural populations (Alcock, 1996). Until the Hellenistic period migration to cities had been voluntary (Errington, 2008). The forced movement of people from surrounding areas into new cities was beneficial to larger more powerful urban centres. New urban settlements were strategically placed to keep people close to agricultural lands to ensure that crops would be maintained to supply the dominant cities. In return for supplying the larger cities the farmers and city residents were protected (Errington, 2008). Even with the improvement of sea travel and trade that would import goods, most cities remained self-sufficient and continued to depend primarily on local crops. No city could survive without a surrounding territory for agriculture and animal husbandry (Chamoux, 2003). Thessaly was, and remained, wealthy in Hellenistic times because it had plentiful agricultural land in comparison to other regions in Greece, which provided food for the new cities and their growing populations (Chamoux, 2003).

During the Hellenistic large urban settlements often had a network of smaller dependent cities nearby. The king, through his council, controlled dominant city-states. This was a change originally implemented by Philip II when he placed pro-Macedonian elites in control of most city-states (Boardman et al., 1988). Macedonian elites made sure that control remained in the hands of Macedonians for many years (Boardman et al., 1988). When the king developed new laws or rules they were

disseminated by his councilors. The larger city-states were often held to these new standards. City-states had to comply with the policies handed down by the king and be compliant to his demands (Billows, 1995). New laws and regulations were imposed onto smaller surrounding cities by the dominant city-state in the area.

Athens was always afraid that Antigonos, the Macedonian King, would take control of the city. The Ptolemaic kingdom constantly protected Athens because it was in their best interests to keep Athens autonomous and free from the control of the Antigonid kingdom (Habicht, 2006). Athens controlled a large port, the Piraeus, and whoever ruled Athens controlled that port. This is significant because large amounts of grain passed through this port and were distributed from that point. Therefore, Athens was of importance to both the Antigonid and Ptolemaic kingdoms, providing each with a motivation to control it.

2.6 Subsistence

In any culture, food is power in a basic tangible form. Hunger, when individuals cannot meet their primary subsistence needs, is the absolute form of powerlessness (Counihan, 1999). Food was intertwined with almost every aspect of Greek life; social relationships were strengthened over a meal, social status was displayed by foods, and religious and public festivals always included food (Skiadas & Lascaratos, 2001).

Greece is a mountainous country with little (approximately 20%) flat land suitable for cultivation (Mee, 2011). The mountain chains limited the size of agricultural plains and also complicated travel across the country. In order for food production to meet the demands of the population farmers had to creatively use the available land. To maximize available agricultural land, conserve water and increase yield, the hills were terraced (Mee, 2011). Small pockets of land on mountainsides were used as olive groves, and where crops could not be grown animals were allowed to graze (Mee, 2011). Farmers kept sheep, goats, donkeys, and mules grazing in mountainous areas and pigs foraging in the forests (Chamoux, 2003; Mee, 2011). Land was strategically used for what it was best suited (Migeotte, 2009).

The Greek climate is mild and rainy during the winter, which is generally the growing period for crops. The summers are dry and hot and have an unpredictable amount of

rainfall (Isager & Skydsgaard, 1992; Mee, 2011; Migeotte, 2009). Greek farmers in the Classical and Hellenistic periods planted diverse crops to protect themselves from crop failure (Mee, 2011). The climate allowed for an adequate harvest, which usually produced enough yield to support dependent populations for a year (Mee, 2011). Archaeological work has found that farmsteads near Athens would have had towers for protection, animal enclosures, and production/processing areas for grain (Chamoux, 2003; Mee, 2011). Two isolated houses, the Dema House and the Vari House, dated to the Classical/Hellenistic period have been excavated in Attica. These houses have similar layouts and structures and are both considered single family farmsteads (Jones et al., 1973; Jones et al., 1962). The Vari farm house was set strategically with mountain ridges surrounding it (Jones et al., 1973). It was a one-family home but it did not have separate storage facilities or housing for livestock (Jones et al., 1973). It has been suggested that this house could have been occupied only at harvest times because there was no evidence of grain processing tools or presses for wine or oil (Jones et al., 1973). Similarly, the Dema house did not provide signs of any distinct function but was probably also a single family farmstead (Jones et al., 1962).

Owning large amounts of cultivable land was a sign of extreme wealth. Around the 4th century BC 7.5% of the Athenian population owned 30% of the surrounding cultivable land (Mee, 2011). Often wealthy landowners rented their land to tenant farmers to work the fields (Chamoux, 2003; Snodgrass, 1987). They would also use slaves, especially during harvest times (Erskine, 2005). This allowed the rich to stay in large urban centres and participate in political events.

2.6.1 Health and Food

Health beliefs are another aspect of Greek life that influenced food traditions. Health was a topic commonly discussed and written about in ancient times. Hippocrates (5th century BC) wrote a treatise on diet, Herodotus, an athletic trainer, wrote extensively on diet, Erasistratus and Heroplius (3rd century BC) belonged to a medical school and stressed the importance of diet in their work, and Plato wrote extensively about health, diet, physicians, athletic trainers, and the ideal Greek body (Gilman, 2004; Skiadas & Lascaratos, 2001). Trainers specialized in diet to produce excellent and healthy athletes. They were not considered professionals but were trusted because of

their work in the gymnasia (Skiadas & Lascaratos, 2001). Training was not limited to athletes, though. In ancient Greece, being overweight was a pathological state that needed to be cured. It was unattractive and associated with laziness and old age (Gilman, 2004). Men spent many hours a day in the gymnasia working on their fitness (Skiadas & Lascaratos, 2001).

Aesculapius, the god of healing, is associated with the medical schools in Ancient Greece, which produced professional physicians. His cult maintained popularity into the Hellenistic era (Longrigg, 1998). Physicians would assess health by considering an individual's humors and their diet (Counihan, 1999). The humors related to four crucial bodily fluids: blood, yellow bile, black bile, and phlegm. Each fluid had specific characteristics; together they were the key to a healthy body shape and physique. When all four were in balance an individual was healthy. Illness occurred when one humor became dominant (Gilman, 2004). In the humoral system there were inherent differences between men and women, and between adult and child, that required different treatments (Craik, 1995). Physicians would use diet as a primary therapy. The diets, which were prescribed to patients to cure an illness, would be influenced by their age, gender, and body type (Skiadas & Lascaratos, 2001).

Cooking and food preparation were considered important tasks, a way of breaking down the negative qualities in food and making it better for digestion. Hippocrates wrote that the taste and enjoyment of food were irrelevant and that keeping the humors in balance was most important (Craik, 1995). Homer described the Greek diet as 'frugal and monotonous' (Garland, 1998); a homogeneous diet with little variation was thought to be better for a person's health. Plato, too, explained that a moderate bland diet with little variation demonstrated self-restraint and would encourage a healthy life (Skiadas & Lascaratos, 2001). In general, the Greeks felt that eating to excess would have severe consequences, which could lead to illness. Control over the body and the natural desires was something that was encouraged and respected. Self-control and restraint indicated that individuals had power over their surroundings.

2.7 Diet in Hellenistic Greece

Information about food comes from various artifacts and written works. Types of food most commonly mentioned in the literature include wheat, barley, grapes, olives,

chickpeas, beans and lentils (Mee, 2011). Food is discussed in terms of public occasions, while private family meals are almost completely absent from written sources (Dalby, 1996).

Olives, wine, and grains have been referred to as the Mediterranean Triad, the staples of the Greek diet (Garland, 1998; Isager & Skydsgaard, 1992). Although the Mediterranean Triad is widely accepted as the basis of the Greek diet, Hamilakis (1999) has questioned this idea because olives can be a risky crop and olive products are labour intensive. Olive trees, which are very expensive to acquire, take approximately seven years to produce their first fruit, after which olives are produced biannually (Hamilakis, 1999). Although they have a long maturation process, olive trees can be productive for hundreds of years (Mee, 2011). Hamilakis (1999) argues that only wealthy farmers could grow olives and that they could not produce a large enough yield to sustain the demand from the wider population. In addition, in times of war crops were often burnt and destroyed to weaken the opposing forces. If this were true, then olive production would be constantly threatened (Hamilakis, 1999). This is an interesting argument but not convincing because along with the numerous written texts about olives and olive oil production, there are numerous paintings on vases showing the production, harvesting, and consumption of olives. The surviving material culture reflects a large olive oil industry that was very important to the life style to which the Greeks were accustomed (Boardman et al., 1988; Haagsma, 2010; Mee, 2011). Olives would be eaten raw, stuffed, mashed, or used to make oil (Migeotte, 2009).

Among the triad, grains were the fundamental staple in Classical and Hellenistic Greece (Casson, 1954; Haagsma, 2010; Mee, 2011), and were considered to be the most nourishing food item according to Plato (Boardman et al., 1988; Skiadas & Lascaratos, 2001). Wheat and barley were the two dominant types of grains grown; other lesser-used grains would supplement diets when supplies of the preferred grains dwindled (Migeotte, 2009). Bakeries were common in urban settings, but rural populations would have had to process grains in the *oikos* (Migeotte, 2009). Bread and gruel were the main dishes made using grains. Barley bread did not rise well and was less appealing to upper class individuals (Dalby, 1996; Migeotte, 2009). Epigraphical

sources also mention the use of grains in religious ceremonies and in sanctuary offerings. At the sanctuary of Demeter and Kore at Acrocorinth remains of wheat and barley were recovered along with olive, pomegranate, grape, and fig seeds (Bookidis et al., 1999). Many different types of cakes were identified at a sanctuary to Demeter and Kore, and some have been interpreted to be made of wheat or barley mixed with milk, oil, honey, and various types of condiments (Brumfield, 1997).

Plato wrote that the plant kingdom existed before the animal kingdom and that the animals were for the gods (Skiadas & Lascaratos, 2001). This statement reflects the ideological importance of plant-based diets. Other plant-derived foodstuffs mentioned in historical sources include legumes such as beans, peas, lentils, chickpeas and vetch, fruits such as apples, pomegranates, figs and pears, and vegetables such as cabbage, cucumber, leeks, onions and turnips (Chamoux, 2003; Mee, 2011). Herbs like fennel and garlic are also mentioned (Migeotte, 2009). Grapes served in many different forms were a particularly prominent food item in Greece. Grapes would be eaten raw, dried into raisins or juiced and fermented to make wine (Mee, 2011). Dried dates and figs, along with honey, were used as sweeteners; sugar cane had not yet become popular (Dalby, 1996). Various nuts and spices rounded out the plant-based portion of the diet (Blumner, 1966; Garland, 1998; Isager & Skydsgaard, 1992).

According to ancient sources meat was not commonly eaten except at festivals and as sacrifices to the gods (Boardman et al., 1988; Haagsma, 2010). Greeks consumed all parts of an animal, and there was very little that they avoided (Dalby, 1996). The same was true of animal species. However, some exceptions did exist. For example, dolphins were considered sacred, people were uncertain about turtles and tortoises, and dogs and horse meat were rarely consumed; otherwise, few animals were avoided as food (Dalby, 1996).

In Athens, public sacrifices were the main source of terrestrial protein for the general public. Fortunately, religious festivals were very common and it has been estimated that people in Athens could access meat every eight or nine days (Prummel, 2003). The animals most commonly consumed at Athenian festivals were sheep, pigs, cattle, and goats (in approximate descending order of osteological representation) (Blumner, 1966; Chamoux, 2003; Halstead, 2007). However, the written sources suggest that pork

was the most common meat in Athens (Dalby, 1996). The contradiction between the archaeological record and the written sources could perhaps reflect reality versus what was considered to be the ideal circumstance. Donkeys, oxen, and horses were also consumed on occasion (Blumner, 1966; Chamoux, 2003; Halstead, 2007). Poultry and other birds were part of the diet but are less commonly mentioned (Boardman et al., 1988). Boar, fox, and deer were a fairly regular addition to the diet because these were not considered foods of the gods (Boardman et al., 1988; Dalby, 1996; Garland, 1998). Although religious symbolism was important, a more prosaic interpretation of why Greeks did not regularly eat meat was that a single family could not consume a large animal before it would rot. It was also a very expensive resource to maintain or purchase (Boardman et al., 1988). Only a large group of people, such as at festivals, could manage to consume an entire animal all at once (Dalby, 1996; Halstead, 2007).

When animal husbandry was practiced animals did provide many resources in addition to meat. Milk (used for cheese and yogurt), eggs, wool, and leather were all valuable secondary products (Dalby, 1996). Generally, only rural pastoralists drank milk, and consumed butter regularly (Dalby, 1996). Cheese, on the other hand, was a versatile and easily accessible product that was heavily consumed. Sheep and goat's milk was used to make cheese and was more popular than products made from cow's milk (Dalby, 1996).

The sources cited above on meat consumption portray the beliefs and practices of the southern Greeks. The landscape and mountainous topography of northern Greece made Thessaly remote from the rest of Greece and allowed different cultural beliefs to develop (Westlake, 1969). In Thessaly and Macedonia, meat was more commonly consumed than in southern Greece. Game was more abundant in Macedonia and the natural resources of Thessaly lent themselves well for raising animals (Haagsma, 2010). The Athenians' perception was that Thessalians overindulged in wine and meat while the south practiced restraint and control (Haagsma, 2010). However, by the Hellenistic period Athens began incorporating the northern custom of consuming meat more frequently (Dalby, 2013; Haagsma, 2010).

Marine resources were mainly consumed by coastal populations, although salted or smoked fish were occasionally transported inland for consumption (Dalby, 2013).

Athens, beginning in the 5th century BC and onwards, had a large seafood market and used marine resources heavily (Dalby, 1996). Fish were a high status food in Athens during the Classical Period and may have made up a large portion of the diet for elite individuals (Dalby, 1996).

Marine resources like fresh, salted, or smoked fish also contributed to the Greek diet (Boardman et al., 1988; Dalby, 1996; Haagsma, 2010). Fish, cuttlefish, anchovies, snails, mussels, squid and octopus are examples of exploited marine resources (Dalby, 1996). In Hellenistic times eels were considered a gourmet item (Dalby, 1996). *Garos* was a fish sauce developed to preserve and use all portions of a fish (Wilkins, 2005). *Garos* (or g*arum*) was used in both Greek and later Roman cooking. *Garos* was made by covering fish in salt and leaving it in jars to ferment for two to three months. After a period of time the mixture would produce a salty sauce, which was eaten with many dishes (Dalby, 1996).

A survey of food based on written evidence indicates that in large coastal cities like Athens the majority of animal products in a meal would have been fish or seafood based, and meat might be completely absent from an entire meal (Dalby, 1996). However, the mention of fish and seafood in ancient sources is difficult to assess in terms of actual dietary impact because the amount and frequency of consumption is not clear and is even less clear for different social classes and geographic regions (Bourbou & Richards, 2007). Availability and cost of fish could have been restrictive for segments of the populations (Wilkins, 2005). It is probable that for peasants cereals were more important than fish in the diet, while wealthy individuals could afford these luxury marine items (Wilkins, 2005). It is likely that marine resources also varied both regionally and seasonally.

While the region and season determined the availability of some foods, trade was also an important factor. One of the most important dietary staples that was traded extensively was grain (Tarn & Griffith, 1961). Athens, the Aegean islands and many other large coastal cities relied on the grain trade for subsistence needs (Casson, 1954). During the 5th century, 50% to 80% of Attica's grain was imported from Sicily, Egypt and the region around the Black Sea (Boardman et al., 1988; Casson, 1954; Migeotte, 2009). A grain market was established on the islands of Rhodes and Delos so that

grain supplies could be tightly controlled (Boardman et al., 1988). Rhodes was the main port which controlled much of the grain trade in the Aegean (Casson, 1954). The region around the Black Sea was the largest exporter and producer of grain, much of which went to Rhodes for redistribution (Boardman et al., 1988). Sea trade depended upon the water conditions and wind for speed and safety. A boat could travel approximately 40 km per day carrying 20-70 tons of cargo (Migeotte, 2009).

A secondary product of sea trade was the importation of new cultural ideas and ways of life that reached the elite groups first. These new ideas would eventually trickle down to the lower classes and influence Greek culture, but unless a city was close to a port imported foods did not always reach far inland (Chamoux, 2003). In spite of the sea trade and grain imports, most small settlements remained self-sufficient and dependent on local resources (Chamoux, 2003). Cities would not have been able to survive without the surrounding farmsteads that sustained their populations (Chamoux, 2003; Snodgrass, 1987).

Overland trade was an alternate way for goods to be circulated. Grain, wine, olive oil, vegetables, fruit, fish, animal skins, leather, wool, fabric, slaves, livestock, wood, stone, metals, and ceramics were all commonly traded over land (Migeotte, 2009). Wagons and beasts of burden were used for transportation and could cover approximately 15-20 km per day, a significantly shorter distance than sea trade. Short distances between markets were essential so that perishables did not spoil before they reached their destination (Migeotte, 2009). Trading was an expensive and time consuming process so instead farmers relied on relationships with adjacent and nearby neighbouring markets to sell their products (Migeotte, 2009).

Archaeological investigation into pottery styles present at New Halos can offer information about diet and also clarify which outside areas influenced the city. Among the recovered ceramic material were many different styles of storage vessels. These vessels came in different shapes, styles, and colours, which suggests imported materials (Reinders & Prummel, 2003). Other items useful in identifying influence or trade in the area are coins. New Halos was one of the few cities in the Hellenistic period that struck its own coins (Reinders, 2003). The pottery and coins found at New Halos demonstrate that the population was in contact with neighbouring cities in

Achaia Phthiotis. Coins found at New Halos from Histiaia, Chalkis, and Egypt indicate contact with these areas through direct or indirect trade (Haagsma, 2010). Peuma, Thebai, Ekkara, and Larisa were also represented in the recovered coins from New Halos (Reinders, 2003). The material culture proves that the population of New Halos had contact with many other cities within a large area. The majority of artifacts came from northern Thessaly; very little material was from south of New Halos (Reinders & Prummel, 2003). New trade routes were developed during the Hellenistic period, bringing large quantities of new supplies and cultural ideas to Greece (Boardman et al., 1988; Tarn & Griffith, 1961). Ceramic vessels and artifacts indicate that goods and foodstuffs were brought into the area, however it cannot identify how the items were distributed within the population or who consumed these items.

Distribution and consumption of food reveals power relations between city-states, social classes, age, and gender (Counihan, 1999). The upper class would choose to consume wheat while the poor or lower class would have to settle for what they could afford; often times that would mean barley (Blumner, 1966; Garland, 1998). The lower classes would consume the less desirable foodstuffs because that was what they could afford, and in so doing, would define their social status. An individual was considered very poor if they could not afford bread to go along with their cheese, or if their diet consisted of wild foods (Dalby, 2013). Age and gender also dictated what was consumed because of certain cultural beliefs. Young well-to-do girls were fed plain foods with little meat or condiments to produce quiet and even tempered women (Garnsey, 1999). Upper class women or girls did not regularly consume wine. If they did, it would be highly diluted with water to avoid over-consumption (Garnsey, 1999).

Food permeated both the private and public life of the Hellenistic Greeks and was a means by which individuals interacted and negotiated social settings. The male symposia and the Amphidromia are two examples of private life that revolved around food. A typical menu at an Amphidromia (a baby's naming day 5-10 days after birth) during the Classical period would include cheese, fried cabbage with oil, stewed mutton chops, wood pigeons and thrushes, cuttlefish, squid, and octopus (Dalby, 1996). Public festivals and sacrifices provided the public with meat that was otherwise a rare addition to a family's diet. Understanding the available food resources in the

Hellenistic period will facilitate the interpretation of the New Halos stable isotope profiles presented in Chapter 6.

2.8 The End of the Hellenistic Period

Nearing the end of the Hellenistic period (146 BC) the Roman Empire began to take an interest in Greek territory. Over several stages, defined by major battles at Kynoskephalai (197 BCE), Pydna (169 BCE) and Corinth (146 BCE), Rome eventually took control of Greece (30 BC) and divided the region into smaller administrative units (Alcock, 1996). Greek city-states and their larger regions were incorporated into the Roman Empire. This did not bring about the demise of Greek cultural identity. Rather, Greek culture continued to thrive as the Romans did not impose a Roman way of life (Alcock, 1996). Under Roman control much of the Greek political system remained the same (Alcock, 1996; Shipley, 2000).

2.9 Conclusion

This chapter attempted to provide a brief history of Greece in terms of economic strategies and settlement patterns starting with the Paleolithic Period and working forward to the Hellenistic Period. Although the picture we have of the Hellenistic period is incomplete because contemporary written sources are rare, archaeological work and extrapolations from existing sources can begin to fill in the gaps. The Hellenistic period was rife with conflict as the Macedonian kings worked to maintain control of their territory.

Also, as this chapter highlighted, there is little known about the daily lives of non-elite individuals. Rural communities, women, children, and slaves are almost invisible in the written sources. This chapter attempted to shed light on these segments of the population, and it is the hope of this study to improve our understanding of rural Hellenistic populations.

Chapter 3 New Halos

The Hellenistic site of New Halos is located in Thessaly (Figure 3.1), which is bordered by Macedonia to the north and Central Greece to the south. The Aegean Sea is to the east and Thessaly is separated from western Greece by the Pindus Mountains. In Antiquity, Thessaly was subdivided into smaller administrative units – called tetrads – named Pelasgiotis, Phthiotis, Thessaliotis, and Hestiaiotis. These four areas occupied the larger central plains in Thessaly. The region in which New Halos is located was named in Antiquity Achaia Phthiotis. Achaia Phthiotis was one of the so-called *perioikoi*, areas of higher elevation, surrounding the centrals plains. The Almiros and Sourpi plains form part of Achaia Phthiotis and contained many cities during the Classical and Hellenistic periods; Peuma, Ekkara, Eretria, Phthiotic Thebai, and New Halos are examples of settlements in this area (Reinders, 2004).

The site of New Halos is situated between the Almiros and Sourpi plains, just west of the Pagasitikos gulf. The Almiros plain is an important commercial agricultural region that produces wheat, barley, cotton, vines, tobacco, and other crops (Haagsma, 2010). Much of the Almiros plain has been farmed in modern times, which has destroyed parts of New Halos, but some intact house foundations from New Halos were found and excavated (Haagsma, 2003; Reinders, 1988). Archaeological studies elsewhere in Thessaly and the area surrounding New Halos are important for comparative information. Kastro Kallithea, a Hellenistic site 25 km west of New Halos, has been the subject of research dedicated to understanding the social, political and economic organization of Hellenistic cities (Haagsma et al., 2011; Haagsma et al., 2015; Rupp, 2007; Tziafalias et al., 2006). This 4th century BC urban centre was situated along a major transportation route to the coast (Rupp, 2007). Another important settlement in the area was Demetrias, founded in 290 BC by Demetrius Poliorcetes. Demetrias was occupied from the Hellenistic to Roman times. It was founded and served as a Macedonian capital and naval harbor (Reinders & Prummel, 2003).

The region in which New Halos is situated is governed by the 13th Ephorate of Prehistoric and Archaeological Antiquities in Volos, Greece. This office has overseen fieldwork investigating the occupational history of the Almiros and Sourpi plains from the

Palaeolithic period to modern times. This was also the office that granted access to the skeletal collection and issued sampling permits for this research.

3.1 The Site and Location of New Halos

A city called Halos was situated on the coast of the Pagasitikos gulf in Achaia Phthiotis during the Classical period. Classical Halos was placed on the western shores of the gulf and was an ideal place to beach ships and for armies to disembark. Desmothenes described a situation around 346 BC when a Macedonian army besieged Classical Halos. Fortunately for the population of Classical Halos an Athenian embassy that was headed to Pella by sea was able to disembark and stop the siege (Demosthenes 19.163). Following the siege a peace treaty was established between Athens and Macedonia; however, Classical Halos was excluded from the peace treaty. The result of this treaty saw the people of Halos subsequently expelled from their homes and the Classical city of Halos was destroyed (Demosthenes 19.39). Near the end of the 4th century BC New Halos, a Hellenistic town, was established 2 km further inland than Classical Halos in a more strategic location and was occupied from approximately 302 BC to 265 BC (Reinders, 2003b). The locations of Classical Halos and New Halos are shown in Figure 3.1.

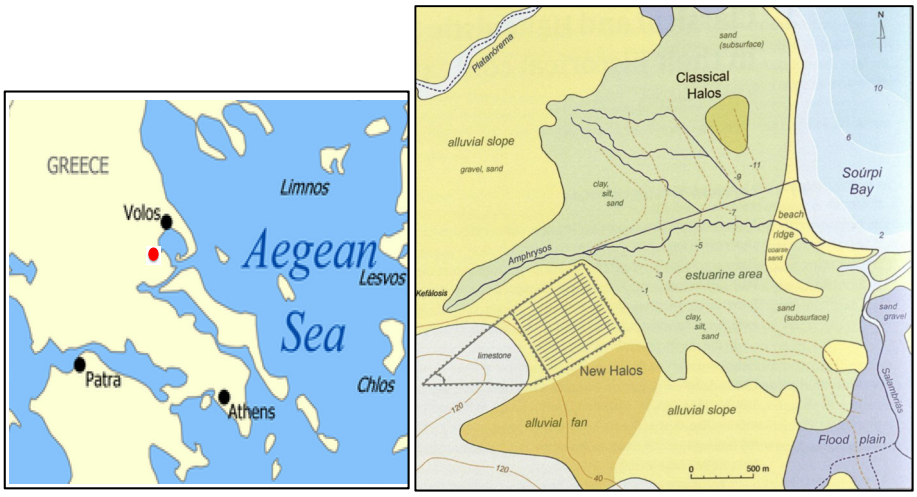

Figure 3.1: Location of Hellenistic Halos represented by red circle (left) (Einstein, 2006). The area of the red dot in the left image is enlarged and the location of Classical Halos and Hellenistic New Halos are shown on the right (Reinders, 2014).

New Halos was located further inland but near the Pagasitikos gulf and the port of the older Classical city may still have functioned as a hub for the exchange of commodities

for the city and the wider region. The major rationale for the inland location of New Halos was defense. The city of New Halos was strategically situated, with the Othris Mountains to the west, the Pagasitikos gulf just 2 km to the east and a salt marsh to the southeast (Reinders, 2003b). The city had a fortification wall with a northwest gate accessible from the Almiros plain and a southeast gate that opened onto the Sourpi plain (Reinders, 2003b). The northwest gate of New Halos was positioned in a way that would force any enemy around the Amphrysos river into striking range from the enceinte towers (Reinders, 2014). The Amphrysos river begins at Kefalosi spring, which lies north of the northern wall of New Halos and empties into the Pagasitikos gulf (Reinders, 2014). Archaeological survey of the city walls found 117 towers (Reinders, 2014). The towers were placed 40 meters apart along the upper and lower town walls. There was limited access in and out of New Halos controlled by gates in the city walls (Haagsma, 2010). The walls were most likely made up of a limestone base and an upper section made of mudbrick (Reinders, 2014).

Strong defendable cities were essential during the Hellenistic period, and Macedonian rulers often provided financial support for the construction of new settlements (Haagsma, 2010). The forced merging of populations creating centralized urban settlements was a common military strategy during the Hellenistic period (Boehm, 2011). It is clear that such cities were established by the resettlement of groups of people, and it is likely, though still unconfirmed, that these settlers usually came from the surrounding area (Haagsma, 2010). There are instances where the *synoikosmos* of a community took a long period of time to complete.

An inscribed stele at ancient Teos is evidence of how a new Hellenistic settlement developed. The stele described how the cities of Teos and Lebedos were instructed to merge. Antigonos ordered this in 303 BC (Syll^3 344.49-52). The merging of the two cities involved the movement of Lebedians to Teos. They were offered free land to build a new house as motivation to settle in the new area. People had three years to complete the construction of their new houses (Haagsma, 2010). A second example is the Classical city of Sikyon. Sikyon was destroyed (Diodorus XX, 102.1-3), denying the population an option to remain, and a new Hellenistic city of Sikyon was built further inland forcing the population to move (Haagsma, 2010). The destruction of

Sikyon and its re-settlement parallels the destruction of Classical Halos and the construction of New Halos. After the abandonment of Classical Halos in 346 BC it is uncertain where the inhabitants went, but one suggestion is that some of the population continued to inhabit the surrounding area. If this were true it is possible that these individuals could have been used as labourers to build and populate New Halos (Reinders, 2014).

A series of excavations at New Halos were conducted between 1976 and 1993 (Malakasioti, 1985, 1992, 1993; Malakasioti & Rondiri, 1990; Reinders, 2014; Reinders, 1986, 1988; Reinders et al., 2011; Reinders & Bottema, 1983; Reinders, 1983; Reinders et al., 2000). In the first investigation, in 1976, all archaeological remains of the city were mapped (Reinders, 2004) and it was determined that the city of New Halos was comprised of an upper and a lower section.

In 1981 and 1982 excavations in the upper town were conducted. The upper city was a smaller triangular area west of the lower city, built on a small mound. Most of the large public buildings were found in the upper city (Haagsma, 2003). A proposed sepulchral building was uncovered in the upper town that contained a double grave in a back room; however further research and reinterpretation suggests that this building could be a shrine to Demeter (Reinders, 2014; Reinders, 1988). In 1993, houses in the lower town were excavated and explored to learn about economic and social dynamics (Haagsma, 2003). The lower town was a rectangular area of approximately 40 hectares with streets laid out in a grid pattern (Haagsma, 2003). There were 14 streets running east-west and three streets running north-south (Haagsma, 2003). The urban centre of New Halos provides important insights because it had remained mostly untouched since its abandonment in 265 BC. The houses at New Halos were excavated because they were relatively well preserved despite the amount of modern farming and plowing that had occurred in the area.

The excavation goals at New Halos were to explore housing, town planning, and the economic and social structure of a Hellenistic city (Haagsma, 2010). The city's houses were constructed of mud brick with ceramic roof tiles. Many of the houses were built with one entrance from the street and had shared walls so they were not separate free standing structures (Haagsma, 2010; Reinders & Prummel, 2003). The architecture of

the excavated houses followed the expected Athenian style that divided public from private space (see Chapter 2.4, section). Various methods exist to estimate the number of occupants in a house. One method calculates the household area and determines a maximum occupancy based on available square meters (Haagsma, 2010). Scholars have agreed upon an estimate of approximately 4-6 people in households of similar size to those found at New Halos. 1400 houses existed in the lower town, which, using the estimate above, would result in almost 9000 inhabitants (Haagsma, 2010; Reinders & Prummel, 2003). The archaeological record at New Halos does not show concrete evidence of an elite social class, nor is there evidence of personal wealth within the population (Haagsma, 2010). It is not known who founded New Halos but it is clear that it was done under Macedonian influence with possible military reasons in mind (Haagsma, 2010). It could also be assumed that at some point New Halos was home to a garrison (Haagsma, 2010). Hellenistic garrisons often consisted of Macedonian soldiers and Greek mercenaries; this is different from the civilian armies in the Classical Period who were closely tied to the region they defended (Haagsma, 2010).

No evidence of garrison barracks was found during the excavations at New Halos. This makes the assumption that New Halos was a garrisoned city difficult to support. However, a possible explanation is that the garrison took on a more domestic lifestyle, that involved marrying local women and settling into daily life at New Halos (Haagsma, 2010). Additionally, little is known about garrison housing. It has been noted that the Ptolemaic army built irregular barracks upon a fortified hill on the peninsula of Koroni in Attica during the Chremonidian War (256-261 BC) (Haagsma, 2010). Perhaps the upper town at New Halos was where the garrison was stationed, as this would follow the pattern employed by the Ptolemaic army during the Chremonidian War (Haagsma, 2010).

After the abandonment of New Halos there is no sign of re-occupation within the excavated houses (Reinders, 2014). The economic functioning of a city is often intrinsically linked to its land and therefore if the population of New Halos was forced to settle in a particular area perhaps they saw the destruction of their city as a way to return to their original locations or find a new place that was better suited. It was originally suggested that the site of Classical Halos still played a role in the religious

and economic practices of New Halos, drawing the population back to the original settlement (Haagsma, 2010). However, after further excavation in the area of Classical Halos it is clear that this was not the case; a more likely scenario is that the inhabitants of New Halos relocated to areas further inland (Haagsma, 2010). Excavation of the southeast gate has revealed that this small area was occupied around 265 BC for approximately 40 years; the gate was permanently sealed and turned into a farmstead during this second occupation period (Reinders, 2014).

3.1.1 Dating Evidence for the Foundation and Destruction of New Halos

It has been suggested that New Halos was founded and constructed by Demetrius Poliorcetes because of his presumed activities in the area (Haagsma, 2010). Demetrius Poliorcetes, the son of Antigonus the-one-eyed, king in Macedonia from 306-301 BC, was tasked with confronting Cassander in the Crocian plain. The two leaders and their armies met near New Halos and were preparing for battle when Demetrius Poliorcetes was called away by his father. A battle between Demetrius Poliorcetes and Cassander never occurred in the Corcian plain. It has been speculated that Demetrius Poliorcetes founded the fortified city of New Halos, near the Crocian plain. It is a potential spot where Demetrius Poliorcetes could have stationed his army while he was away helping his father (Haagsma, 2010). Demetrius Poliorcetes' specialty was maritime strategy and New Halos was located near one of the few accessible ports in the Pagasitikos gulf (Reinders, 2003a).

An alternative foundation hypothesis is that Cassander was responsible for the foundation of New Halos for similar strategic reasons to those mentioned above. Furthermore, Cassander built the city of Dion at the foot of Mount Olympus in Macedonia. Dion and New Halos have a similar layout, making a strong argument that Cassander was the founder of New Halos (Haagsma, 2010).

While excavating the houses in the lower town of New Halos and the southeast gate, coins were discovered that provide evidence about who founded the city and can offer information for dating the settlement. A coin hoard was discovered during the excavation of the southeast gate. It is believed that the hoard was lost or hidden at

some point during the construction of the city wall (Reinders, 2014). The coins can be associated with Demetrias Poliorcetes, as many of the coins correspond with places where we know he travelled in 304 BC on his way to Larisa Kremaste and the Crocian Plain (Haagsma, 2010; Reinders, 2014). These coins suggest that the habitation of New Halos started in the late 4th or early 3rd century BC. Macedonian coins with the monogram 'ΔHMHTPH' were also recovered and they could either be associated with Demetrias Poliorcetes (306-283 BC) or Demetrias II (239-229 BC). There are no other coins in this board that date to the second half of the 3rd century BC and therefore it is argued that the coins most likely represent Demetrias Poliorcetes (Reinders, 2003). The coins' state of preservation also provides clues about the date of occupation. Coins that are very worn suggest that they have been in circulation for a long period of time while well-preserved coins represent newer, less used coins. Based on these observations the foundation of New Halos would have been around the end of the 4th century BC or the beginning of the 3rd century BC (Reinders, 2003).

There were no coins recovered from the houses that date to the second half of the 3rd century BC (Reinders, 2014). All of the coins from the houses were from Thessaly and Macedonia and none from settlements to the south (Reinders, 2003). The coins of Ptolemy II were among those recovered at New Halos. Dates in the 260's BC are given for these coins if the markings represent issuing numbers. If the marking refers to reigning years then a more specific date of 265/4 BC is suggested. This, along with the almost complete absence of coins of Antigonos Gonatas seems to confirm a date shortly after 265 BC for the end of occupation at New Halos (Reinders, 2003).

The ceramic vessels recovered from the house excavations can also be used to date the city of New Halos. Most of the complete and datable pottery comes from the late 4th century BC with only a small portion dating to the first quarter of the 3rd century BC (Beestman-Kruyshaar, 2003). The Attic fish plates and hemispheric bowls at New Halos cannot be assigned a date later than 275 BC (Beestman-Kruyshaar, 2003). The last date determined for the complete vessels is approximately 265 BC; additionally vessels that appear in Athens around 260 BC are not present in New Halos (Beestman-Kruyshaar, 2003). The absence of these later Athenian vessels suggests that New Halos had already been abandoned by this time.

It is assumed an earthquake or large environmental disaster forced the population of New Halos to abandon their homes (Reinders, 2004). Pottery recovered at New Halos supports the assumption that New Halos was abandoned suddenly (Beestman-Kruyshaar, 2003). There is no evidence of a re-occupation within the city after 265 BC. However, the southeast gate and the surrounding area were reoccupied for a short time from 265 BC to 220 BC (Reinders, 2014). The gate was sealed and the area was converted into a farmstead and structures were built along the south city wall (Reinders, 2014). Excavation of the gate found evidence of burning and suggests that the southeast gate complex was destroyed by fire (Reinders, 2014).

3.2 Evidence for Diet at New Halos

The faunal remains excavated from New Halos have been studied in depth and when possible they have been identified to genus and species. In total 1424 animal remains were collected during excavations of the New Halos houses [1] (Prummel, 2003). There is no sign of a rebuilding phase within the borders of New Halos; therefore the animal remains would not be the result of secondary refuse being used to level an area for building (Prummel, 2003). Instead the remains would have been left by the individuals living in the houses and would represent a short term dietary signal (Prummel, 2003). Of the identified faunal remains, sheep/goat bones were the most abundant followed by cattle and pigs. However, reconstructed proportion of consumed mammal meat by weight is as follows: beef 48%, mutton/goat 29%, horse/ass 20%, and pork 2% (Prummel, 2003). Food remains were often discarded in the courtyards as the excavation reports indicate (Haagsma, 2010). The following animal bones showed signs of fire or charring: cattle, sheep, goat, red deer, roe deer, and tortoise (Prummel, 2003). Charred mollusk shells were not recovered. The charred bones could indicate that cooking methods varied for different types of food resources.

Considering the remains in terms of age at death, the horse and ass remains were young (12-48 months) while the sheep/goat remains were generally 3.5 years or older,

[1] For a complete table of faunal remains recovered and identified consult page 178-181 in *Housing in New Halos: A Hellenistic Town in Thessaly, Greece* (Reinders & Prummel, 2003)

with very few young kids or lambs (Prummel, 2003). The increased age of sheep/goats suggests that these animals were used for milk and wool before they were killed and eaten (Haagsma, 2010; Prummel, 2003). Meat consumption in Thessaly and Macedonia was high compared to Athenian practices. Southern Greeks felt that Thessalians and Macedonians consumed meat in excess, and it was not until the beginning of the 3rd century BC that Athenians began to relax their attitude towards meat and increase their consumption (Garnsey, 1999; Haagsma, 2010; Trentmann, 2012).

Grazing animals would have covered the landscape and would have produced important food staples like milk and cheese and produced wool for textiles (Chang, 1994; Haagsma, 2010; Prummel, 2003). It is likely that New Halos utilized the surrounding mountainsides in the summer to graze their animals (Prummel, 2003). In the winters the animals would be brought down out of the mountains into the valleys closer to the town. The wild game species recovered at New Halos (red deer, hare, badger, and other small game) would have supplemented the diet (Haagsma, 2010; Reinders & Prummel, 2003).

Literary sources indicate that fowl was a popular dish in Hellenistic times. The salt marsh to the south east of New Halos would have provided a habitat to many species of birds, migratory animals and fish. However, no bird remains were recovered at New Halos. It is interesting that birds are absent from the archaeological record at New Halos because it suggests that they were not a common dietary source for this population (Haagsma, 2010). During the excavations of 1979 and 1993 some wet sieving took place. Some small unidentifiable bones were recovered, but they did not provide new information about New Halos dietary habits (Prummel, 2003). A possible explanation for the lack of bird bones and other small bones at New Halos is that poor preservation led to underrepresentation in the material record (Prummel, 2003).

New Halos was approximately 2km from the coast (Reinders & Prummel, 2003); this proximity to the coast suggests that the people of New Halos could have utilized marine resources. Additionally the Amphrysos river, which begins at the Kefalosi spring just outside the Northwest gate, flowed year round (Reinders, 2014). It is speculated that the Amphrysos could have been navigable by small boats during the Hellenistic period, which also suggests that it may have been large enough to support fish at the

time (Reinders, 2014). However, only one fish bone and no fish hooks or other fishing equipment was recovered from New Halos (Haagsma, 2010; Prummel, 2003). Poor preservation of small and delicate fish bones, similar to the lack of bird bones, could explain their absence in the archaeological record. Both fish and birds are underrepresented at coastal sites in Epirus, west of Thessaly. Although geographically separate these sites may indicate that birds and fish were not common dietary items for coastal settlements like New Halos (Prummel, 2003).

On the other hand, the faunal remains from New Halos contain an abundance of marine shellfish (Prummel, 2003; Reinders & Prummel, 2003). Many varieties of mollusks and sea snails were identified, including species that live at a variety of different water depths (1m-20m depths)[2]. These shellfish would have been gathered in Sourpi Bay near New Halos (Prummel, 2003). As discussed in Chapter 2 squid, cuttlefish, octopus and other boneless marine animals were also regular dietary items consumed in the Hellenistic period and were potentially consumed at New Halos, yet because they do not leave traces in the archaeological record, this cannot be confirmed through physical evidence. Written sources and works of art that depict marine food consumption are the only sources that identify these types of resources as dietary items (Boardman et al., 1988). Additionally, many of these species can be caught in shallow waters using generic tools like knives not specifically linked to these animals.

Of the identifiable elements, mollusks and shell fragments accounted for 60% of the faunal elements collected by Number of Identified Specimens (NISP) (Prummel, 2003). The difficult and time consuming process of collecting deep water mollusks suggests the people of New Halos valued this resource (Prummel, 2003). However, their dietary value is unclear: were they a luxury, as was the case for most Greek populations, or a dietary staple? Although the mollusks represent 60% of the animal remains it is important to consider that a family consuming a meal of mollusks would produce a

[2] Marine organisms represented in the New Halos archaeological material include he following species: *Gibbula albiba*, *Buccinulum corneum*, *Pinna nobius* and *Spondylus gaederopus.* A complete list of recovered marine specimens see (Prummel, 2003).

greater amount of waste compared to a meal based on meat from a mammal (Prummel, 2003).

As reviewed in Chapter 2, agriculture produced key dietary staples essential to Hellenistic populations' subsistence needs. Therefore not having adequate land for cultivation would put a population at an enormous disadvantage. Strong evidence to support intensive agriculture at New Halos does not exist. The topography of the area did not lend itself easily to large scale agriculture but there would have been small areas of agricultural land outside the city walls (Haagsma, 2010). Agricultural tools like sickles, hoes, and shovels were recovered from houses, so some type of agricultural work was done at New Halos (Haagsma, 2003). Gardening tools could indicate that household courtyards or small areas outside the city walls were used for private gardens to grow fruit, vegetables, olives, and herbs (Haagsma, 2010). No saddle querns were found at New Halos; instead there was large grinding equipment associated with the excavated houses. These grinding tools were large static items suggesting that processing of grain happened at home and was an individual family task, not a large scale specialized operation (Haagsma, 2010). There were also large *pithoi* (storage vessels) found at the site, presumably used for bulk storage of foods like olives and other grains (Beestman-Kruyshaar, 2003; Haagsma, 2003).

Based on documentary evidence for the era, grains like barley and wheat would be harvested once a year, typically in May or June, and then stored in large *pithoi* (Haagsma, 2010). Sources report the use of barley and wheat in Thessaly during the Hellenistic period (Bookidis, 1999; Migeotte, 2009) but there are no references to millet use in the New Halos area. In case of a poor crop yield cities needed to prepare for lean years and store surplus grains. New Halos was equipped for this and had a possible communal storage area, but this storage facility would not support the community's yearly grain needs (Haagsma, 2010). The variety of storage vessels found at New Halos supports the idea that instead many foods, including grain, were imported. Parts of Thessaly were known for their cereal production, meaning that nearby grain would have been available for import to New Halos (Haagsma, 2010). Olive trees were also present in this area and would have contributed to the subsistence needs of the population (Haagsma, 2010).

The people of New Halos, in addition to herding, agriculture, hunting, and fishing would presumably have gathered natural plant resources. Wild resources like asparagus, nettle, herbs, berries, nuts, and mushrooms could have been gathered from the local area to fill out the diet (Haagsma, 2010). Offerings in the Sanctuary of Demeter and Kore at Corinth consist of plant remains that would be typical foods in most 5th century BC houses (Bookidis et al., 1999). Lentils, bitter vetch, chick pea, grass pea, olives, pomegranate seeds, grapes, and figs are among the plant remains found in the sanctuary (Bookidis et al., 1999). These foods would have been grown and gathered in the local area and could have been found around New Halos.

The abrupt destruction of New Halos provided the opportunity to investigate a mostly complete household inventory of ceramic vessels and understand aspects of daily life (Beestman-Kruyshaar, 2003). The ceramic remains from New Halos provide clues about what types of foods people were consuming along with how they were prepared. Vessels local to New Halos have been identified along with styles from Attica, Corinth, and unspecified non-local origins (Beestman-Kruyshaar, 2003). The most common pottery styles recovered from New Halos include large wine storage amphora, *chytrai* (cooking pots), *echinus bowls* (serving bowls), *kantharoi* (wine cups), *lekanides* (household basins), jugs, *lopades* (cooking pots/casserole dishes), and fish plates (a specific style of plate with a circular depression for sauces or collecting juices) (Beestman-Kruyshaar, 2003). The cooking vessels recovered at New Halos may suggest that stews and casseroles were common dishes. There is an absence of braziers or stoves for grilling foods; perhaps food was cooked over an open fire or the instruments necessary were removed after the city's destruction (Beestman-Kruyshaar, 2003). Among the cooking vessels there were also different styles of containers used for serving condiments like salt and other dishes used for serving dry foods like nuts. Based on the ceramic remains it is evident that cooking, serving, eating, drinking and storage of food occurred in all New Halos houses (Beestman-Kruyshaar, 2003).

Wine was a common beverage throughout Greek history. Ceramic wine vessels were recovered in every house at New Halos. There were many different shapes and styles of vessels, suggesting that wine was imported from different regions (Beestman-Kruyshaar, 2003). Vinegar was produced as a by-product of wine making and was an important

resource for preserving and pickling food. Many foods would have needed to be preserved by pickling, salting, or drying (Haagsma, 2010). Wine and vinegar were most likely made at New Halos in addition to what was imported.

In general it appears that the population of New Halos had access to similar dietary resources as other Hellenistic cities in Thessaly. These included grains like wheat and barley, terrestrial meat and dairy products, wild gathered plants like nuts, herbs and fruits, and marine resources. However, it is possible that the people of New Halos relied on meat and dairy products more heavily than other cities because of their lack of agricultural land. Marine shellfish present in the archaeological record also suggest that the people of New Halos were taking advantage of these resources. Regional differences, food accessibility, and human preference all play a role in dietary composition and could have influenced how the population of New Halos approached the available resources.

3.3 The Cemetery at New Halos

The site of New Halos was situated along a narrow passage that connected the northern and southern sections of mainland Greece (Stissi et al., 2004). This area continues to be an important north-south connection for Greece and is where the Athens-Thessaloniki highway was constructed. During the construction of this highway two cemeteries, Voulokaliva and Kephalosi, were discovered (Malakasioti, 2001).

The cemetery of Kephalosi was found within the borders of the upper section of New Halos (Panagiotopoulou et al., 2016). Kephalosi cemetery was dated to the Protogeometric period based on grave goods recovered (Panagiotopoulou et al., 2016). The cemetery is associated with a contemporary domestic building that contained storage jars; because of this detail it has been suggested that this was an intramural cemetery (Panagiotopoulou et al., 2016). Most of the individuals recovered from this cemetery were subadults (Panagiotopoulou et al., 2016). No individuals from this cemetery were sampled for this study.

The cemetery of Voulokaliva is located approximately 2 km north of the Kephalosi cemetery. It was a large cemetery that was used from the later Mycenaean period (~ 1300 BC) through to the Protogeometric period (~900 BC) and re-used during the Hellenistic period (Reinders, 2003a). The long time use of this cemetery was reflected in

the chronological distribution of the graves (Malakasioti, n.d.). There was a mixture of adults and subadults in this cemetery buried in a variety of ways. Pits, cists, burial jars, cremations, and possible tholoi tombs were all burial styles used in Voulokaliva (Malakasioti, 1993; Panagiotopoulou et al., 2016). No remains sampled for this study were associated with Voulokaliva. The locations of these cemeteries are indicated in Figure 3.2.

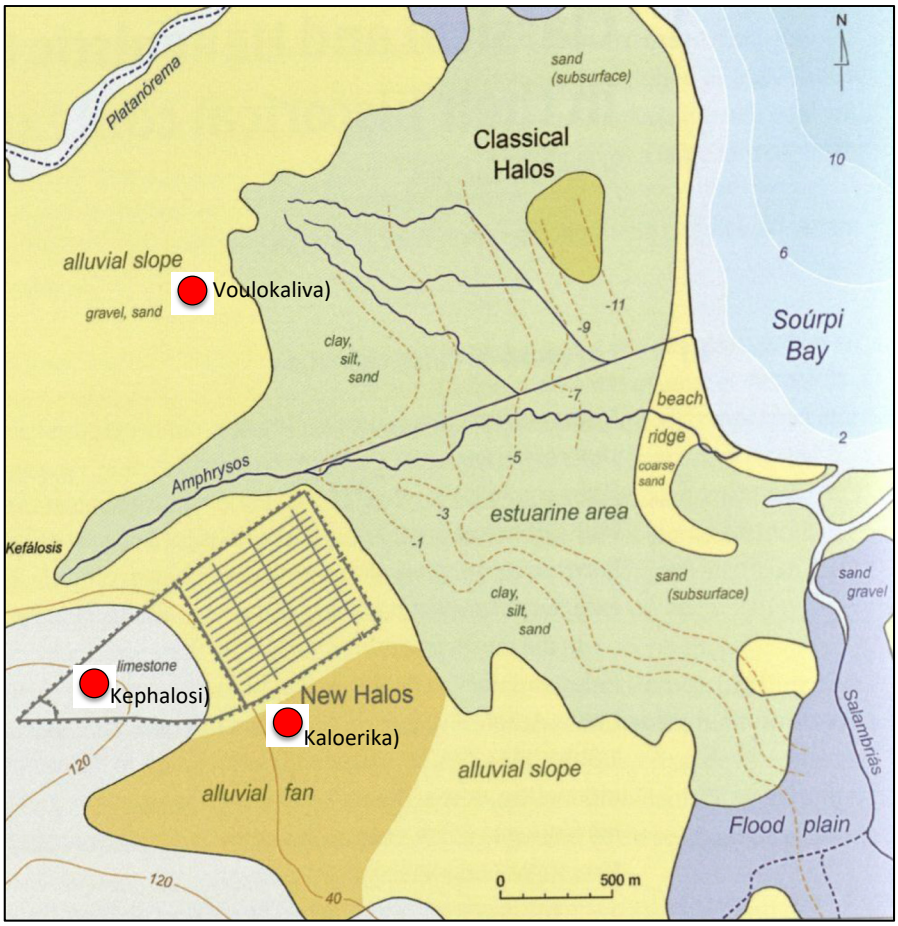

Figure 3.2: This figure indicates the site of New Halos and the approximate location of Kephalosi, Voulokaliva, and Kaloerika, three cemeteries in the area (Reinders, 2014).

Farming operations and the construction of a conveyor belt for a limestone quarry were responsible for the discovery of the New Halos cemetery called Kaloerika near the southeast gate. The 13th Ephorate of Prehistoric and Archaeological Antiquities at Volos excavated the cemetery located approximately 100 m south of New Halos' southeast gate in 1984, 1990 and 1991. There were three sections excavated, Kaloerika, Cemetery A, and Cemetery B. All three sections appear to be from the same cemetery

(Malakasioti, n.d.). Cemetery A and B were approximately 600m south of the southeast gate. A modern irrigation channel separated cemetery A from cemetery B (Malakasioti, n.d.). These three sections produced a large human skeletal sample associated with the use phase of New Halos (Malakasioti, 1985, 1992, 1993; Malakasioti & Rondiri, 1990). Samples from Kaloerika, Cemetery A, and Cemetery B were used for this study.

All graves from Kaloerika, Cemetery A, and Cemetery B were lined with limestone slabs (except for one made of clay) and were oriented on a southwest-northeast axis (Malakasioti, 1985). The graves held one to three individuals, usually adults, placed in a supine position with hands across the chest and contained up to 18 grave items (Malakasioti & Rondiri, 1990). The grave depths ranged from 0.4m to 0.8m below the surface. Their shallow depth is most likely why so many graves were disturbed and why human remains were not always recovered (Malakasioti, n.d.).

Grave goods were used to date each grave [3] (Malakasioti, n.d.; Reinders, 2003a). Among these grave goods were ceramic lamps. The lamps were one type of grave good used to date the cemetery and based on them a previous researcher placed the cemetery at a later time period than the Hellenistic (Reinders, 1988). However, lamps are not good dating devices because the styles do not change quickly over time and it is difficult to identify subtle changes that could reflect changes over time. Therefore a distinct seriation pattern for precise age estimates using lamps is not the best dating method to use (Haagsma, personal communication, July 2016). Bronze objects like jewelry, beauty items, and coins were among the other grave goods that contributed to dating the cemetery (Malakasioti, 1985; Malakasioti & Rondiri, 1990). Using these other grave goods from the New Halos cemetery a Hellenistic date from the late 4th century BC to the mid 3rd century BC was established for these graves (Malakasioti & Rondiri, 1990). The cemetery thus corresponds directly with the short habitation period at New Halos.

[3] For a complete record of the grave goods consult Malakasioti (n.d.).

3.4 Summary

As described above, New Halos was destroyed after a very short occupation and was abruptly abandoned. This brief use period gives archaeologists and bioarchaeologists an opportunity to study life in a small rural community during a time when historical records are sparse. This study will analyze the human remains from this site to learn about diet and how the population came to settle in this area. Specifically, this study aims to answer the following questions: How was the city of New Halos populated? Where did the people come from? What subsistence strategies and food resources did they exploit? Were people consuming large amounts of marine resources at New Halos? Is the abundance of shellfish in the archaeological record reflected in the isotopic values from the New Halos population?

The isotopic data that are presented in the subsequent chapters will be used to address these questions. The skeletal population provides a valuable opportunity to learn about the people of New Halos, where they came from and on a larger scale understand what life was like in a Hellenistic settlement. This study aims to provide more information about these individuals and the community they lived in.

Chapter 4 Stable Isotopes

4.1 Introduction

In *The Republic,* Plato writes "the first and chief of our needs is the provision of food for existence and life" (Skiadas & Lascaratos, 2001). Food is a powerful resource used by people in a variety of ways, for survival and to negotiate social situations. Often the consumption of food is at the centre of social relationships that reinforce positive feelings and bonds between people (Counihan, 1999). These social roles of food make it an important topic for research. As reviewed in Chapter 2, there is limited specific detail about diet in ancient Greece especially for rural communities or small urban settlements.

Material excavated from sites, including faunal material, ceramics, and lithics, can offer information about dietary practices in the past. Such evidence can identify available food resources in an area but it cannot determine what individual people chose to eat. Another limit to these materials is that some foods do not leave behind physical evidence. This can skew how a site is interpreted and may overemphasize a resource or increase its apparent importance (Sealy, 1989). These materials provide excellent information about past populations; however stable isotopes can provide direct evidence about diet and dietary preferences along with mobility patterns of a population.

The diets consumed by archaeological populations and individual people in the past can be studied more directly when the proper components of skeletal tissues are isolated and analyzed using stable isotope analysis. Isotopic signatures provide a way to retrieve information about which food resources were being consumed and can also recreate climate conditions (Bocherens & Drucker, 2003). It is important to know what food resources were available in a region and to understand cultural food preferences. Isotope analysis can directly investigate dietary differences between the sexes and age groups within a population (Katzenberg & Harrison, 1997; Schoeninger et al., 1983).

4.2 What are Isotopes?

Elements are pure substances made only of atoms that cannot be broken down into a simpler form. Atoms are composed of a nucleus containing protons and neutrons,

with electrons surrounding the nucleus. The number of protons in an atom's nucleus defines the element and determines its physical properties (Hoefs, 2009). Isotopes are variations of an element having different numbers of neutrons but the same number of protons in their nuclei, and thus the same number of electrons in a neutral state. The electronic structure of an element determines its chemical behavior (Hoefs, 2009). The loss or addition of a neutron alters the atom's weight (Hoefs, 2009). Isotopes of a single element will behave in a similar way during a chemical reaction; however, the rate at which a reaction occurs is altered because of the different mass. Smaller, lighter isotopes will react faster than the heavier, slower version of the element (Schoeninger & Moore, 1992). The different reaction times of isotopes during chemical reactions will alter the isotopic composition of both reactants and products. Of the 118 known elements there are approximately 300 identified isotopes. Of these, carbon, nitrogen, strontium, and oxygen have proven to be most useful for reconstructing past diets and mobility patterns, and will be used in this study. Each of these elements and their isotopes will be discussed in further detail below.

4.2.1 Measurements, Notation, Fractionation

Stable isotopes are usually measured using an isotope ratio mass spectrometer (Fry, 2006). The samples are converted into pure gasses and are then passed through an elemental analyzer, a gas chromatograph, or a laser (Fry, 2006). Once in the analyzer the molecules are ionized and accelerated out of a flight tube through electric fields. The ions are sorted by a magnetic field that deflects the ions based on their different atomic masses (Fry, 2006). These deflected ions create ion beams that are converted into electrical impulses in a Faraday collector (Hoefs, 2009) that are then processed through computer software to calculate the raw isotopic abundances (Fry, 2006).

For strontium, isotopic abundances are expressed as simple ratios. For carbon, nitrogen and oxygen the isotopic ratio is expressed in per mil (‰) departure from an international standard arbitrarily set at 0‰ and is calculated by the following equation:

$$\delta X(std) = \frac{R(sample)}{R(std)} - 1X \times 1000$$

R(sample) and *R(std)* are the absolute isotopic content of the sample and standard, respectively (Katzenberg, 1992). This is referred to as delta (δ) notation.

When elements are used to synthesize plant and animal tissues, different reaction times of the different isotopes influence the stable isotope signature incorporated into tissues. The metabolic pathways associated with bone and tooth synthesis cause predictable differences between the skeletal tissues and the diet (Ambrose, 1986; Bocherens et al., 1995; DeNiro & Epstein, 1978). Such a stable isotope ratio change is called fractionation. For example, during photosynthesis ^{12}C is preferentially incorporated into plant tissue relative to ^{13}C; this creates a lower ratio of ^{13}C to ^{12}C in plant tissues than in the atmosphere (Katzenberg, 1992). The $\delta^{13}C$ ratio difference between the carbon in plant tissue and the carbon in atmospheric CO_2 is an example of fractionation (Ambrose, 1986; Hoefs, 1997).

4.3 Carbon Isotopes

Carbon has three isotopes: ^{14}C, ^{13}C, and ^{12}C. ^{14}C is a radioactive form used in dating objects but not in dietary research. ^{13}C and ^{12}C are the stable isotope forms of carbon used for dietary reconstruction (Sealy, 1989). Carbon was the first stable isotope system used for paleodietary research (Sillen et al., 1989).

4.3.1 Stable Carbon Isotopes in Plants

Carbon is an effective element for use in paleodietary research because of its two stable isotopes; they occur naturally in large amounts in organic substances and vary significantly across the environment. ^{13}C comprises approximately 1.1% of naturally occurring carbon while ^{12}C is more abundant, making up roughly 98.9% of naturally occurring carbon (Chisholm, 1989; Schoeninger & Moore, 1992). Sample $\delta^{13}C$ values are expressed in comparison to the international standard PeeDee Belemnite (PDB), a marine carbonate. Almost all organic substances have negative $\delta^{13}C$ values because most biological substances have less ^{13}C relative to ^{12}C than the PDB standard (Katzenberg & Saunders, 2000). Carbon isotopes can be used to distinguish between types of plant matter consumed by animals, and can also determine the proportion of marine and terrestrial protein sources in the diet.

Plants use photosynthetic pathways to incorporate atmospheric carbon in the form of CO_2 into their tissues (Björkman & Berry, 1973; Tieszen et al., 1979). There are three photosynthetic pathways, each of which produces different stable carbon isotope ratios in plants. This differential incorporation of isotopes allows researchers to identify types of plants through stable isotope analysis.

The Calvin photosynthetic process initially produces a 3-chain carbon molecule; therefore plants using this pathway are called C_3 plants. This process strongly favours the lighter ^{12}C isotope. Generally C_3 plants are found in temperate areas and include trees, shrubs, most grains, and most vegetables and fruits. C_3 plants also prefer 10-25% full sunlight (Björkman & Berry, 1973). C_4 plants use the Hatch-Slack photosynthetic pathway, which initially produces a 4-chain carbon molecule (Ambrose, 1986; Chisholm, 1989; Katzenberg & Saunders, 2000; Lee-Thorp et al., 1989; Schoeninger & Moore, 1992; Tieszen et al., 1979). C_4 plants discriminate less against the heavier ^{13}C isotope and thus have higher $\delta^{13}C$ values compared to C_3 plants (Smith, 1972). C_4 plants are found in tropical environments and include maize, millets, and other tropical grasses (Schwarcz et al., 1985). C_4 plants function best with 100% full sunlight and fix atmospheric CO_2 efficiently in these conditions (Björkman & Berry, 1973). C_4 plants adapt to the heat and aridity of warmer and more tropical climates by minimizing the amount of time that leaf pores (stomata) are open therefore less water is lost; this also makes them more drought tolerant (Ambrose, 1986; Katzenberg, 2008). There are also plants that have the ability to use both photosynthetic pathways, called Crassulacean acid metabolism (CAM) plants (Tieszen et al., 1979). Cacti, agaves, and bromeliads are examples of CAM plants (Ambrose, 1986). The variation in plant $\delta^{13}C$ values can also be influenced by other factors. Metabolic variation within a species, the effects of fertilization, temperature, salinity, CO_2 concentration, light intensity, and differential loss of CO_2 through respiration can all change a plant's $\delta^{13}C$ value (O'Leary, 1981). However, even with these other influencing factors a plant's $\delta^{13}C$ value is largely determined by mode of photosynthesis.

C_3 plants commonly have an average $\delta^{13}C$ value of -26‰ and a range between -22‰ and -38‰ while C_4 plants have higher values with a $\delta^{13}C$ range between -9‰ and -21‰ and an average value of -13‰ (Ambrose, 1986; Chisholm, 1989; Katzenberg et al.,

1995; Tieszen, 1991). The CAM plants produce an intermediate $\delta^{13}C$ range (Francey & Farquhar, 1982; Tieszen, 1991). For the purpose of this study it is important to note that most plant resources available in Greece prior to the Ottoman era were C_3. The only commonly used C_4 plant resource was millet (Bourbou et al., 2011; Vika, 2011). Modern atmospheric CO_2 has been decreasing since the early 1800's due to the mass combustion of carbon-rich fuels such as coal and currently has a $\delta^{13}C$ value of approximately -7‰ (Katzenberg & Saunders, 2000). The preindustrial $\delta^{13}C$ value is different than the modern atmospheric $\delta^{13}C$ value and this must be corrected for when comparing ancient and modern material (Kellner & Schoeninger, 2007); this issue will be discussed further below.

Carbon in marine environments comes from dissolved carbonate that has a $\delta^{13}C$ value of 0‰, and as a result the $\delta^{13}C$ values of photosynthetic marine organisms tend to be higher than those seen in land plants (Ambrose, 1986; Hoefs, 1997; Katzenberg & Saunders, 2000). This is the root difference between the stable carbon isotope values of marine and terrestrial organisms that makes it possible to compare human diets in terms of the proportion of marine resources eaten compared to terrestrial resources (Katzenberg & Saunders, 2000). Interpreting marine resources can be complicated because dissolved oceanic carbon varies by locale (Katzenberg, 2008). Establishing a local baseline is important when evaluating isotopic values for marine resources in the diet. Freshwater plants have a wide range of $\delta^{13}C$ values that may be similar to C_3 plant values or C_4 plant values because the value of dissolved carbonate in fresh water varies widely (Katzenberg, 2008).

4.3.2 Carbon Isotopes in Animals and in Skeletal Tissues

Carbon moves through the foodweb beginning with primary consumers that eat plant food, and continues up the chain to secondary and tertiary consumers. Carbon becomes incorporated into the tissues of omnivores such as humans through the consumption of plants and animals. The consumers' whole body isotopic signatures reflect their dietary carbon sources (Sealy, 1989). As an animal consumes plants the isotopic signatures of those plants will be recombined into the consumer's tissues with varying degrees of fractionation (Lee-Thorp et al., 1989). Herbivores derive their protein from the plant protein they consume and their dietary energy comes primarily from dietary

carbohydrates and lipids. Carnivores derive their protein from prey proteins and their dietary energy comes from lipids and proteins (Lee-Thorp et al., 1989). DeNiro and Epstein were the first to demonstrate that stable carbon isotope signatures of animals reflect the isotopic composition of their diet, demonstrating that animals tend to have whole-body diet $\delta^{13}C$ values 1‰ above their diet (DeNiro & Epstein, 1978).

Schoeninger and DeNiro (Schoeninger & DeNiro, 1984) found that marine feeders in a large global sample had average $\delta^{13}C$ values approximately 5‰ higher than terrestrial feeders. However, they also found a wide range for marine resources and an 8‰ overlap in the ranges of marine and terrestrial feeders. Part of this reflects regional variation within each group. Shellfish and small marine fish are another reason for the overlap with terrestrial feeders because they have lower $\delta^{13}C$ values compared to higher trophic level marine fish (Chisholm et al., 1982; Garvie-Lok, 2013).

Carbon is present in bones and teeth, two key tissues that are of interest to this analysis. This study utilizes bone collagen and enamel carbonate carbon. Bone collagen, initially used in radiocarbon dating methods, was the first archaeological tissue used in stable isotope analysis (Katzenberg, 2008). Collagen, the major structural protein found in bone and dentine, is mainly derived from dietary protein but can also be synthesized from dietary fats and carbohydrates (Ambrose & Norr, 1993; Froehle et al., 2010; Howland et al., 2003; Krueger & Sullivan, 1984; Sillen et al., 1989; van der Merwe et al., 1987). When adequate or excess levels of protein are present in a diet the majority of bone collagen carbon will be derived from dietary protein. Other dietary carbon sources do contribute to collagen carbon but the proportion in which they contribute is influenced by the amount of protein present in the diet (Ambrose and Norr, 1993). Low protein diets impact bone collagen carbon values relative to the diet because carbon will be drawn from non-protein sources like lipids and carbohydrates in the diet (Ambrose & Norr, 1993). The carbon in hydroxyapatite, the mineral portion of bone, dentine, and enamel, is derived from the whole diet (Ambrose & Norr, 1993; Katzenberg & Harrison, 1997).

Used separately, bone collagen and enamel carbonate are useful in dietary reconstruction studies. However, when used together they provide insights into how the whole diet and dietary protein respond to different proportions of macronutrients in the

diet (Loftus & Sealy, 2012). It is first important to determine the offset value between diet and human or animal tissues. In the stable isotope literature, $\delta^{13}C$ offsets between items are expressed using the delta (Δ) symbol. For example $\Delta^{13}C_{(carbonate\text{-}collagen)}$ refers to carbonate-collagen spacing, the $\delta^{13}C$ difference between collagen and carbonate. $\Delta^{13}C$ spacing values between bulk diet and bone carbonate ranging from 12‰ to 14‰ have been reported in various studies analyzing wild terrestrial animals (Katzenberg & Weber, 1999). However, controlled feeding studies on laboratory animals report lower $\Delta^{13}C_{(carbonate\text{-}bulk\ diet)}$ values around 10‰ (Ambrose & Norr, 1993; Howland et al., 2003). Currently it remains unclear why lab studies show lower spacing values compared to the values from the field. This issue is important to the interpretation of archaeological collagen and carbonate $\delta^{13}C$ values and will be revisited in depth in Chapter 5.

The preferential routing of dietary protein to bone collagen creates a $\delta^{13}C$ spacing between the bone collagen of an animal and its dietary protein ranging between +3‰ and +6‰ (Bocherens & Drucker, 2003). A general +5‰ $\Delta^{13}C$ value between dietary protein and bone collagen has frequently been cited in the literature (Ambrose et al., 1997; Ambrose & Norr, 1993; Hedges, 2003; Katzenberg, 2008). Feeding studies demonstrate that this +5‰ value is most accurate when an individual's diet consists of C_3 protein and C_3 carbohydrates and lipids or C_4 protein and C_4 carbohydrates and lipids (Ambrose & Norr, 1993; Kellner & Schoeninger, 2007). Using this value, a C_3 diet with an average protein $\delta^{13}C$ value of -24‰ would correspond to a collagen $\delta^{13}C$ value of approximately -19‰. The different $\delta^{13}C$ spacing values described above for collagen and carbonate relative to diet indicate that an individual's bone $\Delta^{13}C_{(carbonate\text{-}collagen)}$ value will vary depending on the diet consumed.

Populations that are consuming a diet heavily based on C_3 terrestrial resources should have collagen $\delta^{13}C$ values around -19‰ (Katzenberg, 1992). Marine resources have a wide overall $\delta^{13}C$ range from -10‰ to -24‰; the lowest values in this range are often associated with lower ocean temperatures (Fry & Sherr, 1984). A C_4 plant based diet should produce collagen $\delta^{13}C$ values around -7.4‰ (van der Merwe et al., 1987). A pure vegetarian diet based on the Mediterranean triad (olives, wine, and C_3 grains) should produce collagen $\delta^{13}C$ values between -20‰ and -18‰ (Bourbou et al., 2011). Because dietary lipids are ^{13}C depleted in relation to whole body values for all organisms studied,

diets heavy in lipids would have lower average $\delta^{13}C$ values than the hypothetical diets mentioned above (Garvie-Lok, 2001; Tieszen, 1991).

As humans consume a variable diet including plants, animals, and marine resources an individual's tissues will reflect the $\delta^{13}C$ signatures of those foods. In any given environment, archaeological human bone values are compared to estimated or measured values for potential food items and available dietary resources.

4.4 Nitrogen Isotopes

Nitrogen has two stable isotopes, ^{15}N and ^{14}N, with natural abundance ratios of 0.36% and 99.64% respectively (Schoeninger & Moore, 1992). As with carbon, nitrogen is compared to an international standard. The ambient inhalable reservoir (AIR) is used as the standard for nitrogen because the stable isotope ratio of N_2 in the atmosphere does not vary across the globe and has remained unchanged over the past several million years (DeNiro, 1987; Schoeninger & Moore, 1992). AIR thus has a set $\delta^{15}N$ value of 0‰. Overall, most organic materials fall in a range of $\delta^{15}N$ values between -10‰ and 20‰ (Fry, 2006). Nitrogen isotopes are not affected by photosynthesis like carbon isotopes. Instead nitrogen can be used to examine trophic levels and identify different types of protein in the diet such as marine and terrestrial resources (Sealy, 1989).

4.4.1 Nitrogen in Ecosystems

The $^{15}N/^{14}N$ ratio of an individual's diet is influenced by the $^{15}N/^{14}N$ ratio of plants at the bottom of the food chain (Schoeninger et al., 1983). Nitrogen can only enter the biosphere through the actions of diazotrophs (nitrogen fixers). The nitrogen fixation process of bacteria was originally discovered in the 1800s but it was not until much later that the full capabilities and implications were understood (Postgate, 1981; Young, 1992). The process in which nitrogen enters the biosphere and the role diazotrophs, symbiotic, and non-symbiotic plants play in this process and in further cycling of nitrogen will be discussed below.

Diazotrophs are found in soil, water, or in the roots of some plants. These microorganisms are capable of fixing inorganic atmospheric nitrogen, breaking the N_2 bond and incorporating the nitrogen into compounds that can be utilized by plants (Hoefs, 2009). The $\delta^{15}N$ values of the resulting compounds are often around 0‰ but

have a range between -3‰ to 1‰ (Hoefs, 2009). These compounds pass into the soil and water. The overall $\delta^{15}N$ value of compounds in the soil and water is further affected by other processes including decomposition of organic matter. Local environmental conditions are important. For example, nitrogen fixation in soil is inhibited when soils are dry and when temperatures are high, therefore cool and moist forest soils should have higher nitrogen fixation and decreased $\delta^{15}N$ values relative to hot, dry, open environments (Ambrose, 1991). In order to account for these various soil nitrogen inputs and $\delta^{15}N$ values it is important to establish a local $\delta^{15}N$ baseline.

In symbiotic plants like legumes nitrogen-fixing bacteria are found in bacterial nodules on the plant's roots. These bacteria make nitrogen available to the plant (Meeks & Elhai, 2002). This process results in $\delta^{15}N$ values similar to atmospheric N_2 with values around 0‰ (Ambrose, 1986). Non-symbiotic plants obtain their nitrogen from nitrogen compounds in the soil and not through diazotrophs. A non-symbiotic plant's nitrogen values will reflect the soil it grew in (Peoples et al., 1995). Plants that acquire their nitrogen from the soil can have a wide range of $\delta^{15}N$ values because of the various nitrogen sources involved (Shearer et al., 1978). In addition to the factors mentioned above, modern fertilizer and manure will also affect soil nitrogen levels and $\delta^{15}N$ values (Ambrose, 1991; Bogaard et al., 2007).

Stable nitrogen isotopes can indicate a difference between marine and terrestrial diets (Schoeninger et al., 1983; Schoeninger et al., 1989). Researchers are able to identify the proportion of marine or terrestrial protein that animals or humans were eating based in part on the regular trophic level increases of $\delta^{15}N$ explained below. Most marine animals have higher $\delta^{15}N$ values than terrestrial animals because they are involved in a longer food chain. Freshwater fish often have elevated $\delta^{15}N$ values relative to terrestrial animal $\delta^{15}N$ values for the same reason (Katzenberg & Saunders, 2000). This $\delta^{15}N$ elevation places freshwater fish at the high end of the terrestrial $\delta^{15}N$ range making it difficult to distinguish between freshwater and marine organisms based on $\delta^{15}N$ alone (Schoeninger et al., 1983).

A review of over 100 marine and terrestrial samples produced an average $\delta^{15}N$ value for marine organisms of 14.8‰ +/- 2.5‰ (Schoeninger & DeNiro, 1984). Minagawa and

Wada (1984) evaluated $\delta^{15}N$ values for primary marine consumers like mussels and crabs and found $\delta^{15}N$ values from 8.4‰ to 9.5‰. These values were 2‰ – 3‰ higher than terrestrial plant values. The secondary consumers' samples had $\delta^{15}N$ values ranging from 10.6‰ to 12.7‰. Tertiary consumers ranged from 15.6‰ to 16.8‰, a 4.4‰ elevation above secondary consumers (Minagawa and Wada, 1984). Freshwater fish also have a wide range of $\delta^{15}N$ values; they tend to have higher $\delta^{15}N$ values than terrestrial organisms but lower values compared to marine resources (Katzenberg, 2008). Freshwater fish sampled in one general survey showed an average $\delta^{15}N$ value of 8.0‰ with a range of 6.6‰ to 9.5‰ (Schoeninger & DeNiro, 1984). Vika and Theodoropoulou (2012) published a wide range of isotopic values for marine and freshwater fish from sites around the Aegean. Their study found that marine samples had a range of 6.1‰ to 11.6‰, euryhaline fish 3.6‰ to 12.1‰, and freshwater fish from 4.9‰ to 10.9‰. The samples are from sites located inland, on the coast, and on islands. It would be impossible for an individual to consume resources from all of the sites studied (Vika & Theodoropoulou, 2012). Therefore, when possible, regional isotopic values should be considered for fish to narrow the range for these resources.

4.4.2 Nitrogen in Skeletal Tissues

Nitrogen is integrated into an individual's tissue directly from dietary protein sources. Carbohydrates and lipids do not contain nitrogen, therefore those portions of the diet cannot influence $\delta^{15}N$ values (Ambrose et al., 1997; Lee-Thorp, 2008). The stable nitrogen isotope value of an organism is strongly influenced by the trophic level effect (Schurr, 1997). When herbivores eat plants, the $^{15}N/^{14}N$ ratio becomes higher in the herbivores' tissues compared to the ratio seen in the plants. Minagawa and Wada (1984) determined that the $\delta^{15}N$ increase in herbivore tissue over diet is related to urea excretion. As urea is synthesized, there is a preferential uptake of ^{14}N; this leaves excess ^{15}N in an animal's tissue, which has the effect of increasing the tissue $\delta^{15}N$ value. This increase continues up the food web from herbivores to carnivores and humans (Katzenberg et al., 1995; Schoeninger & Moore, 1992). Thus, animals with high trophic levels will generally have increased $\delta^{15}N$ values. Broadly defined, trophic levels show a +3‰ to +5‰ stepwise $\delta^{15}N$ enrichment from soil and water continuing up the food chain through plants, herbivores and carnivores (Ambrose, 1986; Dupras & Tocheri,

2007; Schoeninger & DeNiro, 1984). However, a field study by Bocherens and Drucker (2003) demonstrated more variable δ^{15}N increases in consumers' tissues of 1.7‰ to 6.9‰ over the estimated dietary values, suggesting that δ^{15}N spacing between trophic levels can vary regionally. Humans generally consume a large amount of animal protein; therefore their δ^{15}N values are also expected to be higher than the animals they consume (Katzenberg, 2008). This principle of trophic level δ^{15}N enrichment is the basis for using stable nitrogen isotopes in dietary reconstruction studies (Katzenberg, 2008).

Agricultural populations with terrestrial diets studied by Schoeninger and colleagues had δ^{15}N values between 6‰ to 12‰ (Schoeninger et al., 1983). An isotopic study of eight Byzantine sites in Greece investigated diet using stable carbon and nitrogen isotopes. Although the sites were from spatially diverse areas in Greece and covered a time period of approximately 900 years, the study showed that the human values from all sites were similar and had an approximate δ^{15}N range of 6‰ to 10‰ (Bourbou et al., 2011). Similarly, Petrousa and Manolis (2010) found a δ^{15}N range of 7.1‰ to 10.4‰ for a population from Kalapodi, Greece thought to have been eating a terrestrial diet. While such studies can provide useful guidelines when interpreting δ^{15}N values regional and contextual isotopic studies are important because environmental conditions and cultural practices can influence the δ^{15}N values of a population (Lee-Thorp, 2008). For example, when working with agricultural populations the cultural practice of fertilizing fields with manure needs to be considered because manure will increase δ^{15}N values of crops (Bogaard et al., 2007). Animal waste generally has a δ^{15}N value greater than 5‰ (Hoefs, 2009), and this value can further enrich the δ^{15}N values of a region's soils.

4.4.3 Other causes of δ^{15}N variation

Physiological adaptations may affect the δ^{15}N values of animal tissues. In dry climates (< 400mm rainfall/ year) animals become stressed and their bodies attempt to conserve water (Katzenberg & Harrison, 1997; Katzenberg & Saunders, 2000; Sealy, 1989). Part of the process of conserving water involves an increase in urine concentration. Urinary urea is the primary pathway for nitrogen excretion by mammals (Ambrose, 1986). Thus an increase in urine concentration causes ^{14}N to be excreted at an increased rate relative to ^{15}N (Wright, 1995). This creates high tissue δ^{15}N values because more ^{15}N is retained in the body (Ambrose, 1986). Therefore a terrestrial animal that has

experienced water stress would show an elevated nitrogen signature that can mimic that of a marine diet (Hobson et al., 1993; Katzenberg & Saunders, 2000; Sealy, 1989). It is important that climate, microhabitat and an animal's physiology along with the local ecology be considered when interpreting isotopic data (Ambrose, 1986; Katzenberg & Harrison, 1997).

Another factor that can influence δ^{15}N values is breastfeeding and weaning. Studies have found that breastfed infants show a trophic level increase above their mothers because they are consuming breast milk, a bodily secretion with a δ^{15}N value similar to maternal tissues (Wright & Schwarcz, 1998). Breastfed infants on average show a 2‰ trophic level increase above their mothers' nitrogen values (Fuller et al., 2006; Wright & Schwarcz, 1998). Fogel and colleagues first demonstrated this process in a lab setting using nail clippings from modern children (Fogel et al., 1989). Modern children had increased δ^{15}N values during breastfeeding, which then plateaued before decreasing and returning to δ^{15}N values similar to that of the mother's tissues. An infant's δ^{15}N values would begin to decrease when weaning was complete and solid foods were the main component of the child's diet (Fogel et al., 1989). Fuller and colleagues (2006) later confirmed this weaning effect. Katzenberg and colleagues (1995), who were working with an Iroquoian population from Ontario, were the first to demonstrate this phenomenon in an archaeological setting. This type of δ^{15}N elevation has been used to investigate weaning in past populations (e.g Dupras & Tocheri, 2007).

Another process that can affect δ^{15}N values is when an individual experiences nutritional stress. This occurs when protein levels in the diet are inadequate and breakdown and reutilization of existing tissue occurs. This results in ^{15}N enrichment of tissues as ^{14}N is preferentially excreted. It has been suggested that this can be used to evaluate disease processes in the body (Katzenberg & Lovell, 1999).

Carbon and nitrogen isotopes, when used together, can distinguish pastoralists from farmers, people consuming different staple crops, and marine based diets from terrestrial based diets (Ambrose, 1986). When used together, as they will be in this research, they are powerful tools for dietary reconstruction.

4.5 Strontium Isotopes

Originally, geologists used strontium isotope analysis to identify different rock outcrops across a geographic region along with the age of the rock (Bentley, 2006; Sealy, 1989). The strontium isotope technique was introduced to archaeology to trace migration and residence patterns for past human and animal populations. Strontium isotopes are used in this study because they are one of the best methods to detect changes in residence (Bentley, 2006).

4.5.1 Strontium Isotopes in Ecosystems

Strontium has four stable isotopes, ^{84}Sr, ^{86}Sr, ^{88}Sr and ^{87}Sr. Of these only ^{87}Sr is radiogenic, produced by the decay of rubidium-87 (^{87}Rb). This decay process allows geologists to calculate a rock's age based on the relative abundances of rubidium and strontium remaining in the rock compared to the time of its formation (Grupe et al., 1997). The general range for $^{87}Sr/^{86}Sr$ in rocks is 0.7000 to 0.7500 (Price et al., 2002). Old rocks (>100mya) that had a high original Rb/Sr content generally have an $^{87}Sr/^{86}Sr$ ratio greater than 0.710 ppm, and recently formed rocks (1-10mya) with low Rb/Sr generally have an $^{87}Sr/^{86}Sr$ ratio less than 0.704 ppm (Bentley, 2006; Price et al., 2002). Volcanic material has a $^{87}Sr/^{86}Sr$ range between 0.7035 and 0.707 (Bentley, 2006). Rocks, however, are not always easily divided into these simple $^{87}Sr/^{86}Sr$ categories. Different minerals within rocks will have $^{87}Sr/^{86}Sr$ ratios that vary widely and regions with two or more types of rock will show an overall average $^{87}Sr/^{86}Sr$ ratio of the different rock sources (Bentley, 2006; Higgins & Higgins, 1996). Tectonic activity can shift and expose bedrock, and weathering over time will release strontium into the ecosystem. The many combinations of rocks with varying strontium content will create specific regional signatures that can be reliably identified and used to trace human mobility patterns (Price et al., 2002).

Geologists have created maps of strontium isotope values in many parts of the world, which, in general, allow archaeologists to match the geochemical strontium signature of a region to a skeleton's signature. For example, a map of strontium values across the UK was developed (Evans et al., 2010); a similar map identifying the strontium isotopic composition in groundwater across Europe is also available (Voerkelius et al., 2010). However, it is slightly more complex than this statement would imply. Although the

geochemical signature does contribute to the strontium isotope value in an individual's skeletal tissue it is more reliable to focus on the biologically available strontium in a region.

In terms of the biosphere, strontium begins in bedrock, and as the rock is weathered or eroded strontium is released into the surrounding soil. Plants then continue the cycle as strontium from the soil is incorporated into plant material, and enters the biologically available strontium pool. Animals then consume these plants, and humans later consume both. Because the relative mass difference of ^{87}Sr and ^{86}Sr is so small these isotopes can passes through this system with negligible fractionation (Bentley, 2006; Grupe et al., 1997). Because of the relatively low fractionation levels plants, animals, and humans from the same area will have similar strontium isotope values.

Strontium is an alkaline earth element that does not have a biologically regulated function within the body. Structurally strontium is similar to calcium, an essential element for proper bodily functions. Because strontium has a similar structure it can substitute for calcium in various tissues (Rosenthal et al., 1972; Schroeder et al., 1972). Plants cannot distinguish between calcium and strontium because of their similar structure so plants do not discriminate against either element (Comar et al., 1957; Elias et al., 1982). This is not true of animals; of the strontium ingested by animals less than 10% is absorbed. More than 90% of the strontium retained in the body is found in bone (Ezzo, 1994). However, because of the low fractionation the strontium values are not changed as they progress up the food chain.

4.5.2 Defining a Local $^{87}Sr/^{86}Sr$ Signature

In order to interpret strontium isotope results it is important to define a local $^{87}Sr/^{86}Sr$ signature for comparison to human values. Animals play a vital role in this process. Animals occupy different size home ranges depending on their size and migration patterns. Humans also inhabit a home range whose size can be influenced by the availability of resources, connections with other groups of people, cultural practices and so on. These home ranges for both animals and humans will have a varied geological base and therefore a variable $^{87}Sr/^{86}Sr$ signature. Unfortunately there is not a uniform area or home range radius that can be applied to all populations to establish a local strontium signature (Ericson, 1985). Local individuals should have similar $^{87}Sr/^{86}Sr$ values

to the local range, and non-local individuals should have $^{87}Sr/^{86}Sr$ values that deviate from the local value.

Three methods were suggested by Ericson (1985) to determine a local $^{87}Sr/^{86}Sr$ signature. Direct empirical study is the first method, which uses the average $^{87}Sr/^{86}Sr$ value of the human population in a particular area to create a local signature. Each individual $^{87}Sr/^{86}Sr$ value is then compared to the average to identify non-local individuals, assuming that individuals who depart from the local average by more than 2 standard deviations from the mean are non-local. Many researchers have used this method to determine local $^{87}Sr/^{86}Sr$ signatures (Price et al., 1994; Grupe et al., 1997; Bentley et al., 2004). The direct empirical study model involves an assumption that every population is similarly composed of a majority of local individuals. In this scenario, two standard deviations from the mean would be acceptable because it would capture the variability of the local population and individuals outside this range would be non-local. However a largely immigrant population may show very high internal $^{87}Sr/^{86}Sr$ variation; this method could create an unreasonably wide local range that would misidentify non-locals as locals. Additionally, this method requires a large sample population in order to make the average and standard deviation statistically sound (Ericson, 1985).

The second method proposed by Ericson (1985) involves grid sampling modern plants and animals from the proposed home range. A local range is created using the average $^{87}Sr/^{86}Sr$ values from sampled plants and animals. The main difficulty with this approach is that modern plant and animal $^{87}Sr/^{86}Sr$ values may not represent past $^{87}Sr/^{86}Sr$ values. Modern fertilizers and new strontium sources in an area can influence the $^{87}Sr/^{86}Sr$ values (Knudson et al., 2004; Knudson et al., 2005).

The third method proposed by Ericson (1985) suggests that researchers take $^{87}Sr/^{86}Sr$ values directly from the parental bedrock. Estimating a local $^{87}Sr/^{86}Sr$ signature using geological mapping of rocks provides a good starting point to estimate the local signature. The region being studied should have regionally distinct characteristics so isotopic boundaries can be defined (Blum et al., 2000). The $^{87}Sr/^{86}Sr$ value of the parental bedrock may not however, be identical to the biologically available $^{87}Sr/^{86}Sr$ values observed in the local dietary items consumed by past human populations (Price et al., 2002). It is important to be aware of the possible local variation in a given region

and what would be a realistic local $^{87}Sr/^{86}Sr$ signal given the local geology.

Another possible method for determining the local $^{87}Sr/^{86}Sr$ signature, proposed by Price et al. (2000) and Bentley et al (2004), is to sample archaeological faunal remains. Archaeological animals are preferred over modern samples because they would not be affected by foreign material, fertilizers, and airborne sources of strontium that may have been introduced to the site over time (Bentley, 2006). Small animals like mice and rabbits can be used as a base line for a particular area. Choosing small animals that have a limited home range is ideal because their $^{87}Sr/^{86}Sr$ ratios will reflect a small catchment area and reduce the variability in their strontium signature (Beard & Johnson, 2000). Likewise, domesticated animals like dogs or pigs that could be consuming similar diets to humans also make a good proxy for $^{87}Sr/^{86}Sr$ signatures (Bentley et al., 2004). Because pigs are often fed human scraps and live locally around humans, their strontium values will often be similar to human values from the same region (Bentley et al., 2004; Howland et al., 2003). Although diagenetic factors can influence the faunal strontium isotope values at a site this should not be a problem when determining a local $^{87}Sr/^{86}Sr$ signature because this soil contamination will only make the faunal samples reflect the local $^{87}Sr/^{86}Sr$ signature (Grupe et al., 1997; Price et al., 2000; Bentley et al., 2004), which is what is being assessed in the first place. In addition to the faunal values a reference map of strontium values for the local bedrock can also be a helpful starting point. One such map was created for the Aegean region using archaeological animal dental enamel and modern snail shells (See Figure 5.1, p.97) (Nafplioti, 2011).

A human strontium isotope value that is different from the local animal $^{87}Sr/^{86}Sr$ values can suggest that an individual is non-local. The area that a person was living at the time of tooth formation will be reflected in the incorporated strontium tooth values. Teeth do not turn over, so they retain these initial values; therefore if an individual's enamel strontium isotope signature does not match the burial environment it is possible to infer that that individual was not from the area. Following the identification of a non-local individual it is possible to use strontium values in the surrounding region to determine if an individual could have been from the greater regional area. If an individual's strontium values are drastically different than the local geological strontium values than it is possible to suggest that the individual was a long-distance immigrant to the area.

However, a possible complication with strontium isotope analysis is as follows: an individual who moved or travelled frequently away from their hometown during their early years could have enamel strontium values that reflect an average of the regions they visited (Bentley, 2006). This average strontium value would give an individual the appearance of being non-local. Another complication is that while an individual whose signature matches the local strontium isotope value could be local, they could also be from an area with a similar geological substrate (Grupe et al., 1997).

The burial environment around a skeleton can influence its chemical composition and alter its isotopic signatures. Archaeological bone can accumulate strontium from the burial environment that can erase or overwhelm the biological signature (Ezzo, 1994; Sealy, 1989). This may occur via deposition of minerals into pores or microcracks in the bone (Bentley, 2006). Diagenetic strontium can also be incorporated directly into the bone or tooth mineral through groundwater exchange (Bentley, 2006). An individual with a non-local strontium value indicates little to no contamination because the sample has maintained its original values and has not been affected by diagenetic processes (Price et al., 2000). However, a local signature need not imply contamination.

As reviewed below, bone is more susceptible to diagenetic processes than enamel because its crystal lattice has larger pores. Tooth enamel has a very dense structure and does not turn over once laid down; therefore it is highly resistant to diagenetic processes and is a preferred tissue for this type of study (Cox & Sealy, 1997; Price et al., 2002). Contamination of enamel strontium in the burial environment is minimal and can be removed during sample preparations (Schwarcz et al., 2010). It has been established that enamel produces a more reliable biogenic signature for analysis (Bentley, 2006).

4.6 Oxygen Isotopes

Oxygen isotopes, like strontium, will be used in this study to detect residential mobility. Human bone and teeth store a record of the complex relationship of climate, diet, and physiology as oxygen is incorporated into the body (White et al., 2004). Oxygen isotope analysis uses two stable isotopes: ^{16}O and ^{18}O. They are expressed in terms of the heavier ^{18}O isotope ($\delta^{18}O$) in relation to two international standards: Vienna Standard Mean Ocean Water (VSMOW) or PeeDee Belmnite (PDB) (Budd et al., 2004). Oxygen

isotope values of tooth enamel reflect those of drinking water consumed when the teeth were formed. Thus, similar values indicate a local origin and different values suggest a non-local origin.

4.6.1 Oxygen Isotopes in Ecosystems

Following the general principle for stable isotopes, ^{16}O and ^{18}O isotopes evaporate at different rates, so water molecules containing the lighter ^{16}O will evaporate faster. Thus water $^{18}O/^{16}O$ ratios will vary environmentally (Knudson, 2009). $\delta^{18}O$ of surface water is influenced by latitude, altitude, temperature and annual rainfall (Gil et al., 2014; Turner et al., 2009). The $\delta^{18}O$ signatures of plants and water sources in an environment will be influenced by atmospheric precipitation (e.g. rainfall). Changes in the $\delta^{18}O$ values of precipitation in various regions will be reflected in the $\delta^{18}O$ composition of regional water sources (White et al., 2004). Increased $\delta^{18}O$ values are often found inland and at increased altitudes (White et al., 2004). This is because water molecules containing the heavier ^{18}O isotope will fall out in precipitation more rapidly in comparison to the lighter ^{16}O-containing molecules (Knudson, 2009). This causes precipitation $^{18}O/^{16}O$ ratios to vary regionally as geographic and environmental conditions change. Having an idea of general environmental and climatic conditions (like average temperatures, local rainfall values, and surface water values) will aid in interpreting $\delta^{18}O$ values from human tissue because the water imbibed by humans will reflect a local signature (Turner et al., 2009). Local rainfall $\delta^{18}O$ values can be approximated using analysis of groundwater. Daux et al. (2005) found that variation in the $\delta^{18}O$ values of groundwater between recent time periods was not significant and that modern drinking water values can be used to estimate values from the past.

Within Greece there are many different climatic regions that can be distinguished using oxygen isotopes (Dotsika et al., 2010). Oxygen values in a region are influenced by the provenance of wet air masses and the direction they travel over continents (Dotsika et al., 2010). Measured $\delta^{18}O$ values for Greece range from +0.4‰ to -19.6‰ VSMOW (Dotsika et al., 2010); this reflects both geographic and seasonal variation. The Mediterranean Sea is a significant source of moisture for Greece and it greatly affects the oxygen values on the eastern side of the country (Dotsika et al., 2010). The Pindos mountain chain affects weather systems moving across Greece from east to west and

the mountains are responsible for year round precipitation and cold winters (Dotsika et al., 2010). Clouds discharge over Epirius because of the Pindos Mountains, which results in isotopically depleted precipitation once it arrives in Thessaly (Dotsika et al., 2010). The western side of continental Greece receives the largest concentration of precipitation followed by the eastern Aegean islands (Dotsika et al., 2010). The most enriched $\delta^{18}O$ values correspond with measurements from Sparta during the summer because it is the hottest region in the south (Dotsika et al., 2010). The hotter weather encourages water evaporation, which will influence the $\delta^{18}O$ values of the area. In Thessaly and Macedonia, at higher altitudes, the $\delta^{18}O$ values are lower than in southern regions of the country; altitude effects have been calculated to be -0.25‰ per 100m in Thessaly (Dotsika et al., 2010).

4.6.2 Oxygen Isotopes in Skeletal Tissues

Oxygen isotope ($^{16}O/^{18}O$) ratios in human skeletal tissues are largely influenced by imbibed water and, to a lesser extent, water in consumed foods (Ayliffe & Chivas, 1990; Bryant et al., 1994; Buzon & Bowen, 2010; Daux et al., 2008; Gil et al., 2014; White et al., 2004). Environmental and meteoric water heavily influence the $\delta^{18}O$ composition of an individual's body water (Longinelli, 1984). Many variables that can affect a person's $\delta^{18}O$ signature are regionally specific, so $\delta^{18}O$ values can be used to recreate regional environments and assess individual mobility (Turner et al., 2009).

Studies indicate that body water $\delta^{18}O$ values vary from species to species because isotopic values are influenced by imbibed water, water in food, and body temperatures (Daux et al., 2008; Wright & Schwarcz, 1998). Water in food can be enriched in ^{18}O compared to meteoric water; therefore animals that derive more water from food sources can have elevated $\delta^{18}O$ values relative to other animals (Kohn, 1996). The plant material that many herbivores ingest can contain up to 50% of their total ingested water (Daux et al., 2008). As a result, large herbivores obtain a large proportion of their body water oxygen from plants.

Most large terrestrial animals' $\delta^{18}O$ values are less affected by the food they consume than by their drinking water $\delta^{18}O$ value. This is because the water turnover in their bodies is related to their body mass and will strongly influence their $\delta^{18}O$ values. Thus

mammals living in an environment with a single water source should have a bone mineral isotopic composition reflecting that local water source. However, animals that live in arid conditions and have some drought tolerance get most of their water from the plants they consume. In this situation humidity affects an animal's $\delta^{18}O$ value because plant $\delta^{18}O$ values are affected by humidity in arid environments (Daux et al., 2008; White et al., 2004).

Ambient temperature has little influence on bone mineral oxygen isotope values of warm-blooded animals because a constant body temperature is maintained and therefore the $\delta^{18}O$ values in bone mineral have a predictable offset from body water (Longinelli, 1984). Mammals are able to regulate and maintain a constant body temperature; for humans that constant temperature is kept at 37.5 degrees Celsius. Oxygen isotopes are incorporated into the phosphate and carbonate of bone and teeth, with a final isotopic composition that reflects the body water $\delta^{18}O$ and a fractionation effect specific to body temperature (Gil et al., 2014; Knudson, 2009; Turner et al., 2009).

Humans are medium size omnivorous mammals. $\delta^{18}O$ values for humans are strongly influenced by drinking water because we ingest less water from our food sources than herbivores (Daux et al., 2008). Thus the $\delta^{18}O$ values of our body water (and our bone mineral) will be mostly affected by drinking water, which is in turn strongly influenced by environmental conditions (Daux et al., 2008). $\delta^{18}O$ values can be altered if a person is regularly consuming large quantities of heated water because the lighter ^{16}O isotope will evaporate faster during heating, thus artificially shifting the $\delta^{18}O$ value of the water away from its local value (Garvie-Lok, 2013; Knudson, 2009). This is important because cooking will alter the oxygen content of food and could influence an individual's $\delta^{18}O$ values if the majority of their imbibed water was heated. Expired breath, sweat, and urine also change the body's $\delta^{18}O$ value by causing preferential loss of the lighter ^{16}O isotope (Bentley & Knipper, 2005; White et al., 2004; Wright & Schwarcz, 1998).

The oxygen in body water is enriched in ^{18}O compared to ingested water (Kohn, 1996). The $\delta^{18}O$ values of human breast milk are elevated above those of the water that a mother ingests because it is formed from her body water pool. This in turn influences an infant's tissues by incorporating a heavier $\delta^{18}O$ signature. When selecting samples for

mobility studies it is important to select teeth that form after weaning to avoid the elevated breastfeeding signatures that may not match the local signature (Garvie-Lok, 2009; Wright & Schwarcz, 1998, 1999).

In antiquity, drinking water would have come from surface water sources and precipitation; these sources would be strongly linked to local geography and climate (Budd et al., 2004). Animal bones recovered from a site can be used to reconstruct the past climate and produce a baseline for the region, but they cannot be directly compared to human values because each species derives different amounts of their body water from their drinking water and thus has a different characteristic $\delta^{18}O$ value in the same environment (Longinelli, 1984). However, $\delta^{18}O$ values within a species do produce regional patterns that are useful for determining mobility patterns within a population.

Theoretically oxygen isotope analysis should work best on a population with little social status differentiation and who consumed a monotonous diet (White et al., 2004). A population that meets these criteria would show little internal isotopic variation because people would not have differential access to food resources. Longinelli (1984) studied the variation in $\delta^{18}O_{(body\ water)}$ values in various species. He found an intrapopulation variation of approximately 1‰ for a number of large-bodied species (wild boar, deer, domestic pigs). Another study reported an intrapopulation range of 2.4‰ for domesticated animals (D'Angela & Longinelli, 1990). Studies on archaeological human populations from Mesoamerica reported intrasite variability between 1.8‰ and 2.1‰ (White et al., 2001; White et al., 2000; White et al., 2002). An intrapopulation variation of 2‰ is a conservative estimate for stationary populations. A wider range of variability would suggest the population was composed of local and foreign individuals (White et al., 2004). Oxygen isotope analysis cannot distinguish between two locations with similar climates, however when used with strontium the analysis becomes more powerful and different environments can be determined (Bentley & Knipper, 2005; Chenery et al., 2010).

4.7 Skeletal Tissues used in Stable Isotope Analysis

The type of skeletal tissue employed in dietary reconstruction studies depends on the research question being posed. The different remodeling rates of skeletal elements

allow stable isotope analysis to reconstruct diet from different stages of life. As bone remodels it incorporates isotopes from the most recent dietary sources. Remodelling of bone is an ongoing process during life. Teeth on the other hand do not remodel and retain a childhood dietary signature. Therefore individual bones and teeth will reflect different portions of an individual's dietary past.

Bone is a composite structure whose matrix includes a non-organic mineral phase (approximately 70%) and an organic phase (approximately 30%). The mineral in bone is from the apatite family called hydroxyapatite (Price, 1989). Hydroxyapatite is responsible for bone rigidity (Landis, 1995). Collagen proteins make up 90% of the organic component of bone; the other portion consists of non-collagenous proteins and lipids (Miller, 1984). Collagen provides bones with their flexibility and it also makes up the bulk of the organic portion of tooth dentin (Hillson, 1996).

There are four main variants of collagen found in the body; the dominant type of collagen is Type I, found both in teeth and bone. Structurally, Type I collagen is made up of three strong amino acid chains that coil tightly around each other into a triple helix (Gage et al., 1989; Hillson, 1996). This tightly coiled arrangement provides molecular strength to withstand degradation and diagenetic processes (Hillson, 1996).

Initial bone formation begins in utero as connective tissue frameworks ossify into immature bone. As bones grow, new bone tissue is laid down by osteoblasts and old bone is resorbed by osteoclasts (White & Folkens, 2005). All bone growth is the result of deposition and resorption. Remodelling of bone continues as an ongoing process after growth is complete, with bone continuously turning over as the osteoblasts and osteoclasts work together to keep the tissue healthy and viable.

The turnover of bone is faster in trabecular bone because of its larger surface area compared to the slow rate at which cortical bone remodels (Price, 1989). Hedges and colleagues (Hedges et al., 2007) developed a model for bone turnover and found that during adolescence bone turnover rates were much higher than in adults. For teenagers the bone turnover rate is approximately 10-30% per year between the ages of 10 to 15; the turnover rate was much higher for teenage males (Hedges et al., 2007). The turnover rate slows after the age of 20 (Hedges et al., 2007). For females the rate slows

from 4% per year at 20 years of age to 3% per year at 80 years. Males 20 years of age have a turnover rate of 3% per year that slows to 1.5% per year at 80 years old (Hedges et al., 2007). Later in life women have faster bone turnover than men, the opposite to what was determined during adolescence.

The size and thickness of a bone will also factor into the turnover rate. Smaller bones with less cortical tissue will reflect a shorter time period compared to a bone with a large amount of cortical tissue. Cancellous bone has a more rapid turnover rate because it is thinner and has more surface area. An adult human femoral bone will take more than 10 years to turn over completely, while a phalanx (finger or toe bone) will turn over in approximately 6.2 years (Hedges et al., 2007; Price et al., 1992).

Teeth, on the other hand, do not remodel and therefore maintain a dietary signature from when they were formed. Human teeth are a very small component of the skeleton but these small structures carry within them a wealth of information. There are three types of hard tissue found in teeth: enamel, dentin and cementum. These tissues all have specific functions and interact in specific ways to make teeth the hardest elements in the body. Here enamel will be discussed in greater detail because it is relevant to this research. Teeth are unique because when they finish forming and come into occlusion they are the only part of the skeleton to interact directly with the external environment (Hillson, 1996). Since teeth interact with the external environment and do not remodel like bone they must be resistant to the types of forces they encounter. The tooth crown can only be changed by tooth wear, breakage or demineralization (Hillson, 1996).

Enamel tissue makes up the outer layer of the tooth. Mature enamel is composed of 95% mineral, 4% water and 1% organic matrix (Garant, 2003; Schroeder, 1991). The mineral component of enamel is mainly hydroxyapatite crystals and gives the tissue its strength (Alt et al., 1998; Hillson, 1996). The prismatic nature of enamel forms a very strong rigid structure that is impermeable to outside influences; the outermost layers are arranged aprismatically to prevent foreign elements attaching themselves to the crown (Budd et al., 2004; Garant, 2003). Enamel does not remodel or have the ability to repair itself because there are no cells in its matrix (Hillson, 1996). Enamel formation is a closely regulated process, and the developmental timing is very important to the proper growth of each tooth crown (Lyngstadaas, 1995). The

controlled nature of tooth development means that teeth lend themselves well to paleodietary research, as it is possible to target a specific period of a person's early life.

4.8 Diagenesis and Skeletal Tissues

During life the human body maintains a homeostatic system that ceases to function at death. As bone interacts with the burial environment new chemical constituents and physical factors begin influencing the body (Katzenberg & Saunders, 2000). In this new environment alterations to the original bone matrix can occur in two ways. The first is with the introduction of new material from the burial environment, which is added to the bone. The second occurs when the original bone matrix is altered by bacteria, fungi, and microflora (Bell et al., 1996; Jans et al., 2004; Krueger, 1991).

The preservation of bone cannot be determined from its external morphology because the organic and inorganic fractions of bone can be altered at the microscopic level (Hanson & Buikstra, 1987). The inorganic portion of bone may experience large chemical changes that affect the original biological signature. For example strontium and lead are two elements that can substitute for calcium in hydroxyapatite even after death (Katzenberg & Saunders, 2000; Sillen et al., 1989). Water is another medium that is important to consider when discussing post-mortem changes. Water is a common transporter of foreign material into the bone and it also encourages minerals to leach out of bone (Hedges & Millard, 1995).

Other factors that affect bone preservation include soil pH, ground temperature and precipitation. Physical aspects of bone such as age, porosity and biochemistry can also protect or hinder bone preservation (Katzenberg & Saunders, 2000). Juvenile bone that is less dense and less organized is more susceptible to diagenesis than mature bone. Also, cortical bone is less affected than trabecular bone because of their different physical structures (Katzenberg & Saunders, 2000).

It is important to assess the quality of skeletal samples used for isotopic analysis. Various methods are used to analyze quality. The collagen yield is calculated using the dry weight of the bone or tooth sample and the dry weight after decalcification (Ambrose, 1990; DeNiro, 1985; van Klinken, 1999). The C/N ratio, %C, and %N are

measured using an elemental analyzer. These quality indicators are compared to the range for modern tissues. Samples that fall outside the modern range are considered altered and not suitable for study. These quality indicators will be discussed in detail in Chapter 5**.**

The carbonate of bone hydroxyapatite (used for δ^{13}C and δ^{18}O analysis) can be found at various sites within the molecule. These include more stable lattice-bound locations as well as a more labile or soluble fraction. Diagenetic carbonate is often also more soluble because it is loosely attached to the surface of the hydroxyapatite crystal (Shin & Hedges, 2012). Because of this, a basic precaution when analyzing bone carbonate is to treat the samples with a dilute acid solution to remove the most labile carbonates. However, this is not always reliable because recrystallization of the sample may occur. Recrystallized bone is another diagenetic product that is typically less soluble than intact bone and thus more difficult to remove from the original matrix because it will not be removed by an acid pretreatment (Garvie-Lok et al., 2004).

In comparison to bone mineral, tooth enamel is more resistant to diagenetic factors because of its low organic content and higher crystallinity (Budd et al., 2004; Shin & Hedges, 2012). Tooth enamel has larger and denser crystals and the enamel surface is less porous which makes it more resistant to chemical alteration (Budd et al., 2001; Hillson, 1996). Thus another common precaution is to use tooth enamel rather than bone mineral for analysis (e.g. Bentley, 2006; Bentley et al., 2004; Montgomery et al., 2005; Nafplioti, 2011; Price et al., 2002).

Being aware of the criteria and limitations mentioned above will ensure that researchers are producing and working with good samples and reliable isotopic signatures. It is important to know about how these criteria may have influenced the skeletal sample to avoid poor sample quality.

4.9 Archaeological Isotopic Studies in Greece

Archaeological stable isotope research in Greece is limited to a small number of completed studies relative to the large output seen for some other regions. Traditionally archaeological records and ancient texts were used in dietary reconstruction (Bourbou & Richards, 2007; Dalby, 2003; Pomeroy, 1997). These sources offer information about the

range of food available and what foods were eaten but do not provide direct evidence for what foods were preferentially consumed by a given individual. Written sources commonly represent the Athenian upper class perspective, omitting the non-Athenian and lower class individuals (Keenleyside et al., 2006). Stable isotope research provides direct evidence about diet and resource use. The available isotopic studies are from areas within the Mediterranean and cover a broad temporal period. The following summarizes some of the stable isotope research done in Greece.

The oldest Neanderthal skeletal material studied in Greece looked at mobility at Lakonis, Greece (Richards et al., 2008). Using strontium isotopes, the researchers were able to determine that the Neanderthal had lived in a different region from its final resting place during adolescence (Richards et al., 2008). However, Nowell and Horstwood (2009) commented on the methods used to determine that this Neanderthal was non-local and suggest the opposite is true. The Neolithic Period in Greece circa 7000 - 3200 BC was a time of transition to a more sedentary lifestyle with the introduction of plant and animal domestication (Papathanasiou, 2003). An isotopic study of three coastal and three inland sites was conducted to test the hypothesis that Neolithic populations ate mostly terrestrial food sources such as grains. Using stable carbon and nitrogen isotopes the researcher was able to determine that all six sites had a similar diet based on terrestrial resources. The $\delta^{13}C$ values reflected a C_3 diet and the $\delta^{15}N$ values were low, indicating minimal marine resource input (Papathanasiou, 2003).

Two Bronze Age studies used stable carbon and nitrogen isotope analysis and had similar results. Petroutsa and Manolis (2010) looked at four mainland sites in Greece. Individuals from all four sites had $\delta^{13}C$ values that correspond with a terrestrial C_3 plant based diet with a small portion of the diet from C_4 plants. Marine resources were not obviously reflected in the isotopic data, leading the researchers to the conclusion that marine foods were not a large part of the diet (Petroutsa & Manolis, 2010). Lerna, another Bronze Age site situated near the sea, was also the subject of a dietary study. This study found that the individuals at this site were eating a mixed terrestrial diet with limited marine input (Triantaphyllou et al., 2008). Another isotopic study investigated the degree of inequality within a population. Richard and Hedges (2008) determined that in contrast to the groups studied by Petroutsa and Manolis (2010) and

Triantaphyllou et al. (2008), the elite individuals from Grave Circle A at Mycenae were consuming a high status diet based on terrestrial animals along with a significant addition of marine protein.

Apollonia is a Greek colonial site on the coast of the Black Sea that existed during the Classical period (5^{th} to 3^{rd} century BC). This site was investigated to understand the importance of marine and terrestrial resources in the diet, as well as to determine if there was any variation in diet according to age, sex, and burial type (Keenleyside et al., 2006). Unlike most of the earlier populations mentioned above, the stable carbon and nitrogen isotope results for this population indicate that a significant amount of marine resources were being utilized in conjunction with terrestrial food sources (Keenleyside et al., 2006). Work by Vika and colleagues (2009) analyzed skeletal samples from Classical Thebes in Greece. They found that the individuals analyzed were consuming a diet of terrestrial C_3 protein with no marine input, despite the site's close proximity to the sea. Additionally, they noted a 5‰ $\delta^{15}N$ enrichment in humans over the faunal samples. Earlier stable isotope work at Classical Thebes had proposed that the enriched $\delta^{15}N$ values were a result of increased protein intake from meat and milk products (Vika, 2011). Other proposed explanations were the inclusion of freshwater fish or general $\delta^{15}N$ elevation of the human diet due to manuring of fields. More recent work has determined that freshwater fish, most likely from the three large lakes surrounding the site, were the source of the high $\delta^{15}N$ values (Vika et al., 2009).

Six sites in Greece where fish bones were collected during excavation were studied to produce isotopic values for archaeological fish bone collagen (Vika & Theodoropoulou, 2012). Four of these sites were in Northern Greece and two were on islands in the Aegean. These sites are spatially diverse and represent different ecological systems. A total of 41 fish samples from the six sites were analyzed and the results demonstrated a complex and variable isotopic range. Euryhaline, freshwater, and marine fish were sampled; while their mean values differed somewhat, all three types had similar large isotopic ranges and included values that would be difficult to distinguish from land resources (Vika & Theodoropoulou, 2012). The study's authors urge other researchers to consider these unexpected isotopic values when discussing human diets in Greece. They

suggest that fish played a larger role in past diets than previously thought because other dietary items may easily mask their isotopic values.

There have been some isotopic studies done for the Byzantine period. A study compiled and compared the results from previous research that involved a total of 142 individuals from eight Byzantine sites in Greece (Bourbou et al., 2011). The data was previously published in separate articles (Bourbou & Richards, 2007; Bourbou, 2010; Garvie-Lok, 2001). The isotopic results show that individuals from the various sites generally have similar values. The low $\delta^{13}C$ values suggest a reliance on the Mediterranean triad of grains, olive oil, and wine and the $\delta^{15}N$ values suggest terrestrial meat and/or dairy products as dietary staples. The values of certain individuals indicate that marine resources would have been included in their diet, but this was not the case for any of the sites as a whole (Bourbou et al., 2011). Another study of the same sites used stable carbon and nitrogen isotopes to establish age of weaning in Byzantine populations. This study used multiple sites in Greece to produce a pooled juvenile sample set. There was some variability within and between the sites studied, but on average the data suggest that infants were weaned at or around the age of four (Bourbou et al., 2013).

A study on Frankish Corinth sampled 16 individuals from three burial areas. The first two burial areas were closely related; therefore the 11 individuals were considered together as one sample group. Their $\delta^{18}O$ values were within the range of the expected local Corinthian signature and their collagen $\delta^{13}C$ and $\delta^{15}N$ values were also within the local range. There were two individuals who stood out from the third burial area. The first individual had increased oxygen values and a $\delta^{13}C$ value indicating a mixed C_3 and C_4 diet. When the $\delta^{15}N$ value was considered it appears that this individual was from a warm arid environment (Garvie-Lok, 2009). The second individual had local $\delta^{18}O$ values but the carbon and nitrogen signatures indicated a diet that was distinctly different from other individuals at Frankish Corinth (Garvie-Lok, 2009). These two outlying individuals clearly demonstrate the strength of isotopic analysis and that isotopes related to mobility patterns are able to identify not just local and non-local individuals but can also suggest likely places of origin and time of immigration.

Another study of Frankish era Greece was conducted using stable carbon and nitrogen isotopes of remains from the site of Mytilene to establish dietary patterns for the

population. The bone carbonate results indicated that people in this population relied on staple foods like wheat, barley and olive oil (Garvie-Lok, 2009a). This is similar to results from other studies mentioned above. The bone collagen data suggest that domesticated animal protein was an important portion of the diet with some marine resources mixed in (Garvie-Lok, 2009a).

Strontium and oxygen studies are not as plentiful in Greece as carbon and nitrogen studies, however this is a growing area of study. In addition to the $\delta^{18}O$ work at Corinth described above, oxygen isotopes were also used at Apollonia to determine how many of the 60 individuals studied were locally born. The oxygen isotope values demonstrated that 55 of the 60 individuals studied could have been locally born; the five non-local individuals identified would have been from a region outside the Black Sea (Keenleyside et al., 2011). In addition to the Neanderthal study mentioned above, strontium isotopes were also used in a study of individuals interred in many different cemeteries within a 2km radius of Knossos, in Crete, during the Late Minoan IB period (ca. 1490 BC) (Nafplioti, 2008). Some of these individuals were found in 'non-local' styled burials (warrior burials, burials with bronzes, and tombs of Mainland architecture) (Nafplioti, 2008). Using strontium isotopes it was determined that all of these individuals could have been locally born, suggesting that a 'mainland invasion' did not bring these individuals to Crete (Nafplioti, 2008).

The University of Alberta has been a large contributor to isotopic work in Greece. For a recent summary of this work see Garvie-Lok (2013). The following are examples of studies completed recently from that institution. Extensive research has been done at the site of Stymphalos (Garvie-Lok, 2014). A residential mobility study of rural Stymphalos was conducted using strontium isotopes. This study looked at a rural Late Roman/Early Byzantine and Medieval population (Leslie, 2012). Pennycook (2008) investigated a Byzantine and Frankish Greek population in the valley of Stymphalos using stable carbon and nitrogen isotopes to look at dietary variation. Strontium analysis was used to investigate birthplace and cultural integration at a 13th century cemetery in Corinth (Lê, 2006). Lastly, carbon and nitrogen isotopes were used to reconstruct diet at Helike, Greece for the Hellenistic, Roman and Byzantine periods (McConnan Borstad,

2013). The research outlined in this proposal will continue to add to the Greek isotope research coming out of this institution.

4.10 Summary

Stable isotope analysis is a powerful tool that can be used to learn about many aspects of the past. Food can indicate how a population chose to utilize available resources. It can also identify if trade was an important subsistence strategy. There are many unknowns about diet in Ancient Greece, especially for rural communities and small urban settlements. Stable isotope analysis is a useful method for dietary reconstruction and investigating mobility patterns within a population when the proper skeletal components are sampled and analyzed. The analysis is strengthened when two or more isotopes are used together because they all reflect different portions of the diet and are synthesized differently within the body. Selecting appropriate skeletal elements is also crucial for a successful study because different elements retain different dietary periods of a person's life.

It is the goal of this study to learn about dietary preferences using stable carbon and nitrogen isotopes. This will identify dietary signatures at New Halos and will answer many questions about diet including how marine resources contributed to the diet at this site. The faunal record at New Halos is represented by an abundance of marine shellfish; carbon and nitrogen isotopes will help to determine the extent to which this resource was being exploited. The isotopic analysis will also provide further information about this rural settlement and compliment the archaeological interpretation of how the people of New Halos were living. This study, using isotope analysis, will also examine dietary patterns by age, sex, and grave date.

Secondly, the geographic origins of the New Halos population will be investigated using stable oxygen and strontium isotopes. During the Hellenistic period new settlements were formed, but it is unclear how the cities were populated. This study will attempt to identify which individuals buried at New Halos were of local and non-local origin. If non-local individuals are identified an attempt will be made to determine where they may have come from. This will help answer the question of how Hellenistic settlements in Thessaly were populated.

Chapter 5 Methods and Materials

This study investigates the dietary signatures and mobility patterns of a Hellenistic skeletal population using stable isotope analysis. $\delta^{13}C$ and $\delta^{15}N$ values measured from bone collagen, along with $\delta^{13}C$ values derived from enamel carbonate, will provide information on diet while population mobility patterns will be identified using oxygen and strontium isotope ratios ($\delta^{18}O$ and $^{87}Sr/^{86}Sr$) of tooth enamel. In order to do this research a sample set of human remains from New Halos was chosen, along with comparative faunal remains. The faunal remains will be used to provide a baseline of what the $\delta^{13}C$ and $\delta^{15}N$ food values would have been in the region and compare them to human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. They will also be used as a baseline for regional $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ signatures from enamel carbonate for mobility studies.

This chapter will discuss the study site of New Halos and the samples collected for this study along with the rationale for why specific skeletal elements were chosen. It will also identify the faunal samples collected. This will be followed by an explanation of the laboratory preparation methods and diagenetic indicators used for bone collagen and enamel isotopic analysis. Lastly, this chapter will discuss methods used to interpret the data from New Halos.

5.1 Site and Sample Selection

As described in Chapter 3, the site of New Halos is located in Thessaly, Greece between the Othris Mountains and the Pagasitikos Gulf where the Almiros and Sourpi plains meet. As also described in Chapter 3.3, three excavated cemeteries in the close vicinity of New Halos – Kaloerika, Cemetery A, Cemetery B – have been dated using associated grave goods and correspond to the occupation period of New Halos. In some cases, specific graves could be assigned a more specific date within this period. Not all of the individual graves were assigned a specific date; for some graves there were not enough diagnostic grave goods to establish a specific date. All graves used in this study were, however, from the Hellenistic period (Malakasioti n.d.) based on the interment style and more broadly datable artifacts; their close grouping with the more precisely dated graves strongly suggests that they are contemporary.

The preservation of the New Halos skeletal material was good overall; however in certain instances the remains showed poor preservation and were highly fragmentary. Much of the skeletal material was stored in a commingled state by tomb/grave. The skeletal material was sorted, inventoried, and when possible separated by individual during the initial assessment of the collection. The inventoried skeletons were assessed for age and sex using methods described by Buikstra and Ubelaker (1994). When present, auricular surfaces and pubic symphyses of the os coxae were used for age estimation, along with cranial suture closure and dental development when appropriate. Sex was determined using non-metric features of the ox coxae and the skull. In many cases the necessary skeletal elements were not present for age or sex estimation and remains could only be identified generically as adult or juvenile. Table 5.1 provides grave date, age, sex, and skeletal element data for each individual that met the sample quality standards (to be discussed below in section 5.6).

Table 5.1: Basic data for accepted human bone and tooth samples from New Halos. Grave dates refer to BC. The specific cemetery was not able to be determined for a sample only indicated by a tomb number. Samples without a specific grave date could not be dated beyond the general Hellenistic use period of the cemeteries.

NH Bone ID	NH Tooth ID	Age	Sex	Cemetery/ Tomb	Grave date	Bone	Tooth
	NH2	A					L M_1
NH3	NH4	A		Sector B, Tomb 8		maxilla	L PM^1
NH6		A	F	Sector B, Tomb 3		R tibia	
NH7		A		Sector B, Tomb 3		parietal bone	
	NH10	A		Tomb 3			R M_2
	NH12	A		Tomb 6			R PM^1
	NH15	A		Tomb 29			L PM_1
NH16	NH17	A		Sector A, Tomb 29	End 4th Early 3rd	R acromium	R PM_1
NH18		A				R rib	
	NH20	A					L PM^1
NH21	NH22	A	M?	Sector A, Tomb 12	~3rd	cranial bone	R C
	NH23	A					PM^1
NH24		A		Sector A, Tomb 12	~3rd	manual phalanx	
NH25		A		Sector A, Tomb 11	~3rd	long bone	

NH26		A		Sector A, Tomb 12	~3rd	L MT5	
NH27		A		Sector A, Tomb 12	~3rd	L MT5	
NH28	NH29	A		Tomb 19		rib	L PM_2
NH30	NH31	15-29	M	Sector A, Tomb 22	~3rd	rib	L PM^2
NH32	NH33	40-44	M	Sector B, Tomb 20	First half 3rd	L rib	L PM^2
	NH35	40-49	F	Tomb 20			L I^2
NH36	NH37	A		Sector A, Tomb 17	End 4th Early 3rd	manual phalanx	R PM^1
	NH38	A		Tomb 18			L PM_2
NH39		A		Sector B, Tomb 18		R talus	
NH41	NH42	35-49	M	Sector A, Tomb 33	First half 3rd	rib	R M^1
	NH44	A		Tomb 8			R PM^2
NH45	NH46	A		Sector B, Tomb 6	Second half 3rd	maxilla	R PM^1
NH49		A		Tomb 7		temporal bone	
	NH50	A		Tomb 7			L PM^1
	NH51	A		Tomb 7			R PM^1
	NH54	A	F	Tomb 10			R PM_2
	NH56	A		Tomb 8			R PM_1
NH57		23-57	M	Tomb 9		R rib	
NH58		A	M	Sector B, Tomb 15	Late 4th	scapula	
NH59		A	M	Sector B, Tomb 15	Late 4th	scapula	
NH60		A		Sector B, Tomb 15	Late 4th	metatarsal	
NH61		A		Sector B, Tomb 15	Late 4th	rib	
NH62	NH63	A	F	Sector B, Tomb 13	First half 3rd	cranial bone	R PM_1
NH64	NH65	40-49	M?	Sector B, Tomb 14	Early 3rd	rib	R PM_1
NH67	NH66	A		Sector B, Tomb 13	First half 3rd	metatarsal	L PM_2
NH68		J		Sector B, Tomb 13	First half 3rd	metatarsal	
NH69	NH70	A	M	Sector B, Tomb 12		R rib	L PM_1
	NH71	A		Tomb 12			R PM_1
NH72	NH73	40-49		Tomb 9		manual phalanx	R M_1
NH74		J		Sector B, Tomb 6		R femur	
NH75		A		Sector B, Tomb 6	Second half 3rd	L distal femur	
NH76		A		Sector B, Tomb 6	Second half 3rd	L distal femur	
	NH77	A		Tomb 6			L PM_1

NH78		J		Tomb 6		cranial bone	
NH79		J		Sector A, Tomb 23	Early 3rd	cranial bone	
NH80	NH81	A	M?	Kaloerika, Tomb 1	End 4th Early 3rd	rib	PM^2
	NH82	J		Tomb 27			L M^2
NH83	NH84	A	M	Tomb 2		cranial bone	R M_2
	NH87	A					L PM^2
NH88	NH89	A		Tomb 26		cranial bone	R M_1
NH90	NH91	A	F	Tomb 25	End 4th Early 3rd	rib	R PM_1
NH92	NH93	A	M	Sector A, Tomb 30		R MT1	L M^3
	NH95	A		Tomb 31			L PM_2
NH96		35-44	F	Sector A, Tomb 31	End 4th Early 3rd	R radius	
NH97		35-44	F	Sector A, Tomb 31	End 4th Early 3rd	R radius	
NH98	NH99	A	F?	Kaloerika, Tomb 4	End 4th Early 3rd	R rib	R PM_1
NH100		40-44	F?	Kaloerika, Tomb 4	End 4th Early 3rd	L rib	
NH101	NH102	A		Tomb 5		frontal bone	R M_1
NH103		40-44	F	Sector A, Tomb 6	End 4th Early 3rd	L rib	
	NH104	A		Tomb 6			R I_2
NH105	NH106	35-39	F	Tomb 19	End 4th Early 3rd	R clavicle	R PM_2
NH108		A		Sector B, Tomb 15	Late 4th	cranial bone	
NH110	NH111	A		Tomb 16		cranial bone	R PM^1
NH112		45-49	M	Sector B, Tomb 17	End 4th Early 3rd	rib	
NH113		45-49	M	Sector A, Tomb 15	Early 3rd	L radius	
NH114		30-39	F	Sector A, Tomb 15	Early 3rd	R radius	
NH115		A		Tomb 6		cranial bone	
NH116	NH117	A	F	Sector A, Tomb 4	First half 3rd	cranial bone	R PM_2
NH118		A		Kaloerika, Tomb 4	End 4th Early 3rd	L distal radius	
NH119		A		Tomb 2		L distal radius	
NH120	NH121	45-49	M	Sector A, Tomb 3	Early 3rd	rib	L M_2
	NH123	35-39		Tomb 3			R I^1
NH124		45-49		Sector A, Tomb 3	Early 3rd	rib	
NH126		30-39	M	Sector B, Tomb 3		os coxae	
NH127		A		Tomb 9		occipital bone	
NH128		A				occipital bone	

NH129		A		Tomb 5		rib	
	NH131	A	M	Tomb 5			L PM^1
NH134	NH135	A		Sector B, Tomb 4		long bone	L PM^2
	NH137	A		Tomb 5			R PM_1
	NH139	A		Tomb 3			R M^3
	NH141	A		Tomb 3			L PM_2

(Grave dating information from Malakasioti, unpublished PhD (Malakasioti, n.d.).

Ideally a bone and tooth from each individual was selected for sampling. However, due to the state of preservation and commingled nature of the remains it was not always possible to obtain a tooth and bone sample from each individual. In some cases individuals are only represented by a bone or a tooth. Each bone sample was photographed and when possible was identified to specific bone elements and side of body. The tooth samples were also photographed and identified by tooth type and position. A total of 142 human skeletal samples were collected for isotopic analysis. Of those 142 samples, 62 bone and 50 teeth samples passed the stable isotope quality tests for and were included in this study; 26 individuals are represented by both a tooth and a bone sample.

Ribs were the preferred bone element to sample because they have thin cortical bone and relatively rapid turnover rates. The commingled state and level of preservation of the skeletal material meant that it was not always possible to identify with certainty to whom a rib belonged, if ribs were present at all. When multiple individuals were stored together the skeletal material was laid out on tables and sorted. Duplicate skeletal elements were identified and a minimum number of individuals was determined for each group of comingled remains. Duplicate elements were sampled instead of the preferred ribs to ensure that two distinct individuals were selected for sampling. When ribs were not used, sampling preference was for other elements with thin cortical bone and abundant trabecular bone. Examples of other elements chosen for sampling are manual phalanges and cranial vault material. Occasionally long bone shaft fragments were chosen when the preservation of an individual was very poor and only the larger long bones were present.

Permanent mandibular and maxillary 1st premolars were the first choice for tooth samples because the enamel cusp begins forming around 2 years of age (± 0.5 years) and the crown is completely formed around 5 years of age (± 1 year) (Hillson, 1996). Mandibular and maxillary 2nd premolars, the second choice for sampling, begin crown formation around 3 years of age (± 6 months) and the crown is complete by 6 years (± 9 months) (Hillson, 1996). In certain instances incisors, second molars, and third molars were chosen when premolars were not available. First molars were selected only out of necessity. They begin forming at birth and the crown is complete between 2.5 and 3 years of age (Hillson, 1996).

Age of formation is important because teeth formed prior to weaning may possess different isotopic values because breast milk is generally the primary food source for infants. Breast milk consumption could have significant effects on enamel $\delta^{13}C$ and $\delta^{18}O$ values because as teeth are formed they reflect the trophic level increase caused by consuming a mother's milk. With the proper study design these effects can be used to reconstruct weaning practices, but in a study such as this one considering typical adult diet and individual origins, the effects act as an interference or distortion. Weaning studies specific to the Hellenistic period in Greece have not been done. Research has shown that the weaning age in Byzantine Greece began before four years of age (Bourbou et al., 2013), so for now the age of weaning in Byzantine Greece is being used to estimate when this stage in an infant's life may have occurred during the Hellenistic period and which teeth should be avoided if possible during sampling.

5.1.1 Faunal Skeletal Remains

Twenty faunal samples were collected for analysis from the excavated Hellenistic faunal material from New Halos. The faunal samples were inventoried and identified during prior research on the New Halos material (Prummel, 2003). The faunal samples are described in Table 5.2. This table identifies each animal to the genus level and indicates which skeletal element was selected.

Table 5.2: Faunal samples collected for isotopic analysis.

Sample ID	**Genus, Species**	**Skeletal Element**
NHB 1	*Ovis/Capra*	Tooth

NHB 2*	*Bos*	Astralagus
NHB 3	*Capra*	Metapodial
NHB 4*	*Caretta* (Sea Turtle)	Humerus
NHB 5	*Bos*	Metapodial
NHB 6	*Bos*	Bone Fragment
NHB 7	*Ovis/ Capra*	Vertebrae
NHB 8	*Aves*, undetermined	Humerus
NHB 9	*Ovis/ Capra*	Os Coxa
NHB 10	*Bos*	Phalanx
NHB 11	*Ovis/ Capra*	Os coxa
NHB 12*	*Bos*	Metatarsal
NHB 13	*Cervus elaphus*	Femur
NHB 15	*Ovis/ Capra*	Mandibular Molar
NHB 16	*Ovis/ Capra*	First Molar
NHB 17	*Ovis/ Capra*	Molar
NHB 18*	*Ovis/ Capra*	Tibia
NHB 19*	*Capra hircus*	Metatarsal
NHB 20	*Ovis/ Capra*	Third Molar
NHB 21	*Ovis/ Capra*	Molar

(* indicates samples rejected due to poor preservation. An error in numbering of the faunal samples resulted in NHB14 being skipped)

When selecting faunal samples the first criterion was choosing samples that had been clearly identified during faunal analysis (Prummel, 2003). Sampling focused on domesticated animals like sheep and goats because they provided much of the meat in New Halos diets according to prior faunal analysis and should reflect a local terrestrial signature around human settlements. Sheep/goat represent 11 of the 20 samples collected; the others are from cow, red deer, bird and tortoise.

5.2 Bone Collagen Preparation

Collagen preparation involves the removal of the mineral phase of bone to isolate collagen. There are two methods commonly used for collagen preparation. The first is a modified Longin method that uses powdered bone. In the modified Longin method

powdered bone is placed in an HCl solution until it is demineralized and then it is soaked in NaOH. The NaOH soak is used to remove any humic contents in the samples. However, certain variations exist and some researchers omit the NaOH soak when dealing with delicate samples (Sealy et al., 2014). The collagen, which at this point is in a gelatinous state, is then filtered for impurities and dried (Longin, 1971). Sealy and colleagues (2014) outline a variation of the modified Longin method that involves the gelatinization of bone powder and then selects for high molecular weight fragments of collagen from the samples. This method is useful for poorly preserved and very old samples (Sealy et al., 2014).

The second method, sometimes called the University of Cape Town method (UCT) (Sealy et al., 2014), involves soaking small chunks of bone in a dilute HCl solution until the sample becomes demineralized. Once demineralized, a gelatinous collagen model should remain if the sample is well preserved. Poorly preserved samples will produce fragments of collagen in the HCl solution. The samples are removed from the HCl and rinsed with distilled water to reach a neutral pH level and then soaked in NaOH to remove humic contents. A period of 20 hours is suggested for the NaOH soak to ensure minimal sample loss; this 20 hour period was demonstrated to be effective and consistent between laboratories (Katzenberg, 1989; Katzenberg et al., 2012; Pfeiffer et al., 2014; Sealy et al., 1986) Some researchers skip the NaOH step in an attempt to reduce the amount of sample loss (Pfeiffer & Varney, 2002).

The UCT method was selected for this study because various comparative methodological studies have shown that it provides reliable results (Jørkov et al., 2007; Sealy et al., 2014). The first step is to wash all samples with ultrapure water and place them in a sonicator to remove surface contaminants. Each sample was sonicated three times for five minutes each. Samples would be sonicated a fourth time if the water was still cloudy after the third wash indicating contaminants were still present. When the water was clear the samples were removed and left to air dry for 48 hours. Once clean and dry each sample was weighed and placed into its own glass container ready for further processing. Sample demineralization was accomplished by soaking the samples in a 1% HCl solution that was changed every two days. The samples were checked at each HCl solution change for softness and transparency. A fully demineralized sample is

soft throughout, is transparent or translucent, and will cease producing bubbles in the acid solution. Once a sample was fully demineralized, it was rinsed in purified water until its pH level reached neutrality and then it was soaked overnight in purified water.

Next, the samples were placed in a 20 hour 0.125M NaOH soak. Following this the samples were once again rinsed and soaked in purified water until they reached neutrality. The water was removed and the samples were then frozen. The samples were freeze-dried and the resulting collagen for each sample was then weighed for comparison to the initial bone weight to calculate collagen yield. 1 mg of dry collagen for each sample was packed in tin capsules using a microbalance. The samples were then run using a EuroEA Elemental Analyzer coupled with an Isoprime Mass Spectrometer in the Biogeochemical Analytical Service Laboratory directed by Dr. Mingsheng Ma in the Department of Biology at the University of Alberta.

5.3 Enamel Apatite Preparation for Strontium Analysis

Prior to analysis each tooth was photographed from all sides for documentation purposes. These photographs will be submitted with the final analytical report to the 13th Ephorate of Prehistoric and Archaeological Antiquities at Volos, Greece.

To begin processing the teeth, each tooth crown was lightly burred with an abrasive head attached to a hand held motorized tool to remove any surface enamel that may have been diagenetically altered in the burial environment. The tooth roots were also removed and saved for possible future work. Next, solid enamel samples were separated from the tooth crown using a scalpel or the hand motor tool and placed into individual vials. Each enamel sample, between 10-20 mg of enamel, was weighed and the value recorded for future calculations. At this stage, the enamel samples were submitted to the Canadian Centre for Isotopic Microanalysis for mass spectrometric analysis, under the direction of Dr. Robert Creaser, in the Department of Earth and Atmospheric Science at the University of Alberta. Methods used by this lab are outlined below, following those presented in Buzon et al. (2007).

The enamel samples were sonicated for 15 minutes in distilled water to remove contaminants. Next, a 5% acetic acid solution was added to the samples and they were again sonicated for 15 minutes. The samples were left overnight in the 5% acetic acid

solution and then rinsed with double distilled water and transferred into vials. The next step was to add a Rb-Sr (Rubidium-Strontium) spike to the samples and then the solution was placed in a microwave oven in 4ml 16N HNO_3 and 1ml ~10N HCl. The samples were dried overnight on a hotplate at 80°C. Once dried the samples were dissolved in 3ml of 0.75N HCl and placed onto 10 cm ion exchange columns containing 1.42ml of 200-400 mesh AG50W-X8 resin. Prior to analysis, strontium bearing aliquots were diluted in a 2% HNO_3 solution and then aspirated into a DSN-100 machine from Nu Instruments Inc. Between samples a 30 second measurement of the gas was conducted as a blank and to reset the machine; this is a critical part of the analysis to ensure good results (Buzon et al., 2007).

5.3.1 Interpreting Strontium Values

$^{87}Sr/^{86}Sr$ analysis in Greece is still a relatively new process. Estimating a local $^{87}Sr/^{86}Sr$ range using archaeological faunal material is the preferred method. However, only one faunal sample returned $^{87}Sr/^{86}Sr$ results in time to be included in this project, so this study was not able to use faunal values to establish a local $^{87}Sr/^{86}Sr$ baseline. Local values have not yet been specifically documented for Thessaly, but approximate strontium values are known for large regions of Greece (Nafplioti, 2011). Thessaly is a geologically diverse area with wide plains and high mountains. Mount Olympos is in the northeastern part of Thessaly; the Othris mountain chain is to the south, and there are large plains located between these mountain chains (Higgins & Higgins, 1996). This geological diversity, as will be discussed below, lends itself well to strontium analysis.

The underlying bedrock of a region is another method that can be used to determine whether or not an individual is local or non-local to an area. Rocks that are more than 100 million years old that have a high original Rubidium/Strontium content have $^{87}Sr/^{86}Sr$ values above 0.710, and old granites have $^{87}Sr/^{86}Sr$ values between 0.7100 – 0.7400 (Bentley, 2006). The strontium content in rocks enters the biologically available strontium pool and influences the $^{87}Sr/^{86}Sr$ values of local flora and fauna which in turn influences human strontium values. Nafplioti (2011) outlined geological regions in Thessaly and used biologically available strontium isotopic values from the regions to create a general strontium map. The biologically available isotopic values for the different regions were amassed from archaeological human and faunal samples as well

as modern snail shells and faunal material (Nafplioti, 2011). Figure 5.1 illustrates the geographic regions outlined by Nafplioti (Nafplioti, 2011).

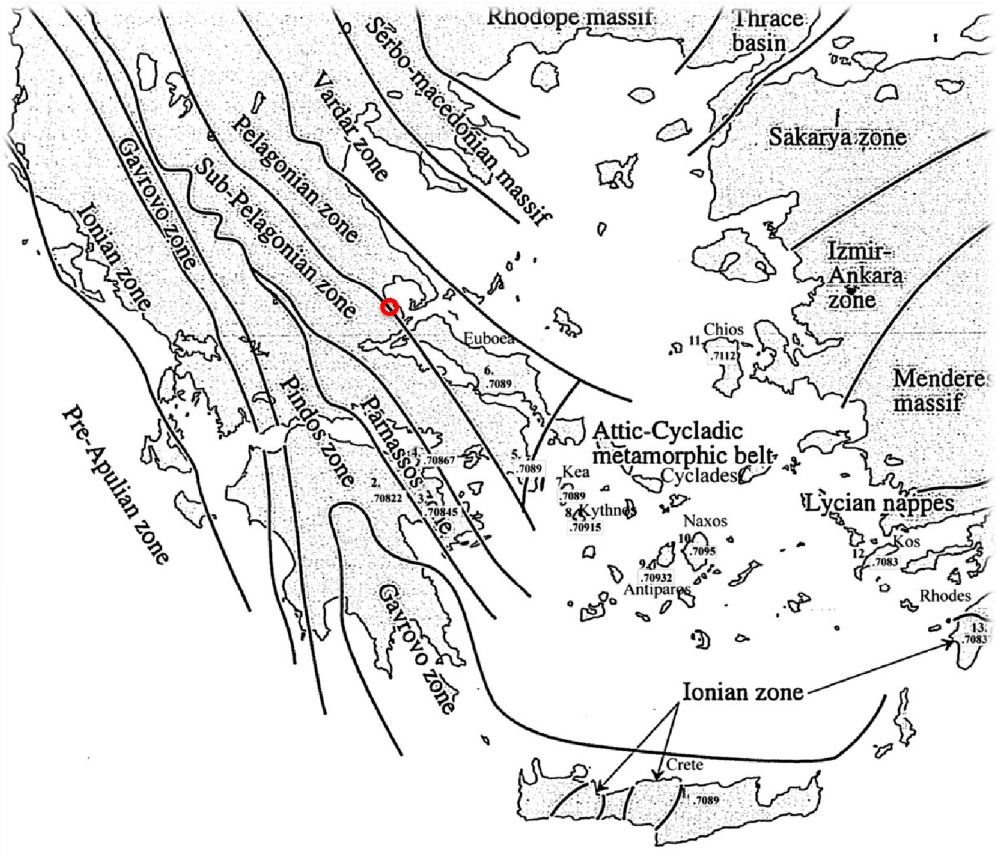

Figure 5.1: Geological regions for Greece with mean $^{87}Sr/^{86}Sr$ values for each area. The red circle indicates the site of New Halos. (Modified from a map in Nafplioti, 2011)

New Halos is located in the Pelagonian Zone, which encompasses the island of Euboea and the areas to the north of and surrounding the Pagasitikos Gulf. The biologically available strontium isotopic values from this region suggest that it has a $^{87}Sr/^{86}Sr$ range of 0.708689 to 0.709271 (Nafplioti, 2011). The Pelagonian zone is composed mostly of limestone and granite, and has an exposed older metamorphic core that is largely made of marbles and schists (Anders et al., 2002; Higgins & Higgins, 1996). According to Burke et al. (1982) limestone values are rarely above 0.7095. $^{87}Sr/^{86}Sr$ values from limestone and marble samples from Euboea analyzed in one study did not exceed 0.7092 (Tremba et al., 1975).

The Sub-Pelagonian zone lies parallel and to the west of the Pelagonian zone and extends south through Central Greece and Attica. It is comprised of deep water limestone and underlying igneous rocks (Higgins & Higgins, 1996). Data available to date suggest that the Sub-Pelagonian zone has a $^{87}Sr/^{86}Sr$ range of 0.70808 – 0.70869 (Nafplioti, 2011).

The Vadar Zone is a mountainous region found parallel and to the north east of the Pelagonian zone; Mount Pelion is located within this zone just north of the Pagasitikos Gulf. Nafplioti (2011) estimated a $^{87}Sr/^{86}Sr$ range for the Vadar zone of 0.70926 – 0.71187. It was suggested that the high biologically available $^{87}Sr/^{86}Sr$ values from the Vadar zone are due to the underlying bedrock, which consists of Palaeolithic flysch and volcanic rocks (Nafplioti, 2011). Volcanic rocks sampled from northern Greece in another study had a $^{87}Sr/^{86}Sr$ range of 0.7010 – 0.7098 (Eleftheriadis et al., 2003). Areas around Thessaloniki in the Vadar Zone have granite outcrops, and although they have not been sampled these rock formations could lead to biologically available $^{87}Sr/^{86}Sr$ values above 0.7100 (Bentley, 2006; Higgins & Higgins, 1996). Although Nafplioti describes other geographic zones the three mentioned above are most relevant to New Halos because they represent the closest, and thus most likely, regions from which the population of New Halos could have originated.

In addition to the recorded $^{87}Sr/^{86}Sr$ values from Nafplioti (2011), the work of Burke et al. (1982) can also be used to estimate $^{87}Sr/^{86}Sr$ values for some types of geological substrates. The study by Burke et al. estimated the curve of seawater $^{87}Sr/^{86}Sr$ versus geologic time using marine derived samples. The $^{87}Sr/^{86}Sr$ curve can be used to help date marine derived limestone. Figure 5.2 is a geological map depicting the area immediately around New Halos. It can help refine our understanding of the geological basis around New Halos.

Within the Almyros plain where New Halos is situated there are different types of bedrock that would affect local $^{87}Sr/^{86}Sr$ values. Using the strontium measurements from Burke et al. (1982), it is possible to estimate the $^{87}Sr/^{86}Sr$ values for various marine bedrock deposits based on their age. The light green area on the map where New Halos is situated consists of Quaternary alluvium and diluvium deposits; based on age this area has an estimated $^{87}Sr/^{86}Sr$ value of 0.7090 – 0.7091. These values fall within the range

established by Nafplioti (2011) for the Pelagonian zone. The light orange colour on the map represents marl and clay deposits from the Neogene period with an estimated $^{87}Sr/^{86}Sr$ range of 0.7080 – 0.7090. The estimated $^{87}Sr/^{86}$ Sr values for the marl and clay deposits are more similar to those estimated by Nafplioti (2011) for the Sub-Pelagonian range; however this area borders both zones, therefore it is understandable that it has intermediate values. The blue/purple region is from a Middle Triassic – Jurassic dolomite and limestone deposit with an estimated $^{87}Sr/^{86}Sr$ range of 0.7070 to 0.7078. As with the marl and clay deposits this outcrop also borders the Pelagonian and Sub-Pelagonian zones. There is a small outcrop of Upper Cretaceous limestone approximately 6 km south east of New Halos that is represented by a blue-green colour; based on its age it has an estimated $^{87}Sr/^{86}Sr$ range of 0.7073 to 0.7077. These values are below the estimated range for the Sub-Pelagonian zone, however it is a small section of rock and strontium signatures developed by Nafplioti are generalized values for geological regions. The rest of the geological deposits in the area are conglomerate or igneous rocks. Strontium values cannot be estimated for these areas using the measurements from Burke et al., (1982) because they are not marine based deposits.

Figure 5.2: Geological map of the area immediately around New Halos. The black line indicates the approximate border of the Pelagonian zone and Sub-Pelagonian zone outlined by Nafplioti (2011). New Halos is indicated on the map by a black circle. (Image modified from IGSR, 1957)

Although geological strontium values cannot precisely determine the biologically available strontium values within an area, they are a useful starting point for establishing a range of local values (Budd et al., 2004). Montgomery (2010) indicates that if there are two or more strontium sources in an area contributing to the biologically available strontium, the bedrock values can offer endpoints for a local range but they cannot be averaged to generate a local range. The values outlined above indicate that within the areas surrounding New Halos, $^{87}Sr/^{86}Sr$ values should be helpful when distinguishing people from different localities.

5.4 Enamel Carbonate Preparation for Oxygen Analysis

The sampling process for stable oxygen isotope analysis began the same way as strontium isotope analysis. The enamel was surface-cleaned and separated from the teeth using the same methods; however once the enamel was separated from the tooth crown further steps were necessary because the enamel carbonate samples had to be submitted in powdered form. A Spex low-temperature mill was used to grind the enamel into powder.

The enamel powder was sent to the Saskatchewan Isotope Laboratory under the direction of Drs. Holmden and Patterson in the Department of Geological Sciences at the University of Saskatchewan for simultaneous stable carbon and oxygen isotope analysis. This analysis took place using a Finnigan MAT 253 Gas Isotope Ratio Mass Spectrometer with a Kiel-IV carbonate preparation device. This system allowed the accurate analysis of extremely small enamel carbonate samples, and was not available in a University of Alberta laboratory.

In buried bone and teeth, biogenic carbonates can be replaced by diagenetic carbonates from the burial environment; diagenetic carbonates can also be incorporated into the tissue matrix. These processes can alter the biogenic isotopic signature of a tissue. Acetic acid pretreatment of archaeological bone and enamel samples destined for carbonate analysis is often done to remove diagenetic carbonates (Budd et al., 2000; Grupe et al., 1999; Sealy et al., 1991; Sponheimer & Lee-Thorp, 1999). Sillen (1986) demonstrated that a pretreatment using a weak solution of acetic acid was able to remove diagenetic components and retrieve a biogenic signature. Stronger acetic acid solutions (≥ 1.0 N) can cause recrystallization within the tissue and can therefore obscure the original isotopic signature (Hoppe et al., 2003). It is normal to lose sample material during the pre-treatment step (Garvie-Lok et al., 2004); in this study there was a concern that this process could result in the loss of too much of the finely powdered sample for a successful analysis.

Previously published studies have shown that reliable isotopic results can be obtained for archaeological enamel when the acid pre-treatment step is omitted during the enamel preparation stages (Laffoon et al., 2013; Pellegrini et al., 2011; Wright, 2013). One study pretreated enamel samples with sodium hypochlorite and acetic acid to

remove organic material. They then compared untreated samples with pretreated samples and found that there was minimal enrichment in the $\delta^{18}O$ values (Pellegrini et al., 2011). Based on these results they chose not to pretreat the rest of their samples. Furthermore, Laffoon et al. (2013) and Wright (2013) did not pretreat their samples because diagenetic alteration of enamel was not expected and enamel sample amounts were small. The researchers were concerned that excessive sample loss would occur and analysis would not be possible if an acid pretreatment step was conducted.

The amount of enamel available for many teeth from New Halos was very small because the available enamel from each tooth had to be separated into two samples, one for strontium isotope analysis and the second for $\delta^{18}O$ and $\delta^{13}C$ analysis. There was a concern that too much sample would be lost in the acetic acid pretreatment phase. Therefore, no acetic acid pretreatment was done on the New Halos samples, although the external surface of the enamel was removed to eliminate the material most likely to have been altered in the burial environment. Enamel is more resistant than bone to diagenetic processes. The $\delta^{18}O$ isotope data from enamel samples returned a range of values indicating different regions. If all samples had returned a 'local' signature then there could be cause for concern because it would suggest that diagenetic processes had affected the samples. The range of values indicates that the 'non-local' samples maintained their original signature. As will be discussed in Chapters 6 and 7 the New Halos enamel $\delta^{18}O$ and $\delta^{13}C$ values largely conform to expectations based on local climate and the collagen $\delta^{13}C$ values, indicating that this strategy was successful.

5.4.1 Interpretation of Oxygen Isotope Values

Interpreting the oxygen isotope data to identify local and non-local individuals involves multiple steps. The literature presents two potential methods for interpreting the human $\delta^{18}O$ data. The first involves comparing the New Halos signatures to values established from other local human studies in Greece. This method does not involve calculations to convert the human $\delta^{18}O$ data to estimated drinking water $\delta^{18}O$ values and has been argued by some to introduce less error (Daux et al., 2008). Unfortunately, oxygen isotope analysis of human skeletal populations has not been done extensively in Greece, specifically in Thessaly, therefore comparative data is not available.

The second method involves converting the human carbonate $\delta^{18}O$ values into estimated drinking water values (Chenery et al., 2012). Estimating drinking water values for individuals allows a comparison to local water sources, thus allowing individuals to be compared to a local signature. This involves two steps. The first converts $\delta^{18}O_{VPDB}$ to $\delta^{18}O_{VSMOW}$ values using the following equation:

$$\delta^{18}O_{VSMOW} = \delta^{18}O_{VPDB} \times 1.03086 + 30.86, \text{ (Chenery et al., 2012)}$$

This conversion is necessary because the data from New Halos were reported using the VPDB standard and the formula in Chenery et al. (2012) uses the VSMOW standard. Additionally the local drinking water values established by Dotiska et al. (2010) were reported as VSMOW values. Therefore, the New Halos values had to be converted in order to make the comparison to the local drinking water values possible. Once $\delta^{18}O_{VSMOW}$ values were calculated they could be converted into drinking water values using an equation by Chenery and colleagues (2012):

$$\delta^{18}O_{DW} = 1.590 \times \delta^{18}O_{VSMOW} - 48.634 \pm 1‰$$

As discussed in the previous chapter, precipitation and groundwater $\delta^{18}O$ values in the New Halos region have not been directly measured (Dotsika et al., 2010). However, there are maps that provide estimated mean yearly precipitation $\delta^{18}O$ values for Greece (Dotsika et al., 2010). Figure 5.3 is a map outlining the precipitation ranges in Greece. Based on these values the range for $\delta^{18}O$ in the New Halos region should be between -6.5‰ and -7.5‰; further north and west the $\delta^{18}O$ values should be closer to -7.5‰ and in the south west in the Othrys mountains the $\delta^{18}O$ values should be around -10.5‰ (Dotsika et al., 2010). The estimated drinking water values for individuals from New Halos will be compared to these estimated local values established for the New Halos region.

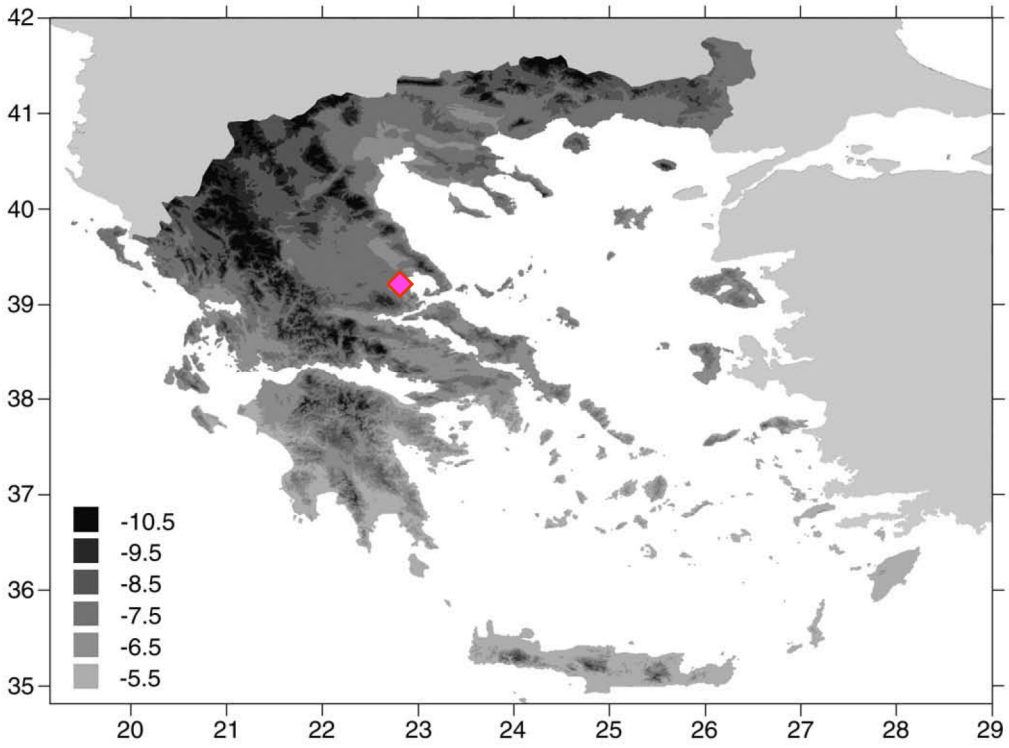

Figure 5.3: Drinking water values for Greece reported by per mil (‰) values . New Halos is marked with the diamond (Dotiska et al., 2010).

In addition to estimating the local drinking water range it is important to understand what the $\delta^{18}O$ values for a stationary population would look like. Intrapopulation variability has been reported to be as low as 1‰ (Longinelli, 1984) and as high as 5‰ (Bocherens et al., 1996). However, the samples in Bocherens et al. (1996) were a mixture of modern and fossil remains. This combination provided comparison within populations for species over time as well as comparison within the modern samples. The wide 5‰ range could be explained by the broad temporal range sampled in this study (Sponheimer & Lee-Thorp, 1999). White et al. (2004) suggest that a stationary population would have a normal range of approximately 2‰ for $\delta^{18}O$ values. The estimated New Halos local drinking water range of -6.5‰ to -7.5‰ was expanded using the 2‰ figure proposed by White and colleagues (2004) to provide an estimate of the expected intrapopulation variation for a stationary group living at New Halos. This was done by assuming 'normal' 2‰ ranges centred at -6.5‰ and at -7.5‰, the low and high ends of the estimated New Halos local drinking water range. The result is a broad range of -5.5‰ to -8.5‰ that will be used for New Halos in this study.

5.5 Interpreting Collagen and Carbonate Results

It is important to give a brief theoretical framework about how carbon sources from the diet influence the carbon in skeletal tissues. There has been extensive research to determine the relationship between $\delta^{13}C$ values of bone collagen and carbonate $\delta^{13}C$ values. Past studies have debated the process in which carbon becomes incorporated into the collagen and carbonate fractions of bone. DeNiro and Epstein (1978) demonstrated that bone collagen and apatite $\delta^{13}C$ values positively correlated with dietary $\delta^{13}C$ values. A study that built on DeNiro and Epstein's (1978) work suggested that $\delta^{13}C$ in bone collagen should mostly reflect dietary protein $\delta^{13}C$ values while $\delta^{13}C$ apatite values should reflect dietary lipid and carbohydrate sources (Krueger & Sullivan, 1984). Another early model proposed that both collagen and carbonate drew their carbon sources from one unified dietary pool (Schwarcz et al., 1985). Controlled feeding studies were then developed to test these relationships. Today, the process is understood to be similar to that outlined in the first model.

The isotopic difference between bulk diet $\delta^{13}C$ and bone carbonate $\delta^{13}C$ ($\Delta^{13}C_{(carbonate\text{ -–}bulk\ diet)}$) has been debated. Initially researchers were looking for a single value for $\Delta^{13}C_{(carbonate\text{ -–}bulk\ diet)}$ that would represent various species. However, this has not been possible. Instead of an absolute $\Delta^{13}C_{(carbonate\text{ -–}bulk\ diet)}$ value for all species, different relationships between $\delta^{13}C_{(bulk\ diet)}$ and $\delta^{13}C_{(apatite)}$ arose from controlled feeding studies involving pigs, rats and mice and from field studies of larger animals (Kellner & Schoeninger, 2007). Based on early controlled feeding experiments with small animals (Ambrose & Norr, 1993; DeNiro & Epstein, 1978; Tieszen & Fagre, 1993) a $\Delta^{13}C_{(apatite\text{ -–}bulk\ diet)}$ value of approximately 10‰ was suggested. A number of archaeological studies on humans have used this value. However, field studies of larger animals, as well as some work on human archaeological samples (e.g. Katzenberg & Weber, 1999) support a larger value around 12‰ to 14‰ for $\Delta^{13}C_{(apatite\text{ -–}bulk\ diet)}$. If it is assumed that large free-ranging animals are a better model for humans, the wider gap should be used. However, one issue that has been raised with some field studies is that many of the animals were ruminants. These animals have digestive systems specially adapted to digest large volumes of plant matter. Within their digestive systems, ruminants produce large quantities of methane gas, some of which enters the bloodstream, affecting the animals'

plasma $\delta^{13}C$ value and thus influences the $\delta^{13}C$ value of bone carbonate. These traits make ruminants a poor parallel for humans which are monogastric and do not rely on fermentation for digestion. A later controlled feeding study by Howland and colleagues (2003) used pigs to investigate the δ relationship between diet and a consumer's tissues. Pigs are a better proxy for humans than ruminants because they share a similar digestive system. The results of this study showed that the $\delta^{13}C$ values of bone apatite reflected the $\delta^{13}C$ values of bulk diet; the value found for $\Delta^{13}C_{(apatite - bulk\ diet)}$ was 10.2‰ ± 1.3‰ (Howland et al., 2003). Based in part on those data, the model that will be used in this study for interpreting carbonate and collagen $\delta^{13}C$ values (Kellner and Schoeninger, 2007) also assumes a 10‰ gap for $\Delta^{13}C_{(apatite - bulk\ diet)}$ spacing. Therefore, a value of 10‰ for $\Delta^{13}C_{(carbonate - bulk\ diet)}$ will be used for this study. Based on grouped data from a number of feeding studies, Kellner and Schoeninger (2007) argue that a 10‰ gap between $\delta^{13}C_{(bulk\ diet)}$ and $\delta^{13}C_{(apatite)}$ was consistent, and unaffected by protein levels in the diet or by body size.

For bone collagen, feeding studies suggest a complex system in which bone collagen carbon is derived mostly from dietary protein, with the addition of some carbon from other dietary fractions (Froehle et al., 2010; Howland et al., 2003; Jim et al., 2004). Tieszen and Fagre (1993) found that collagen $\delta^{13}C$ values were strongly correlated with dietary protein $\delta^{13}C$, however, other dietary fractions were found to influence the values of collagen $\delta^{13}C$ to a lesser degree. Overall, $\Delta^{13}C_{(collagen - dietary\ protein)}$ spacing values ranging from 1.5‰ to 5.5‰ were reported (Tieszen and Fagre, 1993). This spacing pattern agrees with the assumption that most collagen carbon is derived from dietary protein with the addition of a significant amount of non-protein carbon. Ambrose and Norr (1993) came to similar conclusions, publishing $\Delta^{13}C_{(collagen - dietary\ protein)}$ values ranging from -0.5‰ to +12.5‰. The wide range reported by Ambrose and Norr (1993) reflects participation of non-collagen carbon in collagen for animals placed on diets with distinctive $\delta^{13}C$ values and nutrient patterning intended to explore the possible extreme values of $\Delta^{13}C_{(collagen - dietary\ protein)}$; these included diets in which all protein was C_4 and all energy (lipids and carbohydrates) was C_3 (or vice versa), as well as diets extremely high or low in protein.

The smallest $\Delta^{13}C_{(collagen\ –dietary\ protein)}$ values found by Ambrose and Norr (1993) were associated with diets that had sufficient levels of C_4 protein combined with C_3 energy. This is argued to reflect a situation in which some non-protein carbon (C_3, so very low $\delta^{13}C$ relative to dietary protein) was incorporated into the collagen, resulting in a lower $\delta^{13}C$ value and therefore a smaller $\Delta^{13}C_{(collagen\ –dietary\ protein)}$ value. On the other hand, a diet based on C_3 protein and C_4 energy would have a higher bone collagen $\delta^{13}C$ value because of some participation from non-protein sources, resulting in a larger $\Delta^{13}C_{(collagen\ –dietary\ protein)}$ value. In the data they reviewed, Kellner and Schoeninger (2007) found that the two animals with the highest and lowest $\Delta^{13}C_{\ (collagen\ –dietary\ protein)}$ values were fed low protein (5% protein) diets. These two animals only had a 1‰ difference in $\delta^{13}C_{(collagen)}$ values, although their $\delta^{13}C_{(diet\ protein)}$ values were drastically different. This implies that animals fed low protein diets will rely more heavily on carbon from dietary energy sources for bone collagen synthesis. As mentioned above, these studies were designed to make $\Delta^{13}C_{\ (collagen\ –dietary\ protein)}$ vary as much as possible. When pure C_3 or C_4 diets with good levels of protein are evaluated the $\Delta^{13}C_{\ (collagen\ –dietary\ protein)}$ values are much more consistent (Tieszen & Fagre, 1993).

5.5.1 A Carbon Isotope Model for Reconstructing Diet

The above discussion draws on a synthesis and review done by Kellner and Schoeninger (2007) of data from a number of controlled feeding studies (e.g. Ambrose & Norr, 1993; Howland et al., 2003; Tieszen & Fagre, 1993). Based on this work, Kellner and Schoeninger (2007) developed a model that facilitates the interpretation of collagen and carbonate $\delta^{13}C$ values. Their model was developed as a direct result of the discovery that non-protein dietary carbon variably affects collagen $\delta^{13}C$ values. Kellner and Schoeninger (2007) wanted to find a way to use collagen and carbonate $\delta^{13}C$ together to comment on aspects of human diets and to get around the problem of variable energy carbon contributions to collagen.

Kellner and Schoeninger's (2007) model is based on three regression lines. The regression lines represent C_3 protein, C_4 protein, and marine protein diets. These three regression lines were developed after bone collagen and carbonate $\delta^{13}C$ data from the controlled feeding experiments were plotted. Although $\Delta^{13}C_{\ (collagen\ –dietary\ protein)}$ varied widely, when the three dietary protein sources were considered this approach showed a

clear grouping of the collagen and carbonate data around the regression lines. Each regression line represents changing collagen and carbonate $\delta^{13}C$ values for a particular protein $\delta^{13}C$ value as the $\delta^{13}C$ value of the non-protein of the diet changed. Figure 5.4 is from Kellner and Schoeninger (2007) and presents the three protein source regression lines and the controlled feeding study animal data for bone carbonate $\delta^{13}C$ ($\delta^{13}C_{apatite}$) plotted against $\delta^{13}C_{collagen}$.

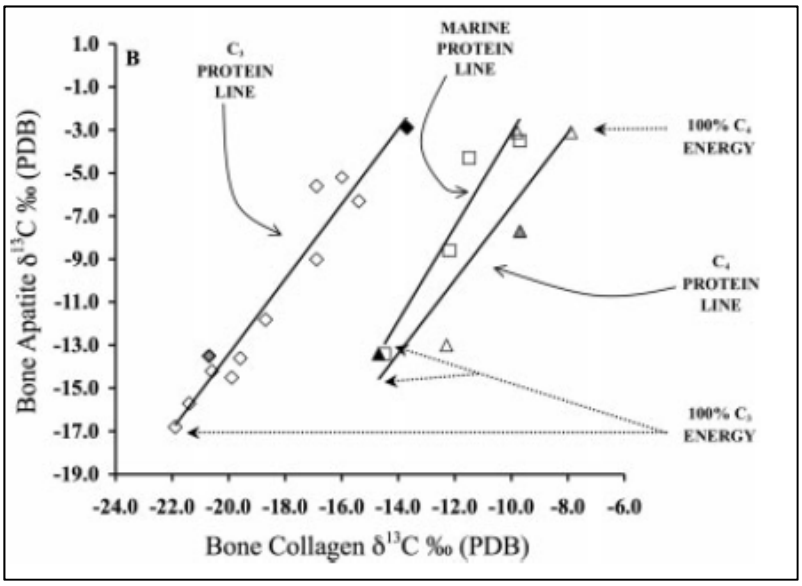

Figure 5.4: $\delta^{13}C_{apatite}$ values plotted against $\delta^{13}C_{collagen}$ values from controlled feeding studies on animals and the three regression lines for C_3, C_4, and marine protein sources (From Kellner and Schoeninger, 2007).

The data indicate that $\delta^{13}C_{(carbonate)}$ reflects whole diet $\delta^{13}C$, which is strongly determined by energy $\delta^{13}C$, while carbon atoms from the dietary protein used to synthesize collagen have a strong impact on $\delta^{13}C_{(collagen)}$ (Kellner & Schoeninger, 2007). This is demonstrated by the fact that the three regression lines all have a slope of two; for every 1‰ increase in $\delta^{13}C_{(collagen)}$ a $\delta^{13}C_{(carbonate)}$ increase of almost 2‰ is observed (Kellner & Schoeninger, 2007). Kellner and Schoeninger found that the amount of protein in the diet did not affect an animal's $\delta^{13}C_{(collagen)}$ or $\delta^{13}C_{(carbonate)}$ values in a consistent manner (Kellner and Schoeninger, 2007). Animals that were fed excess amounts of protein had $\delta^{13}C_{(collagen)}$ values in agreement with their model. However, animals fed low-protein diets had $\delta^{13}C_{(collagen)}$ values showing that a larger amount of the carbon in their bone collagen came from dietary energy (lipids and carbohydrates).

As Kellner and Schoeninger state, this model can be applied to identify major dietary components used by an archaeological population. An individual consuming a diet based on C_3 protein and C_3 energy sources (carbohydrates and lipids) will fall along the C_3 regression line near the lower endpoint. An individual consuming a diet based on C_3 protein and C_4 energy sources will fall along the C_3 regression line near the higher endpoint. The position of an individual on a protein regression line is linked to the $\delta^{13}C$ value of their dietary energy source. This model helps to visualize data and understand what protein and non-protein sources are influencing a person's and a population's diet. To apply this model to archaeological populations it is necessary to correct the human bone carbonate and collagen values by 1.5‰ to account for the $\delta^{13}C$ offset between modern and pre-industrial atmospheric CO_2 (Kellner & Schoeninger, 2007). Once this correction factor has been applied to an archaeological sample it is possible to use this model to evaluate past diets if both collagen and carbonate values are available.

5.6 Diagenetic Indicators used to Assess Sample Quality

The sample data were analyzed to determine sample quality using various techniques. Carbon and nitrogen content, C/N ratio and collagen yields were calculated to assess the integrity of the collagen samples. If samples failed to meet the quality standards they were considered and a decision as to whether to exclude them from the study was made. Enamel samples in this study were prepared according to established methods and the outer surface of each tooth was abraded to remove contaminated layers.

5.6.1 Collagen Model Quality

Collagen model quality was observed and recorded during the demineralization process. Collagen is a strong fibrous protein that when well preserved holds its shape. A good collagen model is expected to maintain its original shape and be rubbery and translucent in appearance (Sealy et al., 2014). Adequate models are produced when collagen is moderately preserved; in these, small portions may break away from the main body of the sample but its core retains cohesion. Poorly preserved models will break apart and appear frayed because the collagen fibers have degraded to such an extent that they can no longer hold together. A good collagen model is more likely to contain intact collagen molecules and be free of contaminants from the burial environment. Assessing model quality is a subjective process that works along a

continuum from excellent to poor. Each sample prepared for stable isotope analysis at the University of Alberta Department of Anthropology using the UCT method is evaluated for its collagen model quality to assist in determining the level of preservation (Garvie-Lok, 2001; Pennycook, 2008). While collagen model quality is a useful indicator it cannot be used on its own for sample quality assessment.

5.6.2 Collagen Yield by Weight

Often studies will use collagen yield to assess sample quality (Ambrose, 1990; Sealy et al., 2014; van Klinken, 1999). The collagen yield describes the amount of organic material isolated from an archaeological bone using the process outlined in section 5.2, expressed in terms of percent of the dry weight of the initial whole bone sample (Ambrose, 1990; van Klinken, 1999). The following formula is used to estimate collagen yield:

$$= Freeze\ dried\ collagen\ weight \div dry\ bone\ weight\ \times\ 100$$

Fresh modern bone contains approximately 22% collagen by weight (van Klinken, 1999). Low collagen yields indicate that a sample has experienced a large degree of protein loss and/or degradation resulting in little or no collagen being present. A very low collagen yield could also indicate that the small amount of collagen present has been contaminated and broken down, which would alter its isotopic signature (Ambrose, 1990; DeNiro & Weiner, 1988). Ambrose (1990) suggested a cut off value for collagen yield of 3.5%. DeNiro and Weiner (1988) found that samples below 2% were problematic and should be rejected. A cut off value as low as 1% has also been proposed for this quality indicator (van Klinken, 1999). Collagen samples with yield values lower than the suggested cut offs mentioned above have been found to differ isotopically from fresh bone (Schoeninger et al., 1989). Very high apparent collagen yields (>25%) may indicate incomplete demineralization, which can alter the measured $\delta^{13}C$ value if residual bone mineral carbonate remains in the sample (DeNiro & Weiner, 1988). This study used a range of 1% - 25% for acceptable collagen yield. This was based on previous work that assessed quality indicators for modern and archaeological bone (DeNiro & Weiner, 1988; van Klinken, 1999).

5.6.3 %C and %N

These diagenetic measures use the concentration of carbon and nitrogen in the prepared collagen sample by weight, which are determined by the elemental analyzer and provided along with the $\delta^{13}C$ and $\delta^{15}N$ values. Modern mammalian collagen has %C values in the 15% to 47% range; %N values range between 5% and 17% (Ambrose, 1990). Ambrose (1990) suggests that values below these ranges can indicate problems with archaeological collagen and are often associated with low collagen yields and unacceptable C/N ratios. Studies have shown that a sample can fail the %C and %N check but pass using other methods, and vice versa (Pfeiffer & Varney, 2002). Thus, using C and N content values alone is not a strong reason to reject a sample. However, they can be a strong tool when used alongside other indicators. The New Halos samples have a %C range of 25.5 to 49.2 and a %N range of 8.6 to 16.8. The samples with a %C above the proposed range by Ambrose (1990) was evaluated in terms of the other quality indicators and was included in this study because it passed other tests.

5.6.4 Atomic Carbon to Nitrogen Ratio (C/N ratios)

The atomic carbon to nitrogen ratio (C/N ratio) of a collagen sample is a robust measure used to determine whether a sample is of good or poor quality. The amino acid composition of collagen, with its high glycine content, produces a distinctive C/N ratio close to 3:1 that allows researchers to establish the presence of well-preserved collagen in a sample (Schoeninger & Moore, 1992). As collagen breaks down it is possible for carbon or nitrogen to be lost during this process. The loss of carbon or nitrogen will affect the C/N ratio.

Modern bone samples have C/N ratios ranging from 2.84 to 3.52 (Ambrose, 1990; DeNiro, 1985). A range between 2.9 and 3.6 for prehistoric samples is considered well preserved (DeNiro, 1985). A narrower range of 3.1 to 3.5 was proposed by van Klinken (1999) because it was felt that the range advocated by DeNiro (1985) was not sensitive enough to detect contamination. This study chose to use the range proposed by DeNiro (1985), as it is a widely accepted range for sample quality (Ambrose, 1990; Sealy et al., 2014). Values above or below the range proposed by DeNiro (1985) indicate that a collagen sample is of poor quality and should be treated with caution because potential diagenetic modification may have occurred (Ambrose, 1990). Schoeninger and Moore

(1992) caution that C/N ratios should not be relied upon alone to indicate a good sample, however a poor C/N ratio should indicate rejecting a sample for analysis.

5.6.5 Diagenesis in Enamel

It is still difficult to assess archaeological enamel hydroxyapatite for diagenesis. Minerals from the burial environment may simply penetrate the surface of skeletal remains through pores and cracks, thus contaminating these tissues with non-biogenic components (Price et al., 1992). Enamel hydroxyapatite crystals are much longer and denser than those in bone and the surface is less porous making enamel more resistant to diagenetic alteration (Price et al., 2002). Additionally enamel has less organic content; this combined with a dense crystal lattice makes mineral exchange and alteration more difficult and for this reason enamel is a preferred skeletal tissue for stable isotope analysis (Bentley, 2006; Budd et al., 2004; Hillson, 1996; Zazzo et al., 2004). There are preparation techniques to mediate diagenetic changes in enamel. A tooth crown can be manually abraded before samples are taken from the tooth to remove surface layers that were in direct contact with the burial environment and more likely to be permanently altered by chemical reactions. It is also possible to pretreat samples with acetic acid or other reagents. One study found that such enamel pretreatment can remove exogenous carbonates but does not completely eliminate diagenetic signals (Zazzo et al., 2004). This is due at least in part to the presence of recrystallized material resistant to the pretreatment (Garvie-Lok et al., 2004). Enamel-dentin isotopic signature comparisons can also be done; these comparisons can only indicate if enamel is less altered than dentin, but do not prove that the enamel is providing a biogenic signature (Zazzo et al., 2004). Attempts have been made to develop diagenetic indicators analogous to those used for collagen. Proposed measures include sample crystallinity and Ca/P ratio; however, these do not appear to be consistent indicators of degradation, and there have been difficulties in agreeing upon cut-off points (Garvie-Lok et al., 2004; Hoppe et al., 2003; Price et al., 1992). Like most recent stable isotope studies of archaeological enamel (e.g. Grimes & Pellegrini, 2013; Wright, 2013), this study does not use diagenetic indicators.

5.7 Summary

This chapter discussed the skeletal elements collected for this study along with a rationale for why each sample was collected. Preferred skeletal elements, ribs and premolars, were chosen when they were well preserved and could be confidently associated with a specific individual. When possible a bone and tooth pair was sampled from every individual in order to obtain isotopic data for diet and mobility for each individual. This was not always possible because of the preservation and storage methods of the skeletal collection. Age and sex were determined, when possible, based on the presence of appropriate skeletal material.

The various laboratory methods used to prepare the samples were outlined and the rationale for using these methods explained. Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values will be used for dietary analysis along with $\delta^{13}C$ carbonate values from tooth enamel. $\delta^{18}O$ and Sr^{87}/Sr^{86} values from tooth enamel will be used for mobility studies to assess the population composition. This chapter also reviewed research on how bone collagen and carbonate $\delta^{13}C$ reflect diet and described a model from the literature that uses bone collagen and carbonate $\delta^{13}C$ values to discriminate between diets of different composition that will help with dietary reconstruction. The interpretation of the strontium and oxygen data will be assisted by the models presented above for determining if the individuals from New Halos are local, regional or from further afield. Lastly the diagenetic indicators used in the study were discussed.

The methods outlined above have set the framework for interpreting the isotopic data and will allow this research to comment on dietary habits at New Halos and population composition during the Hellenistic Period.

Chapter 6 Results

This chapter presents the bone collagen and enamel stable isotope results from human and animal remains from New Halos in Thessaly, Greece. This chapter is divided into four sections. The first will present and discuss the results of the bone collagen quality indicator tests for all samples. The second will present human and animal $\delta^{13}C$ and $\delta^{15}N$ values for accepted bone collagen samples. Age and sex will be explored to determine if there is any variation in diet when both of these variables are considered. It will be shown that in general, the collagen values cluster tightly showing little dietary variation within this population. However, a few individuals fall outside the main cluster with higher $\delta^{13}C$ collagen values. Overall, the $\delta^{15}N$ values have a wider scatter than the $\delta^{13}C$ values. The third section will outline whole diet values obtained from enamel carbonate. Carbonate will then be compared to bone collagen values to examine differences between whole diet and dietary protein $\delta^{13}C$ values. The carbonate-collagen spacing will also be used in the overall interpretation of diet in order to strengthen this analysis. Sections two and three of this chapter provide the basis for understanding diet at New Halos, and will also aid in understanding the isotopic interpretations in the discussion that follows. The fourth section will discuss the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values from enamel and how these isotopes relate to individual mobility and population movement. The $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ results will be compared to local values to establish which individuals appear local or non-local. The results for the population of New Halos show that some individuals were not originally from the area directly surrounding New Halos while many others were. Lastly, dietary information is considered using local and non-local individuals to see if diet varied based on a person's place of origin. The dietary information does not show significant differences when presented in this fashion.

6.1 Bone Collagen Preservation of Human and Faunal Samples

A total of 92 human bone samples, 50 teeth samples, and 15 faunal samples from Hellenistic New Halos were submitted for bone collagen analysis. This chapter will consider the data from 62 human bone, 50 human teeth, and nine faunal samples that met or passed the quality indicator checks. Collagen yield, % carbon, % nitrogen, and atomic C/N ratios were all considered when determining which samples would be included in the final collagen analysis. The sample groups were further investigated to

determine if any strong correlations between quality indicators exist that reveal trends in sample preservation.

The New Halos data will be considered in terms of the various quality indicators and the acceptable or normal ranges for samples that were outlined in Chapter 5.6. Table 6.1 lists all accepted human and animal collagen samples included in this study along with pertinent data for quality analysis for each sample.

Table 6.1: New Halos Human and Faunal Collagen Data from Accepted Samples (NH= human; NHB = faunal)[1].

Sample ID	Collagen Yield (%)	$\partial^{13}C$ (‰PDB)	$\partial^{15}N$ (‰AIR)	C/N (Atomic)	%C	%N
NH 3	10.4	-19.6	9.6	3.3	45.9	16.0
NH 6	3.6	-20.1	8.5	3.4	44.7	15.3
NH 7	5.1	-20.1	9.8	3.5	43.9	14.7
NH 16	6.7	-20.1	9.4	3.3	45.3	15.8
NH 18	10.7	-19.8	9.1	3.4	45.1	15.5
NH 21	3.9	-19.7	10.8	3.4	41.0	14.0
NH 24	6.8	-19.5	10.7	3.5	28.1	9.3
NH 25	9.5	-19.7	8.7	3.4	41.2	14.1
NH 26	11.5	-19.6	10.2	3.4	37.0	12.8
NH 27	12.1	-20.0	8.4	3.4	36.4	12.5
NH 28	6.6	-19.6	8.9	3.5	38.9	13.1
NH 30	4.8	-19.9	10.2	3.4	43.8	15.2
NH 32	7.2	-20.0	9.4	3.4	44.8	15.3
NH 36	5.3	-19.9	8.8	3.4	49.2	16.9
NH 39	4.5	-19.6	11.1	3.5	31.4	10.4
NH 41	3.8	-19.9	10.4	3.4	44.4	15.2
NH 45	8.3	-18.7	10.1	3.4	39.8	13.6
NH 49	8.3	-19.7	10.0	3.6	39.3	12.9
NH 57	6.2	-19.6	10.2	3.4	42.8	14.8
NH 58	6.7	-19.8	9.4	3.5	45.7	15.0
NH 59	8.7	-20.0	9.2	3.4	44.6	15.1
NH 60	4.8	-19.9	8.0	3.5	42.0	14.0
NH 61	5.8	-19.8	9.1	3.4	44.1	15.0
NH 62	6.4	-20.1	9.9	3.6	40.5	13.1
NH 64	5.9	-20.1	9.3	3.5	29.2	9.7
NH 67	5.5	-19.8	9.5	3.4	43.5	14.8
NH 68	5.6	-20.2	8.6	3.4	45.9	15.7
NH 69	5.7	-19.6	10.5	3.5	40.1	13.2
NH 72	6.3	-20.3	10.2	3.6	41.2	13.4

NH 74	3.8	-19.8	8.5	3.5	44.1	14.7
NH 75	6.5	-20.2	7.8	3.5	44.3	14.7
NH 76	3.9	-19.2	8.8	3.5	46.5	15.6
NH 78	5.7	-18.5	9.1	3.3	47.8	16.8
NH 79	3.1	-19.6	9.1	3.4	42.7	14.8
NH 80	6.5	-19.7	9.7	3.3	45.1	15.7
NH 83	6.7	-17.9	9.1	3.4	32.4	11.0
NH 88	6.1	-20.2	9.9	3.6	27.8	8.9
NH 90	6.9	-20.1	9.5	3.3	43.3	15.1
NH 92	6.8	-20.3	7.3	3.4	41.9	14.3
NH 96	7.4	-19.7	9.0	3.5	33.4	11.0
NH 97	5.7	-19.9	9.3	3.5	35.7	11.8
NH 98	5.3	-20.2	8.5	3.4	42.9	14.5
NH 100	5.8	-20.2	8.3	3.4	44.0	15.2
NH 101	7.0	-19.8	9.2	3.4	45.3	15.7
NH 103	5.4	-20.1	9.2	3.4	41.8	14.3
NH 105	5.3	-20.0	9.6	3.5	25.5	8.6
NH 108	3.2	-19.8	9.4	3.4	33.7	11.5
NH 110	2.4	-20.2	9.4	3.5	29.5	9.9
NH 112	3.3	-19.4	10.3	3.4	41.3	14.1
NH 113	2.4	-19.8	9.5	3.5	42.5	14.2
NH 114	5.6	-19.6	10.5	3.4	45.1	15.5
NH 115	2.6	-20.1	8.3	3.4	46.2	15.7
NH 116	6.3	-20.1	9.4	3.5	42.7	14.3
NH 118	5.3	-19.9	8.7	3.4	46.5	15.9
NH 119	5.3	-20.0	7.7	3.4	46.5	16.1
NH 120	3.2	-19.7	9.7	3.4	40.4	13.8
NH 124	3.2	-19.6	9.9	3.5	28.0	9.4
NH 126	5.9	-20.0	9.4	3.4	45.8	15.8
NH 127	13.8	-20.0	8.8	3.3	42.9	15.0
NH 129	4.2	-20.2	7.7	3.5	41.2	13.6
NH 134	4.6	-20.2	9.3	3.3	42.9	15.0
NHB 3	8.8	-20.4	4.1	3.5	40.3	13.6
NHB 5	13.6	-20.6	4.9	3.5	36.8	12.3
NHB 6	9.7	-21.6	7.5	3.6	31.7	10.3
NHB 7	9.1	-20.6	5.4	3.4	37.6	13.0
NHB 8	12.3	-21.2	3.2	3.3	42.1	14.7
NHB 9	15.1	-20.7	4.7	3.4	41.1	14.3
NHB 10	8.7	-21.3	3.4	3.5	36.3	12.2
NHB 11	10.3	-20.7	6.0	3.5	36.0	11.9
NHB 13	11.5	-20.5	7.3	3.4	38.3	13.0

[1] There were 20 faunal samples collected for analysis. Of the 20 faunal samples collected for analy 5 bone samples were rejected for study. Nine bone and 6 teeth samples were accepted for study. The 6 teeth samples were submitted for strontium analysis only.

The accepted human and faunal collagen samples have a collagen yield ranging from 2.4% to 15.1% with an average of 5.9%. Ambrose (1990) argued that collagen yields below 2% should be rejected, while DeNiro and Weiner (1988) cautioned against the inclusion of collagen yields above 25%. The C/N range for the New Halos samples was 3.32 to 9.36 with a mean value of 3.9. DeNiro (1985) suggests an acceptable range for C/N is between 2.9 and 3.6 and this was the range applied to the New Halos samples. It was decided that samples that failed to meet the standards for C/N would be rejected automatically because C/N has long been accepted as a robust indicator of preservation quality. Samples that failed other tests were considered on a case-by-case basis. Thus, samples outside the 2.9-3.6 range were excluded from the study. As van Klinken (1999) explains, as collagen degrades over time and collagen yield decreases often the C/N values are altered and the sample no longer reflect the original *in vivo* values. Figure 6.1 illustrates that the relationship between C/N and collagen yield is as van Klinken described. In all, 27 human and five animal samples fall outside of the acceptable C/N and yield ranges and were therefore excluded from this study. Sample NH-62 has a C/N ratio of 3.60, which is at the upper limit of the acceptable range. It was included in the final sample group because the other quality indicators were well within their acceptable ranges. NH-88 has a C/N ratio of 3.63. It was included in this study because values for the other quality indicators were unproblematic and were not approaching the high or low cutoff values. NH-128 was included in this study despite having a low collagen yield of 1.27. The C/N ratio for this sample is 3.57 and the other quality indicators were acceptable.

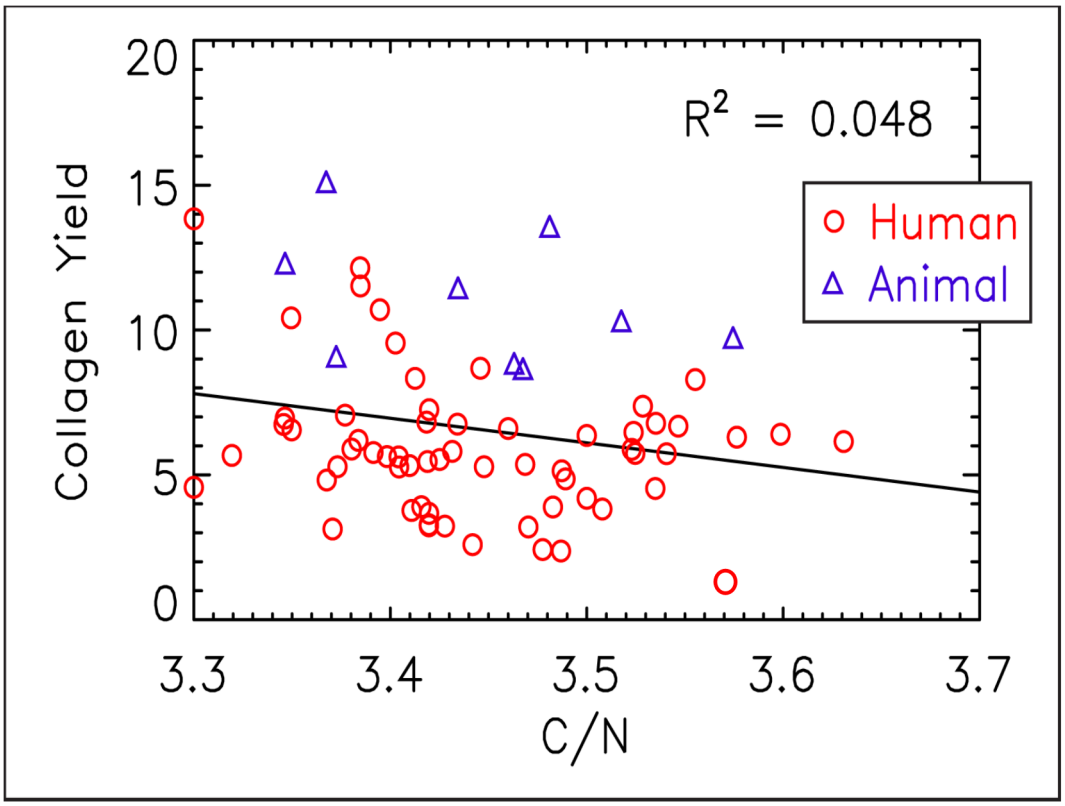

Figure 6.1: C/N vs. collagen yield for all accepted human and animal samples.

Figure 6.1 shows a correlation (R^2 = 0.048, p = 0.0787) between C/N and collagen yield that is not significant. The overall preservation of the included samples has been determined to be good based on the data in Figure 6.1. The faunal samples have a higher mean collagen yield value than the human samples, but a similar range for C/N values. All samples presented in Figure 6.1 have collagen yield and C/N values within the accepted range. There are many possible explanations for the discrepancy between the human and animal values. The burial environment for the human samples may have been less conducive to preservation than where the faunal remains were recovered. Often animal bones have thicker cortical bone than humans, which could result in better preservation over time. Alternatively, the different collagen yields could be a result of where the excavation materials were stored. The faunal remains were stored in a windowless room while the human skeletal remains were exposed to sunlight during their long curation. This may have degraded the human bones over time.

%C in the New Halos collagen samples showed a wide range from 3.2% to 49.2% with a mean of 35.0%. Samples falling between 15% and 47% for %C were included in the study (Ambrose, 1990); samples outside this range were considered more carefully. Two

samples that were included in this study have %C values slightly outside the acceptable range. NH-36 has a %C value of 49.2% and NH-78 has a %C value of 47.8%. These samples were included in the analysis because they had acceptable C/N, collagen yield and %N values. %N exhibited less variation and showed values between 0.4% and 16.8% with a mean of 11.5%. All samples included in this analysis had %N values between 5% and 17% (Ambrose, 1990).

A look at the relationship between C/N, %C, and %N can reveal overall trends in collagen preservation. In the New Halos samples, as %C and %N decrease the trend is for C/N to increase, which is consistent with the pattern seen in most sample sets (Ambrose, 1990; van Klinken, 1999). These relationships are examined in order to understand if there are any outlying samples that have irregular values that could indicate if a sample was incompletely demineralized. Although there are samples that approach the limits of good collagen preservation for %C, %N and C/N they remain within the acceptable ranges and have therefore been included in this study.

Of the 32 human and faunal samples rejected from this study, four (NH-11, NH-13, NH-14, NH-47, NBH-2) did not return data when run through the mass spectrometer, suggesting that the samples had been severely degraded and the extracted material was not in fact collagen. There were 17 samples that were rejected because they failed two or more quality indicators. The final 11 samples were rejected because they did not fall within the acceptable range for C/N.

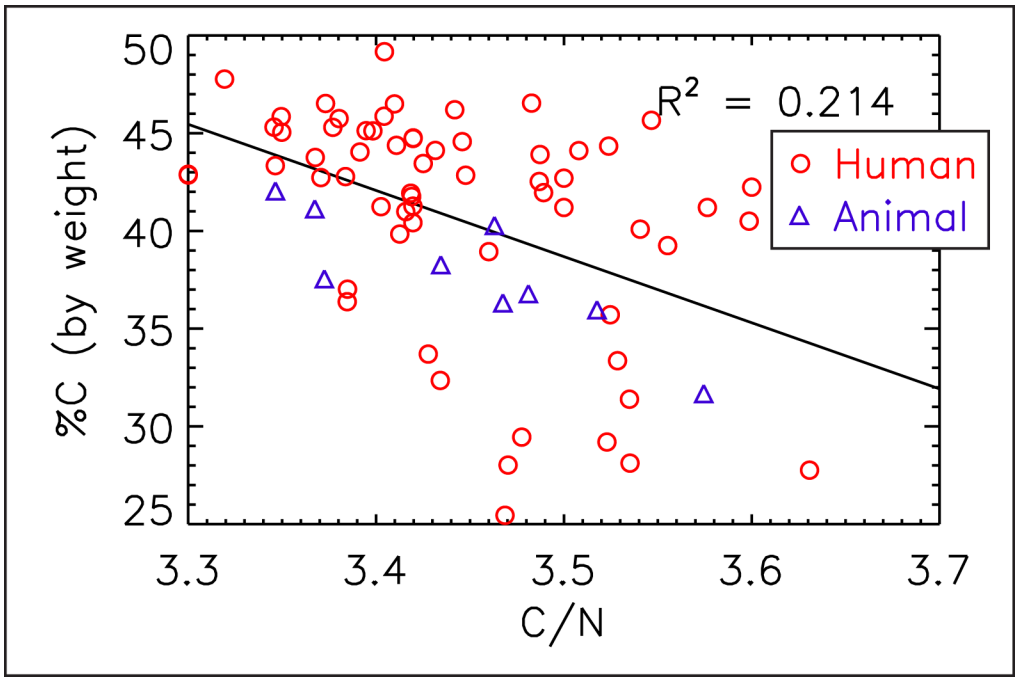

Figure 6.2: C/N vs. %C for all accepted human and animal samples from New Halos.

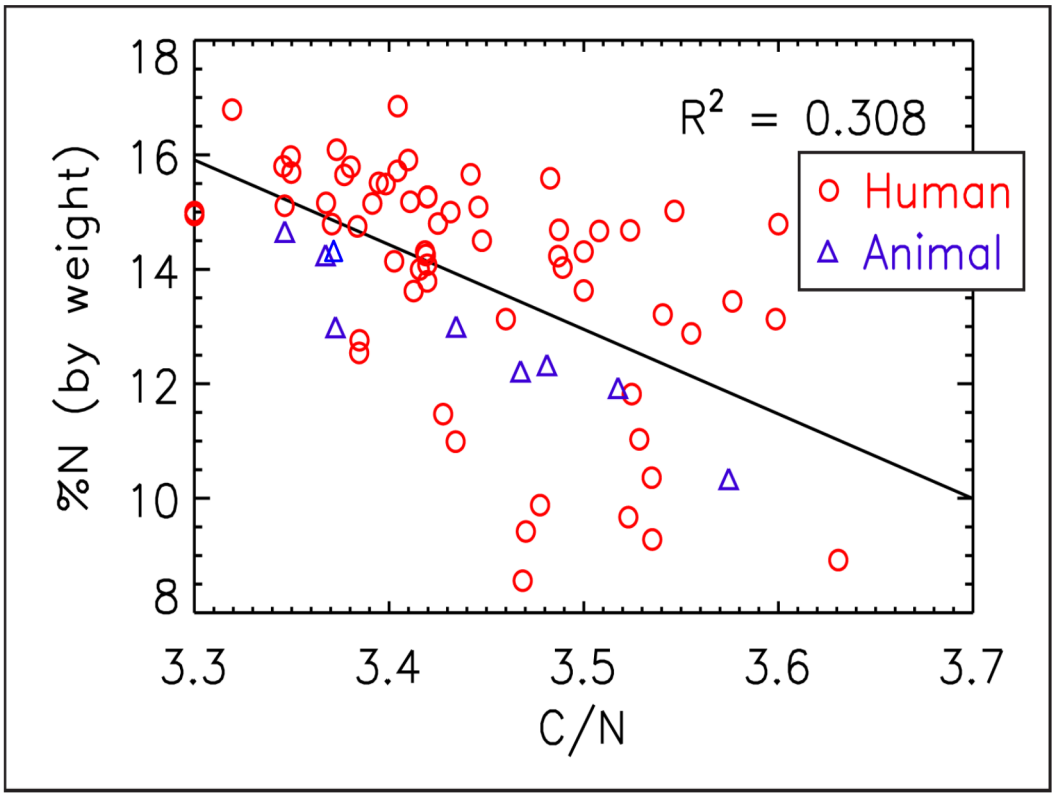

Figure 6.3: C/N vs. %N for all accepted human and animal samples from New Halos.

The correlation values for human and animal samples in Figure 6.2 and Figure 6.3 are both significant ($R^2 = 0.214$, $p < 0.0001$; $R^2 = 0.308$, $p < 0.0001$ respectively). As %C and

%N decrease the C/N values increase, which confirms that the collagen is gradually degrading. However, the degradation has not reached a level for concern for the included samples.

Table 6.2 outlines the human and faunal samples that were rejected for study. The quality indicator values are outlined in the table and the rationale for their exclusion is given below.

Table 6.2: Rejected Human and Faunal Bone Collagen Samples[1]. (NH=Human; NHB=Animal)

Sample ID	Collagen Yield (%)	$\partial^{13}C$ (% PDB)	$\partial^{15}N$ (% AIR)	C/N (Atomic)	%C	%N	Rationale
NH 1	3.4	-20.6	9.9	4.0	37.8	11.0	C/N
NH 5	3.3	-20.7	10.4	4.0	39.7	11.5	C/N
NH 8	3.2	-20.6	10.0	4.0	39.5	11.6	C/N
NH 9	3.3	-20.6	9.7	3.9	41.3	12.5	C/N
NH 11	3.1	N/A	N/A	N/A	N/A	N/A	FTPD
NH 13	4.0	N/A	N/A	N/A	N/A	N/A	FTPD
NH 14	7.5	N/A	N/A	N/A	N/A	N/A	FTPD
NH 19	4.4	-21.1	9.7	4.4	21.8	5.8	C/N
NH 34	4.4	-20.5	9.3	3.7	31.1	9.9	C/N
NH 40	6.3	-20.5	8.2	3.7	24.3	7.7	C/N
NH 43	4.8	-20.6	7.3	9.4	3.2	0.4	C/N. %C, %N
NH 47	5.1	N/A	N/A	N/A	N/A	N/A	FTPD
NH 48	4.9	-21.2	9.0	9.1	9.2	1.2	C/N. %C, %N
NH 52	4.5	-22.0	12.4	6.6	10.9	1.9	C/N. %C, %N
NH 53	4.4	-20.6	10.8	5.3	12.0	2.7	C/N. %C, %N
NH 55	1.9	-21.1	11.4	5.4	11.9	2.6	C/N. %C, %N, Y
NH 85	3.9	-19.9	9.7	3.8	27.4	8.4	C/N
NH 86	6.0	-21.2	8.9	5.2	5.2	1.2	C/N. %C, %N
NH 94	5.4	-20.8	11.4	8.2	3.7	0.5	C/N. %C, %N
NH 107	1.7	-20.1	9.7	4.0	25.8	7.5	C/N, Y
NH 109	2.3	-19.9	8.6	3.9	16.1	4.9	C/N. %N
NH 122	1.8	-20.1	9.8	3.9	24.0	7.2	C/N, Y
NH 125	3.5	-20.6	9.0	3.9	34.4	10.3	C/N
NH 128	1.3	-20.3	9.3	3.6	42.2	14.8	C/N, Y
NH 130	1.2	-20.6	13.0	5.4	11.4	2.5	C/N.%C,%N, Y
NH 132	1.9	-20.7	10.9	4.5	19.4	5.0	C/N, %N, Y
NH 133	5.7	-18.6	9.3	3.8	23.7	7.4	C/N
NH 136	2.3	-22.4	8.8	6.6	17.1	3.0	C/N, %N
NH 138	3.0	-21.3	11.6	5.9	12.1	2.4	C/N. %C, %N
NH 140	4.9	-21.3	10.5	5.3	14.2	3.1	C/N. %C, %N
NHB 2	N/A	N/A	N/A	N/A	N/A	N/A	FTPD

NHB 4	4.2	-23.0	7.5	7.3	13.8	2.2	C/N. %C, %N
NHB 12	11.9	-21.1	4.8	4.0	44.6	12.9	C/N
NHB 14	3.8	-20.8	9.7	4.2	22.7	6.3	C/N
NHB 18	6.6	-21.1	5.3	3.7	36.1	11.5	C/N
NHB 19	11.3	-21.0	4.2	3.8	21.9	6.7	C/N

[1] FTPD = Failed to produce data, Y= collagen yield.

The following figures illustrate the relationship bone collagen $\delta^{13}C$ and $\delta^{15}N$ and the various quality indicators (Figure 6.4-Figure 6.9). There are no strong correlations between the following: $\delta^{13}C$ and collagen yield (Figure 6.4), $\delta^{13}C$ and C/N (Figure 6.5), $\delta^{13}C$ and %C (Figure 6.6), $\delta^{15}N$ and collagen yield (Figure 6.7), $\delta^{15}N$ and C/N (Figure 6.8), and $\delta^{15}N$ and %N (Figure 6.9). Once again, these results show that the included samples are of good quality and have produced reliable data. Although the preservation indicators drift gradually as preservation quality drops, this is not associated with any detectable alteration of $\delta^{13}C$ or $\delta^{15}N$.

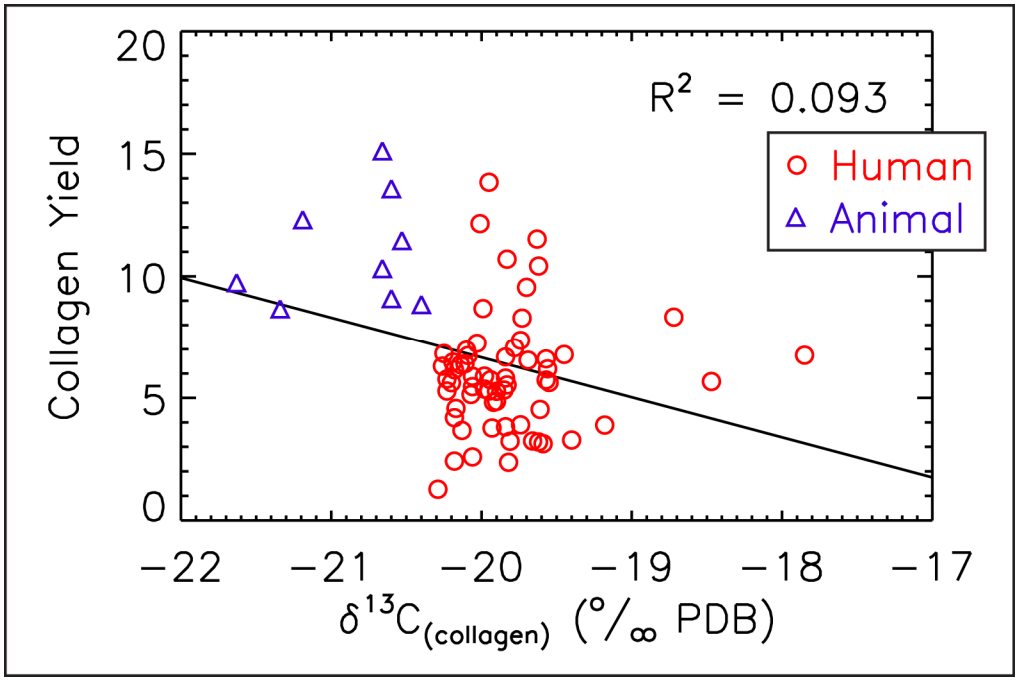

Figure 6.4: $\delta^{13}C$ vs. Collagen Yield for all accepted human and animal samples from New Halos.

In Figure 6.4, as collagen yield increases $\delta^{13}C$ values decrease. The correlation does show significance when human and faunal values are considered together ($R^2 = 0.093$; $p = 0.009$). As was mentioned above the faunal remains show an overall higher collagen yield than the human samples, likely because of better curation or a burial environment

that was more conducive to preservation. Additionally, humans were consuming animal products resulting in a trophic level effect enriching the human $\delta^{13}C$ values relative to the fauna. The correlation between collagen yield and $\delta^{13}C$ values shows significance, however this is a result of the trophic level effect raising human $\delta^{13}C$ values above faunal values and creating an apparent relationship between the two variables. This does not indicate a problem with sample quality as we expect humans consuming animal tissue to have higher $\delta^{13}C$ values compared to faunal $\delta^{13}C$ values.

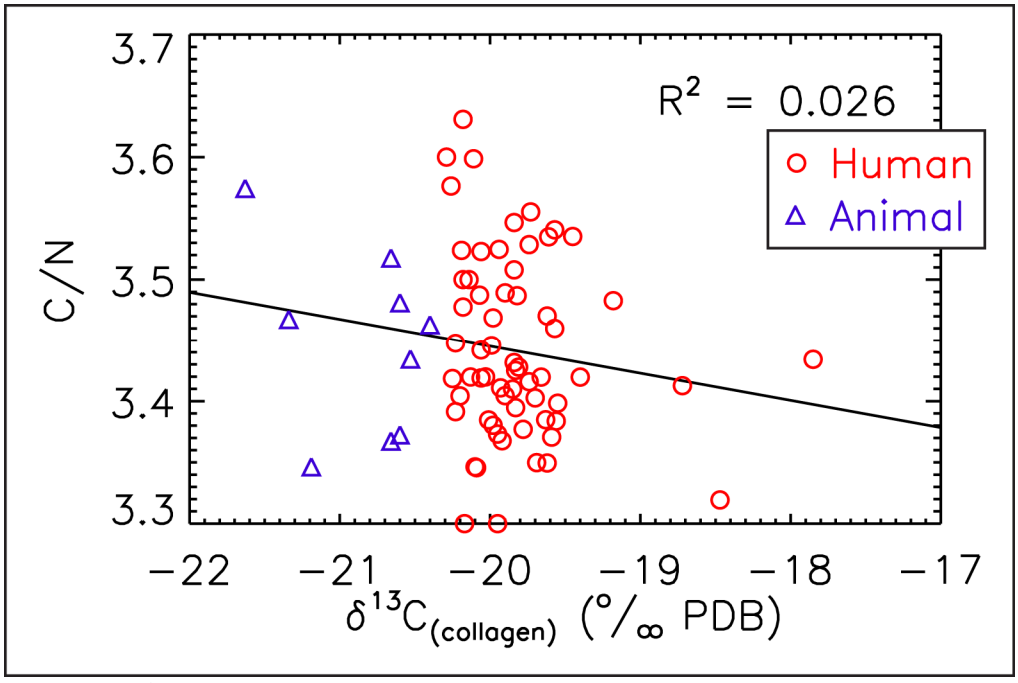

Figure 6.5: $\delta^{13}C$ vs. C/N for all accepted human and animal samples from New Halos.

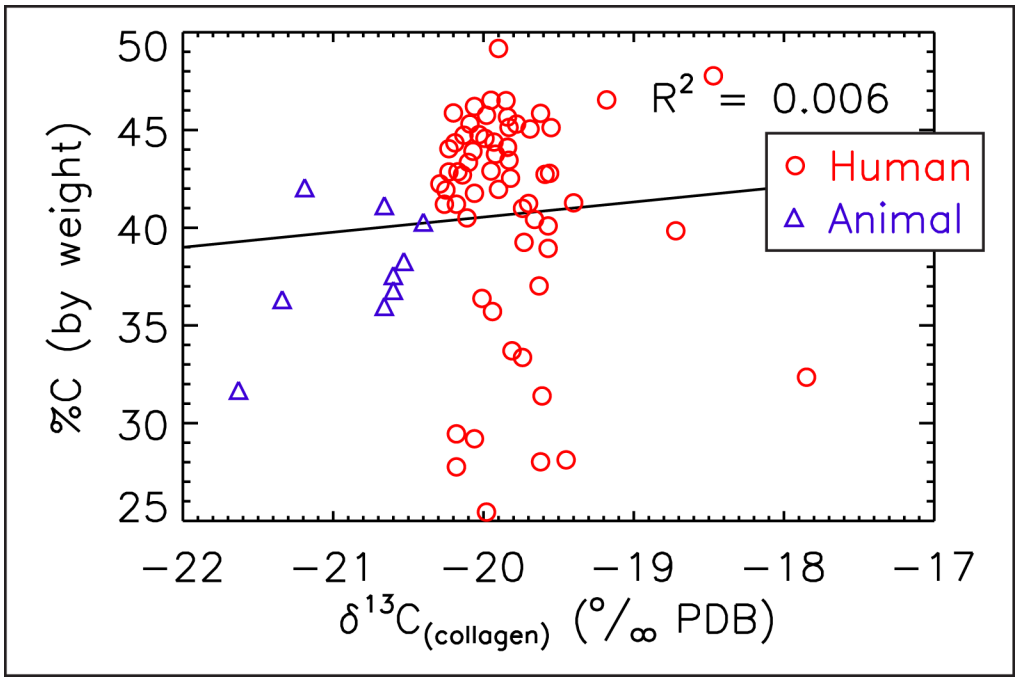

Figure 6.6: $\delta^{13}C$ vs. %C for all accepted human and animal samples from New Halos.

Figure 6.5 and Figure 6.6 show correlation values that are not significant ($R^2 = 0.026$, $p = 0.179$; $R^2 = 0.006$, $p = 0.52$). This suggests that neither C/N nor %C has influenced the $\delta^{13}C$ values. The human and faunal samples have similar C/N values but the human samples show a wider range for %C than the animal samples. The way in which the human samples were stored (in direct sunlight) compared to the faunal samples (in a windowless room) could have affected the %C content for some of the human samples with low values.

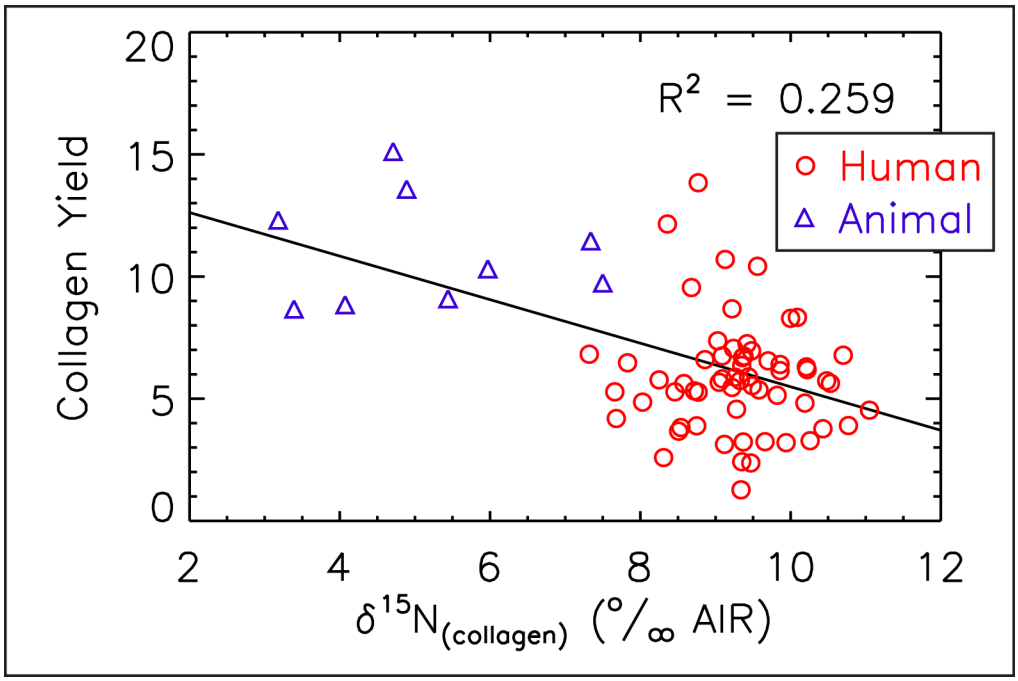

Figure 6.7: $\delta^{15}N$ vs. Collagen Yield for all accepted human and animal samples from New Halos.

Figure 6.7, however, does show a significant correlation ($R^2 = 0.259$, $p < 0.001$) between $\delta^{15}N$ and collagen yield. As $\delta^{15}N$ increases, collagen yield decreases. However, when the animal samples are removed from consideration the correlation is not seen within the human samples ($R^2 = 0.00208$, $p = 0.724$), demonstrating a lack of relationship between collagen yield and $\delta^{15}N$ values in the human data. The correlation between $\delta^{15}N$ and collagen yield is created when the animal and human samples are considered together, and stems from the same reasons as the relationship between collagen yield and $\delta^{13}C$ discussed above. The animal samples show lower $\delta^{15}N$ values because of the trophic level effect; humans will have higher $\delta^{15}N$ values if they were consuming faunal material. The higher collagen yield for animal samples can be explained by differential collagen preservation in the burial environment or better preservation because of post excavation storage conditions.

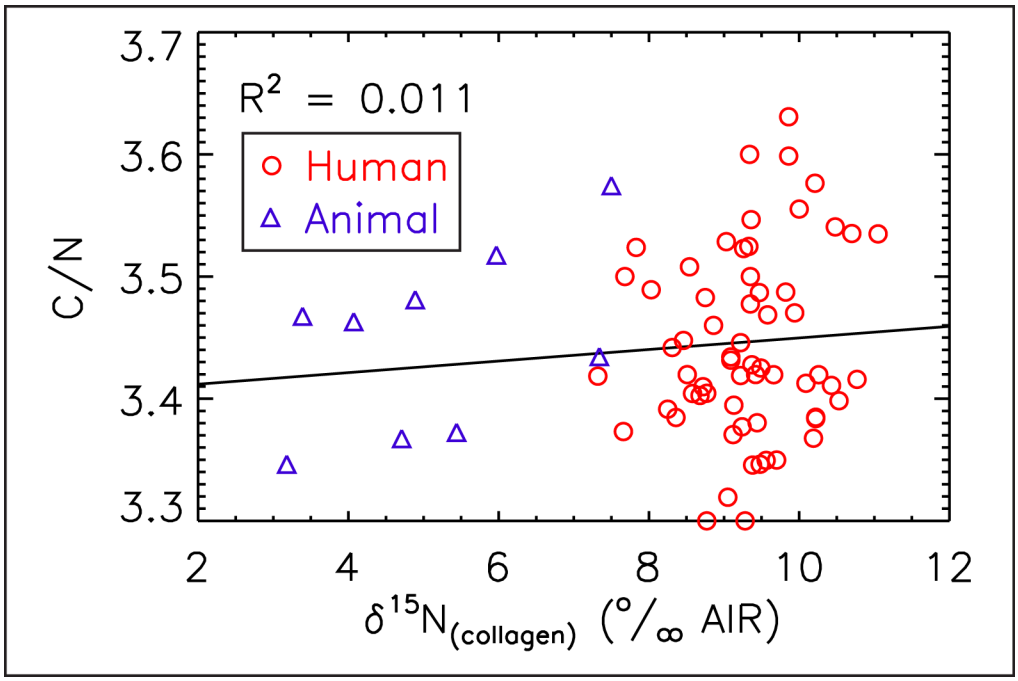

Figure 6.8: $\delta^{15}N$ vs. C/N for all accepted human and animal samples from New Halos.

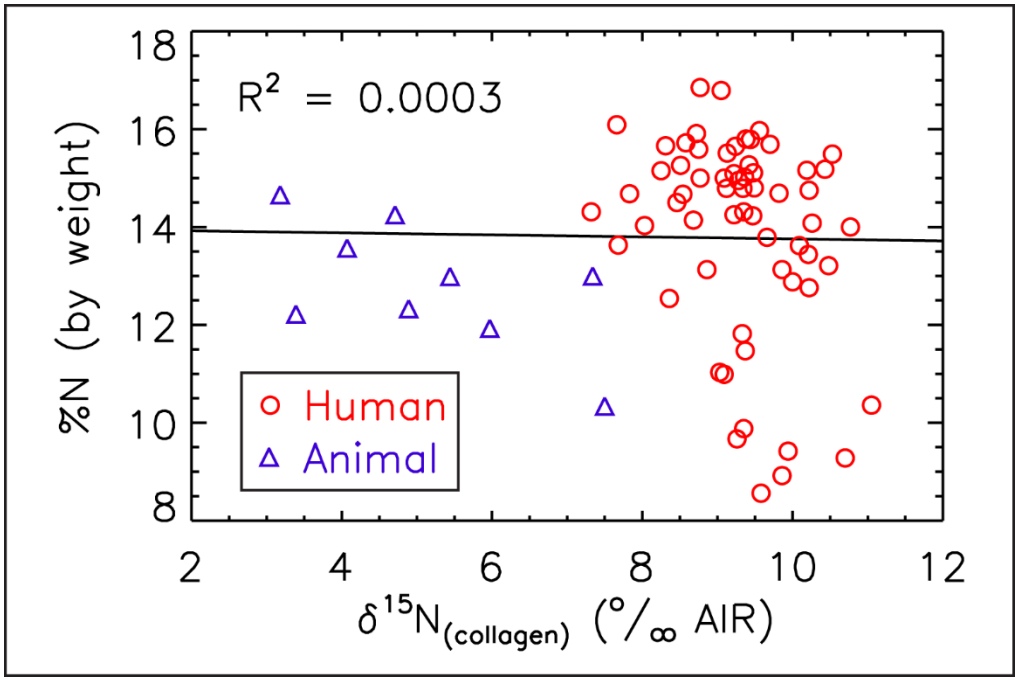

Figure 6.9: $\delta^{15}N$ vs. %N for all accepted human and animal samples from New Halos.

Figure 6.8 and Figure 6.9 show that there is no significant correlation between $\delta^{15}N$ and C/N or %N ($R^2 = 0.011$, $p = 0.388$; $R^2 = 0.0003$, $p = 0.888$ respectively). The human $\delta^{15}N$ values are more tightly clustered than the faunal values in both figures. These quality indicators again indicate good preservation for the accepted samples.

Overall, the relationships $\delta^{13}C$ and $\delta^{15}N$ have with the quality indicators show that stable isotope values are not being offset or influenced by poor collagen preservation and that their isotopic composition is intact. The data included in this study can be accepted with confidence and the analysis below can be interpreted without concern about diagenetic alteration to the isotopic signatures.

6.2 Stable Isotope Results for Bone Collagen

Figure 6.10 compares the $\delta^{13}C$ and $\delta^{15}N$ collagen isotope values from human and animal samples. Table 6.3 below provides data for the accepted human samples. It includes data pertaining to age, sex, $\delta^{13}C_{(collagen)}$, $\delta^{15}N_{(collagen)}$, $\delta^{13}C_{(carbonate)}$, and $\Delta^{13}C_{(carbonate\text{-}collagen)}$[4]. The human $\delta^{13}C_{(collagen)}$ values range from -17.9‰ to -20.3‰ with a mean of -19.8‰. As will be discussed in the following chapter, the $\delta^{13}C_{(collagen)}$ values are low compared to other Greek dietary studies. There are four individuals (NH-45, NH-76, NH-78, NH-83) who pull away from the central cluster and show slightly higher $\delta^{13}C_{(collagen)}$ values; they are indicated by solid circles in Figure 6.10. These four individuals do not have increased $\delta^{15}N$ values in relation to the rest of the group.

The $\delta^{15}N$ values for human collagen range from 7.3‰ to 11.1‰ with an average of 9.3‰. The $\delta^{15}N$ values are not as tightly grouped as the $\delta^{13}C_{(collagen)}$ values. When the total sample is considered the spread of human $\delta^{13}C$ and $\delta^{15}N$ values is narrow (ca. 2.4‰ and 3.8‰ respectively). The correlation between $\delta^{13}C$ and $\delta^{15}N$ values approaches significance ($R^2 = 0.064$, $p = 0.048$). This is a very low correlation that should be considered with caution when considering the relationship.

The animal $\delta^{13}C_{(collagen)}$ values range from -20.4‰ to -21.6‰ and animal $\delta^{15}N$ values range from 3.2‰ to 5.2‰. A small cluster of five animal values, identified by the blue circle in Figure 6.10, has average values for $\delta^{13}C$ and $\delta^{15}N$ of -20.6‰ and 5.0‰ respectively. There are animal values outside this range that may indicate a non-local origin and will be discussed further in the following chapter. The average human $\delta^{13}C_{(collagen)}$ value is approximately 1‰ above the cluster of animal $\delta^{13}C$ values, while the average human $\delta^{15}N$ collagen value is enriched approximately 4‰ above the cluster of five animal values (see Figure 6.10).

[4] Moving forward the abbreviated version will be used: $\Delta^{13}C_{(carb\text{-}coll)}$.

At first glance the $\delta^{13}C_{(collagen)}$ values appear to reflect a diet based on C_3 plants and/or terrestrial animals that consume C_3 products. As will be discussed in the following chapter, the $\delta^{15}N$ values suggest that the overall trend in this population is that terrestrial protein was being consumed and very few marine resources were being added to the diet. Further discussion of these values in Chapter 7 will add to our understanding of diet at New Halos and will consider the variation within the human and animal sample sets and their relationship to each other.

Table 6.3: Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values with enamel $\delta^{13}C$ data including age and sex determination[1] for accepted human samples from New Halos.

Sample ID	Age	Sex	$\delta^{13}C_{(collagen)}$ (‰)	$\delta^{15}N_{(collagen)}$ (‰)	$\delta^{13}C_{(carbonate)}$ (‰)	$\Delta^{13}C_{(carb\text{-}coll)}$
NH 3	A	?	-19.6	9.6	-11.6	7.9
NH 6	A	F	-20.1	8.5		
NH 7	A	?	-20.1	9.8		
NH 16	A	?	-20.1	9.4	-12.5	7.6
NH 18	A	?	-19.8	9.1		
NH 21	A	M?	-19.7	10.8	-10.9	8.7
NH 24	A	?	-19.5	10.7		
NH 25	A	?	-19.7	8.7		
NH 26	A	?	-19.6	10.2		
NH 27	A	?	-20.0	8.4		
NH 28	A	?	-19.6	8.9	-11.6	7.9
NH 30	15-29	M	-19.9	10.2	-11.4	8.5
NH 32	40-44	M	-20.0	9.4	-12.3	7.6
NH 36	A	?	-19.9	8.8	-11.3	8.6
NH 39	A	?	-19.6	11.1		
NH 41	35-49	M	-19.9	10.4	-11.7	8.2
NH 45	A	?	-18.7	10.1	-10.9	7.8
NH 49	A	?	-19.7	10.0		
NH 57	23-57	M	-19.6	10.2		
NH 58	A	M	-19.8	9.4		
NH 59	A	M	-20.0	9.2		
NH 60	A	?	-19.9	8.0		
NH 61	A	?	-19.8	9.1		
NH 62	A	F	-20.1	9.9	-12.6	7.4
NH 64	40-49	M?	-20.1	9.3	-11.2	8.8
NH 67	A	?	-19.8	9.5	-12.2	7.5
NH 68	J	?	-20.2	8.6		
NH 69	A	M	-19.6	10.5	-12.1	7.5
NH 72	40-49	?	-20.3	10.2	-9.4	10.9
NH 74	J	?	-19.8	8.5		
NH 75	A	?	-20.2	7.8		
NH 76	A	?	-19.2	8.8		
NH 78	J	?	-18.5	9.1		

NH 79	J	?	-19.6	9.1		
NH 80	A	M?	-19.7	9.7	-11.7	8.0
NH 83	A	M	-17.9	9.1	-9.3	8.6
NH 88	A	?	-20.2	9.9	-10.3	9.8
NH 90	A	F	-20.1	9.5	-12.2	7.8
NH 92	A	M	-20.3	7.3	-12.5	7.7
NH 96	35-44	F	-19.7	9.0		
NH 97	35-44	F	-19.9	9.3		
NH 98	A	F?	-20.2	8.5	-12.4	7.8
NH 100	40-44	F?	-20.2	8.3		
NH 101	A	?	-19.8	9.2	-12.2	7.6
NH 103	40-44	F	-20.1	9.2	-11.8	8.2
NH 105	35-39	F	-20.0	9.6	-11.8	8.1
NH 108	A	?	-19.8	9.4		
NH 110	A	?	-20.2	9.4	-12.3	7.9
NH 112	45-59	M	-19.4	10.3		
NH 113	45-49	M	-19.8	9.5		
NH 114	30-39	F	-19.6	10.5		
NH 115	A	?	-20.1	8.3		
NH 116	A	F	-20.1	9.4	-12.5	7.6
NH 118	A	?	-19.9	8.7		
NH 119	A	?	-20.0	7.7		
NH 120	45-49	M	-19.7	9.7	-12.5	7.1
NH 124	45-59	?	-19.6	9.9		
NH 126	30-39	M	-20.0	9.4		
NH 127	A	?	-20.0	8.8		
NH 129	A	?	-20.2	7.7		
NH 134	A	?	-20.2	9.3	-12.6	7.5
			Mean: -19.8	**Mean: 9.3**	**Mean: -11.7**	**Mean: 8.0**

[1] A= Adult, J= Juvenile, M= Male, F=Female. Age and sex estimates were determined using methods outlined in Buikstra and Ubelaker (1994).

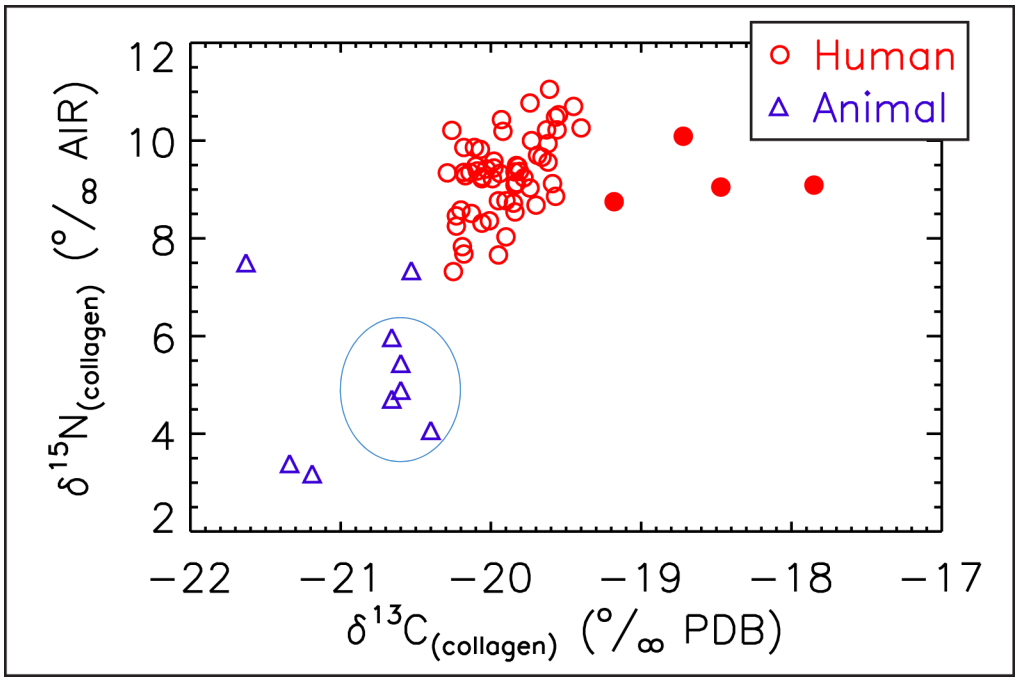

Figure 6.10: Human and animal $\delta^{13}C$ and $\delta^{15}N$ collagen values. The solid red circles indicate the four outliers (NH-45, NH-76, NH-78, NH-83) and the blue circle outlines the cluster of 5 faunal samples mentioned in the text above.

Figure 6.11 and Figure 6.12 display only the human collagen data from Figure 6.10, separating the data according to age and sex respectively. In Figure 6.11, the individuals were divided into five categories: adult, old adult (50+ yrs), middle adult (35-50 yrs), young adult (18-35), and juvenile (<18yrs). The 'adult' category was created for all individuals whose skeletons showed adult traits but did not have the necessary skeletal elements available to establish a more precise age estimation. Figure 6.11 shows that the $\delta^{13}C$ and $\delta^{15}N$ distributions for each age group do not vary widely. Statistical tests were not run to determine if there is a significant difference between the age groups because the sample sizes are too small to produce meaningful results. As seen in Figure 6.11 and Figure 6.12 the human collagen $\delta^{13}C$ and $\delta^{15}N$ values do not show strong patterning when separated by age or sex. The sample size is small for each category, which makes any interpretation less reliable. Perhaps with a larger sample size dietary distinctions between age groups or sex would be more apparent. Table 6.4 and Table 6.5 provide the range and mean for $\delta^{13}C$ and $\delta^{15}N$ collagen values for age and sex, respectively.

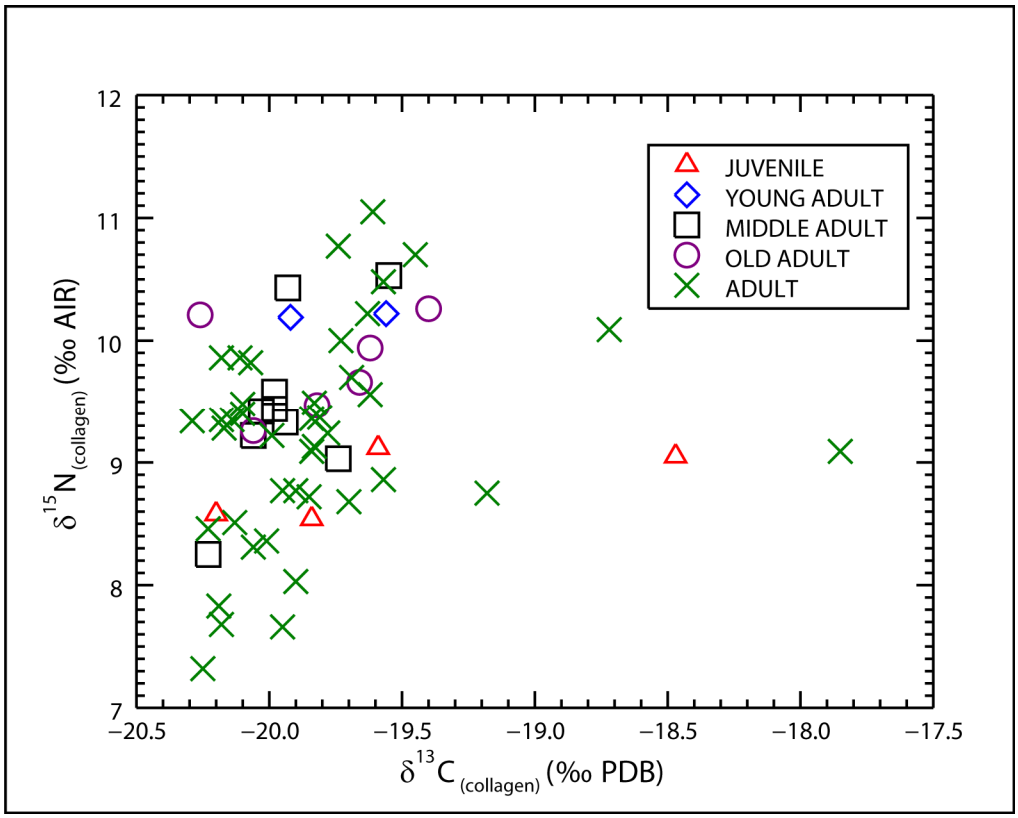

Figure 6.11: Human $\delta^{13}C$ and $\delta^{15}N$ collagen values separated by age.

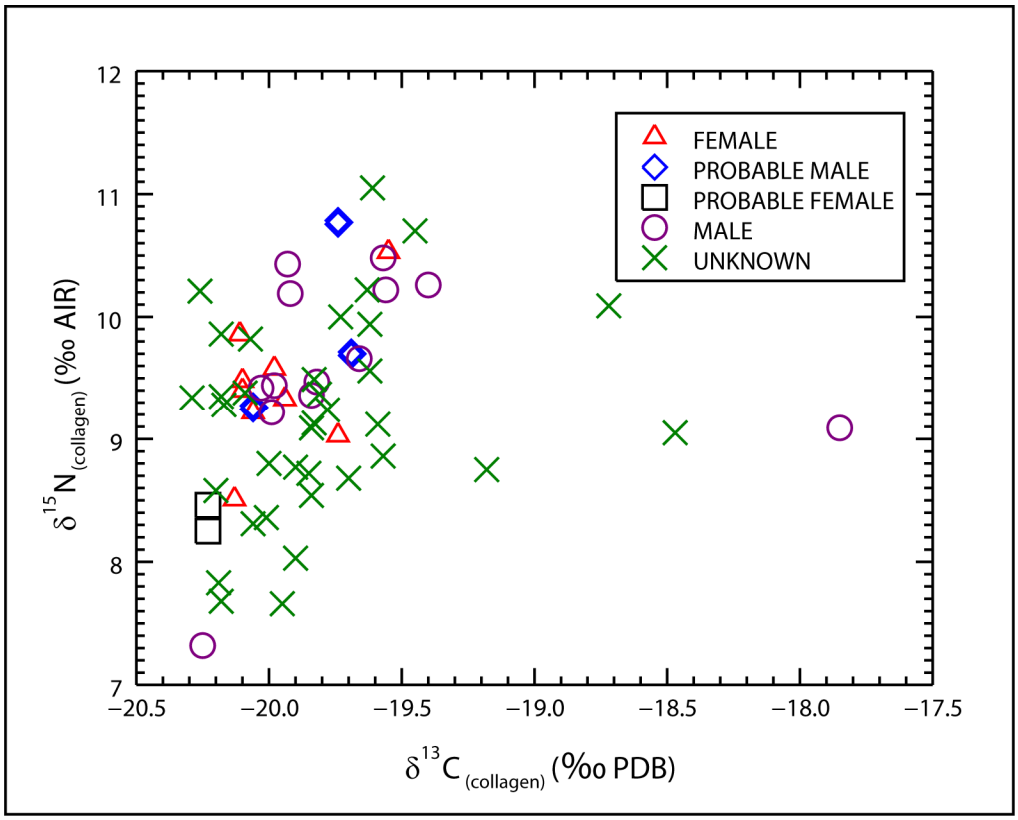

Figure 6.12: Human $\delta^{13}C$ and $\delta^{15}N$ collagen values separated by sex.

Table 6.4: Human $\delta^{13}C$ and $\delta^{15}N$ data separated by age groups

Age	n	$\delta^{13}C$ (Collagen)		$\delta^{15}N$ (Collagen)	
		Range	Mean	Range	Mean
Juvenile	4	-18.5 to -20.2	-19.5	8.5 to 9.1	8.8
Young Adult	2	-19.6 to -19.9	-19.7	10.2	10.2
Middle Adult	9	-19.6 to -20.2	-19.9	8.3 to 10.5	9.5
Old Adult	6	-19.4 to -20.3	-19.8	9.3 to 10.3	9.8
Adult	41	-17.9 to -20.3	-19.8	7.3 to 11.1	9.2

Table 6.5 provides the collagen data separated by estimated sex. The probable females were combined with the female group and the probable males were combined with the male group in order to increase the sample size. There were no significant correlations between $\delta^{13}C$ and $\delta^{15}N$ collagen values found with respect to sex except for a moderate correlation for female $\delta^{13}C$ and $\delta^{15}N$ values. The samples size for females (n = 10) is small, so although the correlation exists its reliability should be considered with caution. Unequal variance t-tests (Ruxton, 2006) were run to determine if there was a significant difference between the mean male and female $\delta^{13}C$ and $\delta^{15}N$ values. Both t-tests determined that at the 95% confidence level there was no statistically significant difference between male and female $\delta^{13}C$ values or between male and female $\delta^{15}N$ values ($\delta^{13}C$: t = 2.079, p = 2.0860; $\delta^{15}N$: t = 1.411, p = 2.0639).

Table 6.5: Data for New Halos samples separated by sex.

Sex	n	$\delta^{13}C$ (Collagen)		$\delta^{15}N$ (Collagen)		r^2 ($\delta^{13}C$ vs $\delta^{15}N$)	p ($\delta^{13}C$ vs $\delta^{15}N$)
		Range	Mean	Range	Mean		
Full sample	61	-17.9 to -20.3	-19.8	7.3 to 11.1	9.3	0.064	0.48
Unknown	36	-18.5 to -20.3	-19.8	7.7 to 11.1	9.2	0.067	0.134
(Probable) Female	10 (8+2)	-19.6 to -20.2	-19.6	8.3 to 10.5	9.2	0.449	0.03
(Probable) Male	15 (12+3)	-17.9 to -20.3	-19.7	7.3 to 10.8	9.6	0.012	0.691

Figure 6.13 compares the $\delta^{13}C_{(collagen)}$ values to $\delta^{13}C_{(carbonate)}$ values of the 26 individuals from which both bone and tooth samples were available. The carbonate and collagen values are significantly correlated (R^2 = 0.23, p = 0.011). The majority of the group has very low values for both collagen and carbonate. Most $\delta^{13}C_{(collagen)}$ values cluster

between -19.5‰ and -20.4‰ and most of the $\delta^{13}C_{(carbonate)}$ values range from -11‰ to -12.6‰. There are however, four individuals who have isotope signatures outside of the main cluster (NH-45, NH-72, NH-83, NH-88). They are represented by solid circles in Figure 6.13. Two of the four individuals (NH-72, NH-88) have low $\delta^{13}C_{(collagen)}$ values in relation to the rest of the population but their $\delta^{13}C_{(carbonate)}$ values are elevated. The other two individuals (NH-45, NH-83) have high collagen values as well as high carbonate values; these two individuals also fall outside of the main cluster for collagen $\delta^{13}C$ and $\delta^{15}N$ in Figure 6.10. When the individuals with low collagen and high carbonate values (NH-72 and NH-88) are removed from the data set the correlation becomes even stronger ($R^2 = 0.67$, p. < 0.001). This indicates that for the majority of the sample, as collagen values increase so do the carbonate values; NH-72 and NH-88 do not follow this pattern.

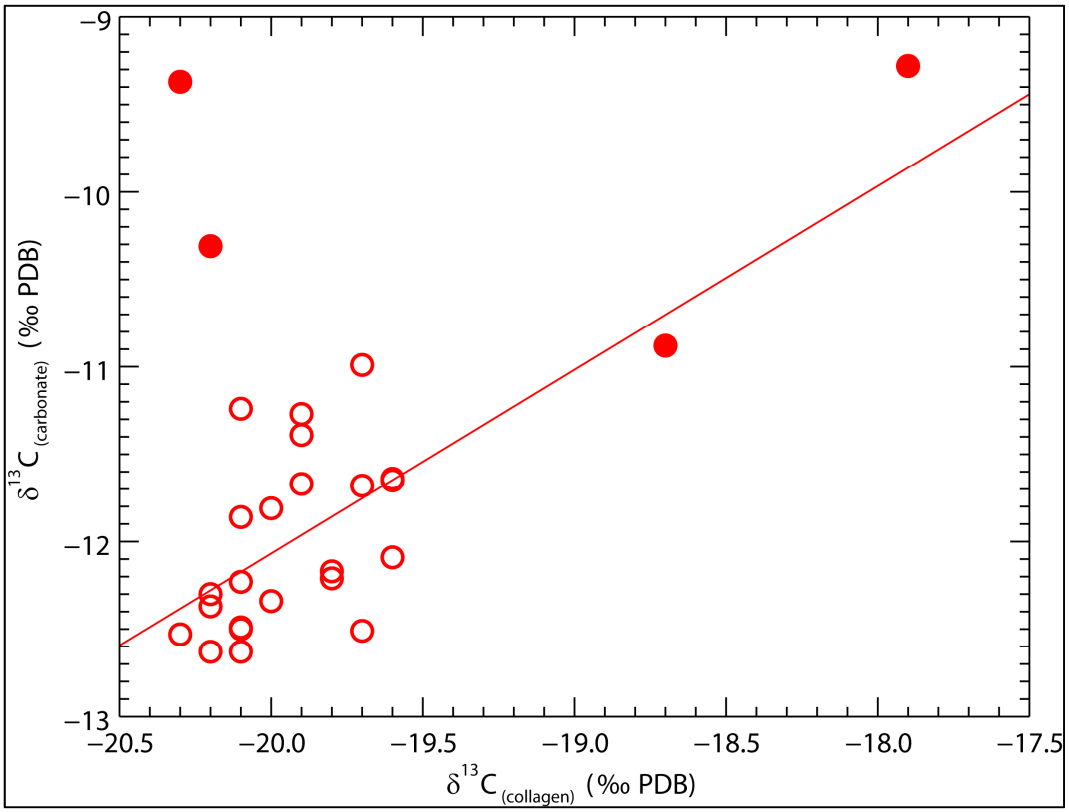

Figure 6.13: $\delta^{13}C_{(collagen)}$ and $\delta^{13}C_{(carbonate)}$ values of human samples. The regression line was calculated by excluding the 4 outliers; slope of the line is 1.05. The solid circles indicate specific samples mentioned in the text (NH-45, NH-72, NH-83, NH-88).

Figure 6.14 compares $\delta^{13}C_{(carbonate)}$ to $\delta^{15}N$ collagen values for the same subset of individuals in Figure 6.13. In contrast to the situation for $\delta^{13}C_{(collagen)}$, there is no significant correlation between $\delta^{15}N$ and $\delta^{13}C_{(carbonate)}$ values (R^2= 0.083, p = 0.145).

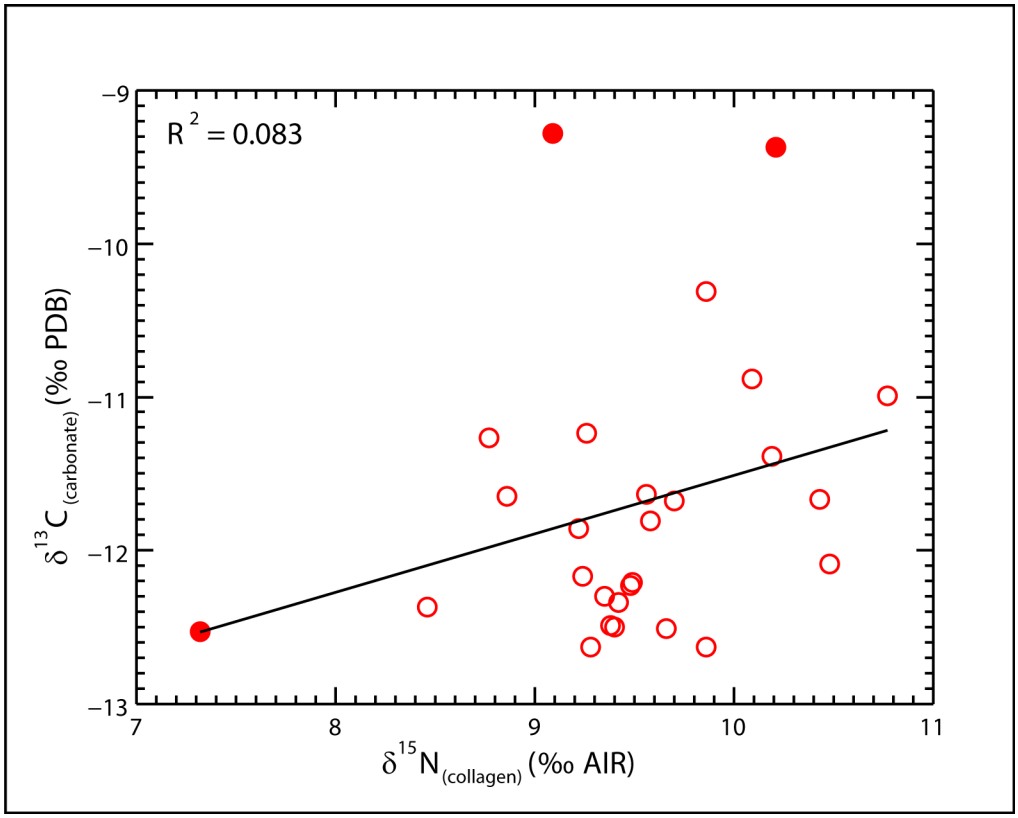

Figure 6.14: $\delta^{15}N$ and $\delta^{13}C_{(carbonate)}$ values from human samples. Solid circles indicate specific samples mentioned in the text (NH-72, NH-83, NH-92).

Two individuals (NH-72, NH-83) have higher $\delta^{13}C_{(carbonate)}$ values than the rest of the population while their $\delta^{15}N$ values are consistent with the rest of the samples. NH-72 was also identified as an outlier in Figure 6.13 because of higher $\delta^{13}C_{(carbonate)}$ but lower $\delta^{13}C_{(collagen)}$ values. NH-83 was identified as an outlier in Figure 6.10 because its $\delta^{13}C_{(collagen)}$ values were higher than the main cluster of individuals. NH-83 was also identified as an outlier in Figure 6.13 because of its high collagen and carbonate $\delta^{13}C$ values. One individual (NH-92) has a low $\delta^{15}N$ values but a $\delta^{13}C_{(carbonate)}$ values that is consistent with the rest of the samples. NH-92 was not identified as an outlier in any other context. When the two individuals from Figure 6.14 with higher $\delta^{13}C_{(carbonate)}$ values are removed from the sample there is a correlation that shows near significance (R^2 = 0.147, p =

0.058). However, when all three identified outliers (NH-72, NH-83, NH-92) are removed the correlation does not exist (R^2= 0.069, p = 0.213).

Figure 6.15 and Figure 6.16 show the carbonate-collagen $\delta^{13}C$ spacing values ($\Delta^{13}C_{(carb\text{-}coll)}$) compared to $\delta^{13}C_{(collagen)}$ and $\delta^{15}N$, respectively. Neither comparison showed significant correlations (R^2 = 0.0067, p = 0.684; R^2 = 0.058, p = 0.22).

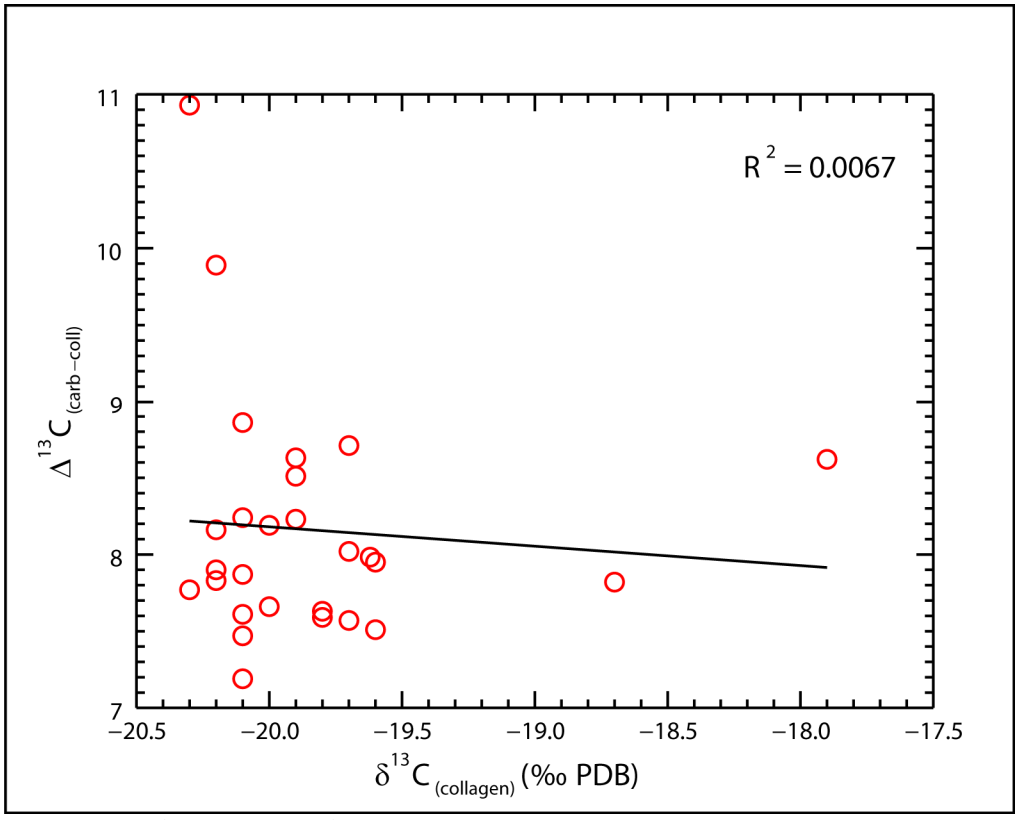

Figure 6.15: $\delta^{13}C_{(collagen)}$ and $\Delta^{13}C_{(carb\text{-}coll)}$ for human samples.

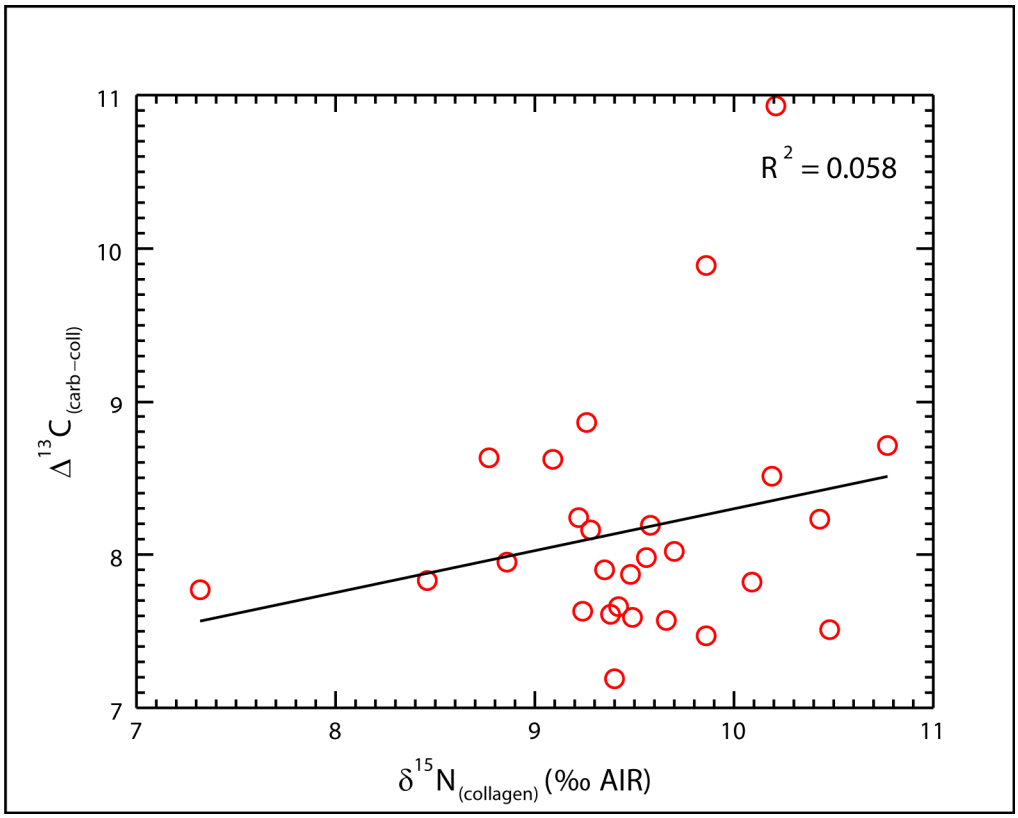

Figure 6.16: $\delta^{15}N$ vs $\Delta^{13}C_{(carb\text{-}coll)}$ values for human samples.

The average $\Delta^{13}C_{(carb\text{-}coll)}$ spacing for the New Halos population is 8.2‰. With a few exceptions, the people of New Halos have small $\Delta^{13}C_{(carb\text{-}coll)}$ spacing values. The importance of these values will be discussed and interpreted in Chapter 7.

6.3 Oxygen Isotope Analysis

Stable oxygen isotope data were collected from tooth enamel in order to determine if a person appeared to be local to New Halos or non-local based on the established $\delta^{18}O$ regional signature for the area. As mentioned in Chapter 4.6, the stable oxygen isotope values of rainfall vary with temperature, altitude, and proximity to the coast and create a generalized regional signature. The stable oxygen isotope signature of the human body is determined primarily by drinking water; therefore if a childhood local drinking water value can be estimated from enamel samples we can compare human oxygen isotope signatures to estimated local water source values to get a rough idea of where people are from. Table 6.6 presents the data for all samples used for oxygen isotope analysis.

Table 6.6: Isotope values from human enamel samples used for oxygen analysis including estimated drinking water $\delta^{18}O$ values[1].

Sample ID	Tooth	$\delta^{13}C_{(carbonate)}$	$\delta^{18}O$	$\delta^{18}O_{(drinking\ water)}$ values
NHS 2	L M1	-12.3	-4.41	-6.80
NHS 3	L PM^1	-11.6	-4.72	-7.31
NHS 10	R M_2	-10.7	-5.08	-7.90
NHS 12	R PM^3	-11.9	-3.70	-5.64
NHS 15	L PM_1	-12.3	-5.52	-8.61
NHS 17	R PM_1	-12.5	-4.03	-6.18
NHS 20	L PM^1	-12.3	-3.34	-5.03
NHS 22	R C	-10.9	-4.70	-7.27
NHS 23	PM^1	-11.8	-5.18	-8.06
NHS 29	L PM_2	-11.6	-4.33	-6.67
NHS 31	L PM^2	-11.4	-5.05	-7.84
NHS 33	L PM^2	-12.3	-3.61	-5.49
NHS 35	L I^2	-9.8	-5.77	-9.03
NHS 37	R PM^1	-11.3	-5.05	-7.84
NHS 38	L PM_2	-12.2	-5.18	-8.06
NHS 42	R M^1	-11.7	-4.55	-7.03
NHS 44	R PM^2	-10.5	-7.11	-11.21
NHS 46	R PM^1	-10.9	-6.36	-10.00
NHS 50	L PM^1	-11.4	-5.20	-8.09
NHS 51	R PM^1	-10.1	-5.76	-9.01
NHS 54	R PM_2	-12.8	-4.35	-6.70
NHS 56	R PM^1	-11.8	-5.61	-8.76
NHS 63	R PM^1	-12.6	-6.22	-9.76
NHS 65	R PM_1	-11.2	-4.08	-6.25
NHS 66	L PM_2	-12.2	-5.23	-8.14
NHS 70	L PM_1	-12.1	-4.25	-6.53
NHS 71	R PM_1	-11.4	-3.68	-5.60
NHS 73	R M_1	-9.4	-7.55	-11.95
NHS 77	L PM_1	-11.0	-7.29	-11.52
NHS 81	PM^2	-11.7	-5.45	-8.49
NHS 82	L M^2	-10.1	-6.31	-9.91
NHS 84	R M_2	-9.3	-5.13	-7.98
NHS 87	L PM^2	-11.3	-6.41	-10.07
NHS 89	R M_1	-10.3	-6.10	-9.57
NHS 91	R PM_1	-12.2	-4.24	-6.52
NHS 93	L M^3	-12.5	-5.03	-7.81
NHS 95	L PM_2	-11.5	-4.64	-7.16
NHS 99	R PM_1	-12.4	-4.91	-7.61
NHS 102	R M_1	-12.2	-3.72	-5.67

NHS 104	R I_2	-11.8	-5.17	-8.04
NHS 106	R PM_2	-11.8	-4.32	-6.64
NHS 111	R PM^1	-12.3	-5.31	-8.27
NHS 117	R PM_2	-12.5	-4.02	-6.15
NHS 121	L M_2	-12.5	-5.30	-8.26
NHS 123	R I^1	-12.1	-4.17	-6.41
NHS 131	L PM^1	-12.7	-4.11	-6.31
NHS 135	L PM^2	-12.6	-5.12	-7.96
NHS 137	R PM_1	-11.5	-4.62	-7.13
NHS 139	R M^3	-11.6	-5.90	-9.24
NHS 141	L PM_2	-11.4	-4.25	-6.53

[1] Highlighted samples are from first molars.

Figure 6.17 compares $\delta^{18}O$ values to $\delta^{13}C_{(Carbonate)}$ values. There is a significant inverse correlation ($R^2 = 0.29$, $p < 0.0001$) between $\delta^{18}O$ and $\delta^{13}C_{(Carbonate)}$ values; as $\delta^{18}O$ decreases the $\delta^{13}C_{(Carbonate)}$ values increase.

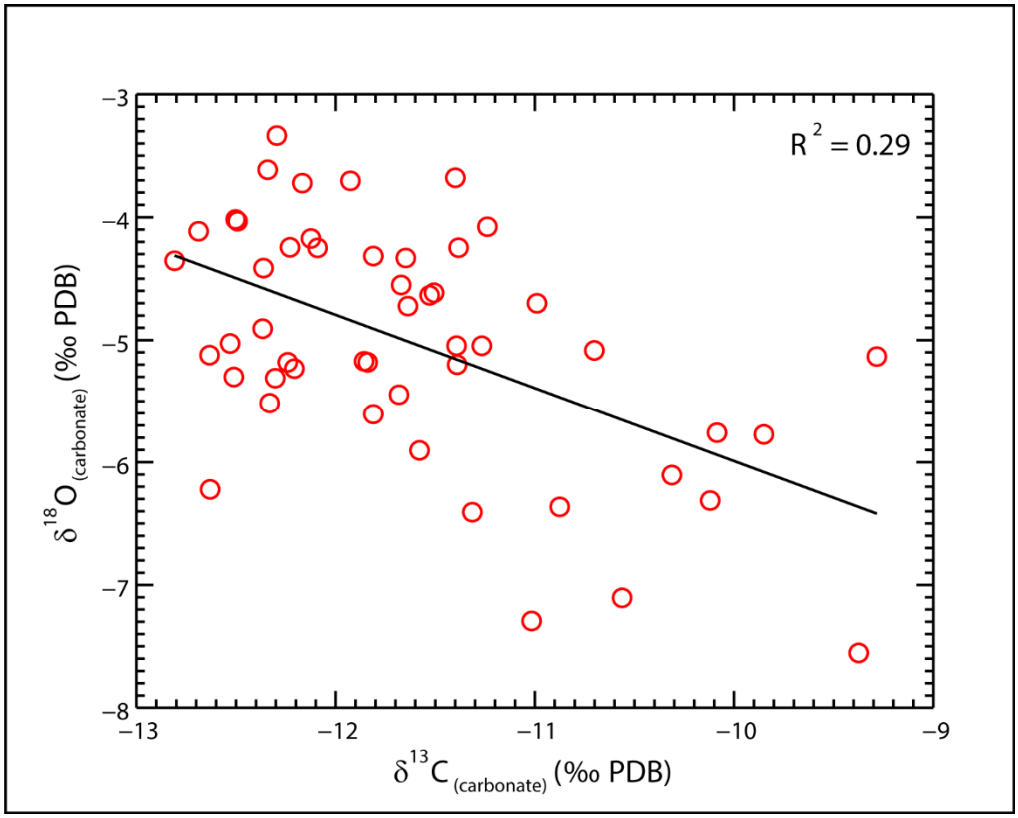

Figure 6.17: $\delta^{18}O$ and $\delta^{13}C_{(carbonate)}$ values from New Halos human enamel samples.

Figure 6.18 shows the estimated drinking water values for the New Halos population. Based on the extrapolations of Dotsika et al. (2010), the local drinking water values for the area around New Halos should be between -6.5‰ and -7.5‰. As discussed in Chapter 5, a stationary population is expected to have a normal range of variation of about 2‰ around its drinking water. Since the local estimate for drinking water values at New Halos, established by Dotiska et al. (2010), spans 1‰ the range was expanded to -5.5‰ to -8.5‰. This accounts for the biological variation of 2‰ within a stationary population as well as a 1‰ uncertainty in the drinking water value. The local drinking water range used for New Halos is indicated by the horizontal dotted lines in Figure 6.18.

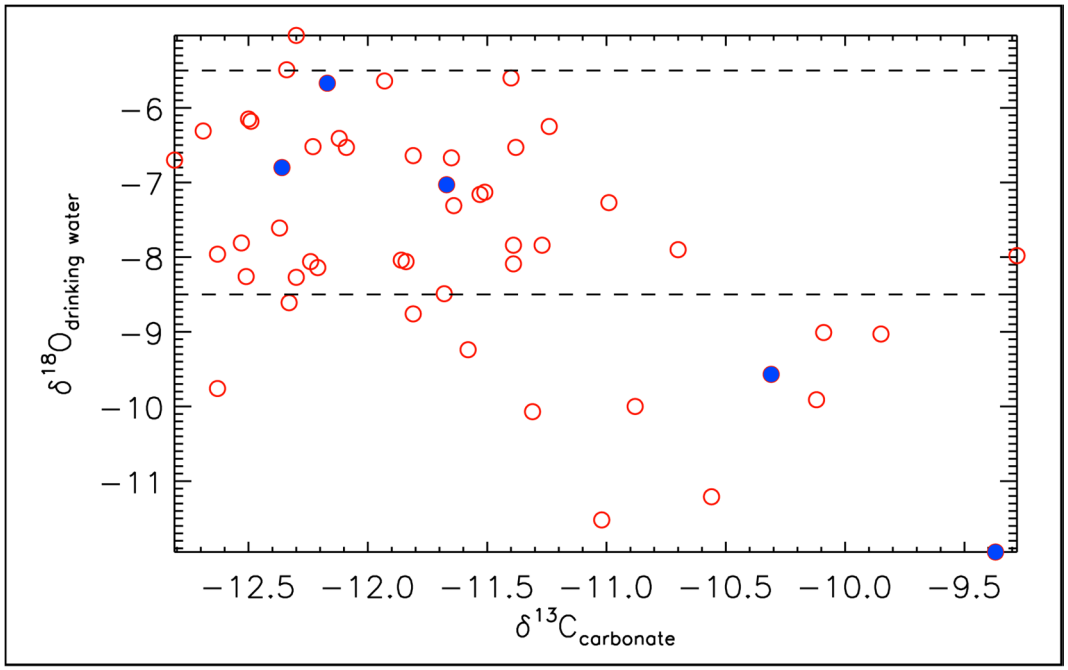

Figure 6.18: $\delta^{18}O_{(drinking\ water)}$ values compared with $\delta^{13}C_{(carbonate)}$ values. Drinking water values calculated using Chenery et al. (2012). Solid blue circles indicate samples from first molars. The dashed lines indicate the local drinking water range for New Halos.

Figure 6.18 illustrates that many individuals (n = 15) fall outside the estimated local drinking water range. Many of these individuals have lower $\delta^{18}O$ values than the predicted local range for New Halos. These $\delta^{18}O$ values suggest an origin in areas of higher altitudes, colder climates, or higher latitudes. Two individuals have higher $\delta^{18}O$ values, which would suggest that they grew up in a climate with higher temperatures.

There are five first molar (M1) samples (NH-2, NH-42, NH-73, NH-89, NH-102) indicated by solid blue circles in Figure 6.18. NH-73 has the lowest $\delta^{18}O$ value. NH-73 is a tooth

sample that comes from the same individual as the bone sample NH-72. This individual was identified as an outlier based on their high $\delta^{13}C_{(carbonate)}$ and their low $\delta^{13}C_{(collagen)}$ values in Figure 6.13 and Figure 6.14.

First molars are formed prior to weaning and can therefore have higher $\delta^{18}O$ values. For example, Wright and Schwarcz (1998) demonstrated that enamel formed during breastfeeding had higher $\delta^{18}O$ values (~0.6%) relative to enamel formed after weaning. Thus, the data in Figure 6.18 were also considered with the M1 sample values removed. By removing the M1 samples the potential breastfeeding-related enrichment of the $\delta^{18}O$ values does not need to be considered. When the five M1 samples are removed 32 samples fall within the estimated local range of -5.5‰ to -8.5‰, two individuals show higher $\delta^{18}O$ values, and 11 individuals show lower $\delta^{18}O$ values. The relevance of these data will be discussed in the following chapter.

6.4 Strontium Isotope Analysis

A second method for determining local and non-local individuals within the New Halos population involved the use of strontium isotopes. Strontium isotopes data were collected from tooth enamel samples. Table 6.7 presents the strontium isotope data for all analyzed human (n = 36) and faunal (n = 1) samples. Six faunal samples were submitted for analysis, however due to time restrictions and laboratory equipment issues data from only one faunal sample was returned. The New Halos human strontium samples have a range of 0.70757 to 0.71190, with a mean value of 0.70913. This data is presented in Figure 6.19.

Table 6.7: New Halos Human and Faunal Strontium data (NH = human; NHB = animal).

Sample ID	Sr (ppm)	87Sr/86Sr	2SE
NH-2	37.6	0.70886	0.00008
NH-4	32.3	0.70881	0.00004
NH-12	101.1	0.70892	0.00002
NH-15	68.5	0.70902	0.00004
NH-20	116.0	0.70980	0.00007
NH-22	103.1	0.71028	0.00004
NH-23	74.7	0.70908	0.00004
NH-29	72.3	0.70893	0.00002
NH-31	52.8	0.70910	0.00002
NH-33	67.0	0.70847	0.00002
NH-35	70.8	0.70881	0.00002

NH-37	62.1	0.70895	0.00002
NH-38	60.6	0.70893	0.00002
NH-42	63.2	0.70882	0.00004
NH-44	98.2	0.70891	0.00006
NH-46	54.9	0.70994	0.00002
NH-51	82.1	0.70818	0.00002
NH-54	47.0	0.70908	0.00008
NH-56	133.3	0.70951	0.00005
NH-63	64.7	0.70904	0.00002
NH-65	67.5	0.70902	0.00003
NH-66	40.1	0.70895	0.00002
NH-70	91.7	0.70893	0.00003
NH-71	48.5	0.70822	0.00002
NH-77	215.4	0.70757	0.00003
NH-84	70.5	0.70982	0.00009
NH-87	77.6	0.70893	0.00002
NH-93	150.7	0.70965	0.00004
NH-95	57.9	0.71172	0.00005
NH-102	67.6	0.70900	0.00005
NH-104	90.1	0.70863	0.00004
NH-121	74.8	0.71190	0.00008
NH-123	95.0	0.70875	0.00009
NH-131	82.1	0.70873	0.00003
NH-135	62.3	0.70886	0.00002
NH-139	54.9	0.70858	0.00004
NHB-15	100.6	0.71123	0.00002
Human Mean	**78.0**	**0.70913**	**0.00004**
Standard Deviation	**34.5**	**0.00083**	

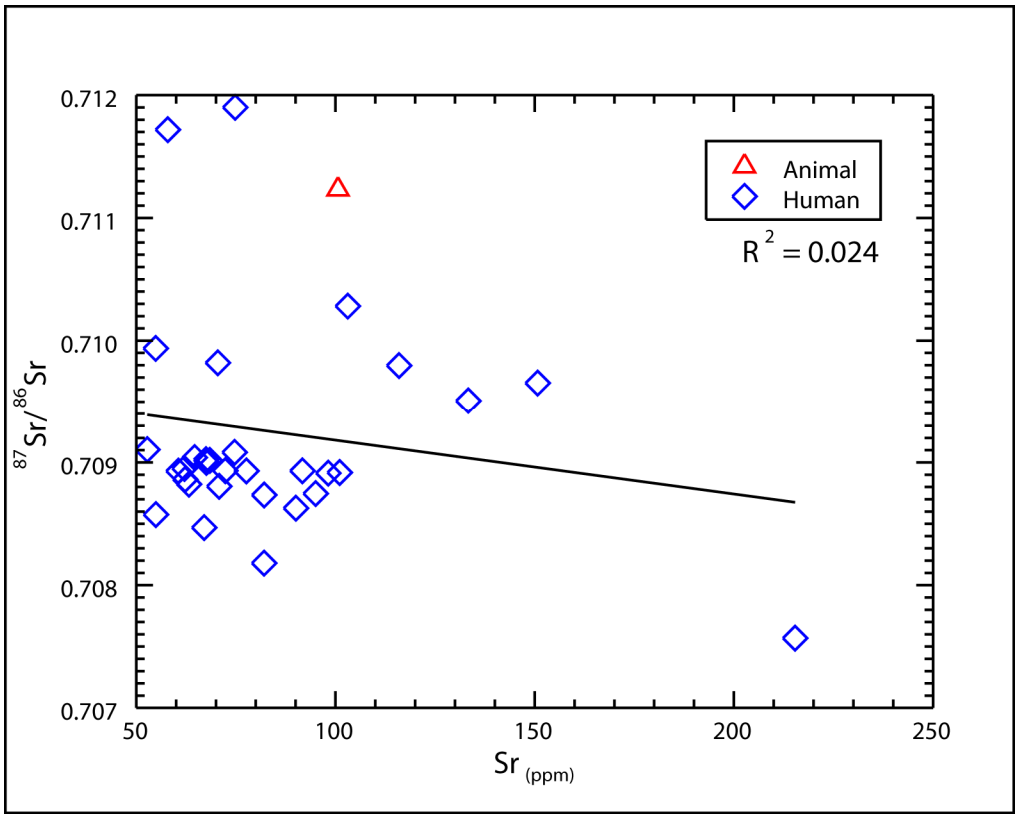

Figure 6.19: Human and Faunal $^{87}Sr/^{86}Sr$ values compared to strontium content.

As discussed in Chapter 5.3.1, there are various methods used to define a local strontium signature. Using archaeological faunal samples as a way to create a baseline for local $^{87}Sr/^{86}Sr$ signatures is one method that has been successful in past studies. Due to time constraints data from many of the faunal samples submitted for analysis were not yet available. However, in future publications the other faunal $^{87}Sr/^{86}Sr$ results will be considered and discussed. With only one faunal value it is not possible to determine a local range and learn very much from the New Halos population using this method. Therefore, two other methods are presented below and will be discussed further in Chapter 7 to compare and contrast their results.

As discussed in detail in Chapter 5, the first method used in this study calculated a local range for this population (0.70748-0.71079) by using +/- 2 standard deviations from the sample mean. This is a maximally inclusive range that is arbitrarily determined by using $^{87}Sr/^{86}Sr$ values from the entire sample. It is also based on the assumption that a population will be comprised of mostly local individuals, which is not necessarily the case for the population of New Halos. By definition 97.5% of the population will fall

within this range and therefore many individuals will be improperly identified as local (Price et al., 2004). Figure 6.20 displays this 'local range' defined by the dotted black lines.

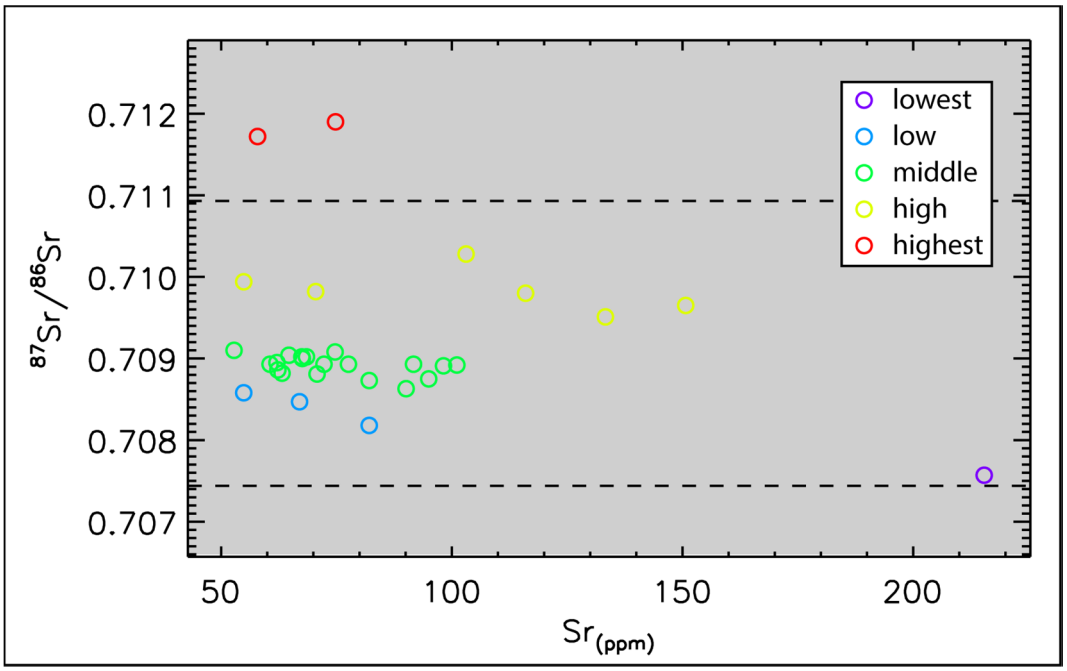

Figure 6.20: New Halos local strontium range with human $^{87}Sr/^{86}Sr$ values and strontium content (ppm).

Using +/- 2 standard deviations to calculate a local range, only two individuals are considered non-local. NH-95 and NH-121 are both above the upper limit of this local range. It was not possible to assign age or sex to sample NH-95 but NH-121 is an adult male. This wide local range determined by +/-2 standard deviations does not account for the large internal variation within this sample and produces a result that suggests that the majority of the New Halos population is local.

The method above resulted in a very wide local range. The mean standard deviation for the New Halos population is 0.00083, which is unreasonably large if it is to be used to create a local range and account for all the internal variation within the population. Bentley (2004) took enamel samples from 17 children from Thailand and determined that one standard deviation from the mean for that population was 0.00006. This sample population had very low internal variance. A sedentary human population from Grasshopper Pueblo, Arizona had a standard deviation of 0.0005 (Ezzo et al., 1997). In this same study the small local mammals had a similarly small standard deviation of

0.00031. According to Bentley (2006) large animals like elephants have a large $^{87}Sr/^{86}Sr$ standard deviation. Bone samples from six elephants from South Africa had a standard deviation of 0.00130 and 21 elephants from Kenya had a standard deviation of 0.00079. This is explained because elephants have a wide and geologically diverse range that would incorporate a variety of dietary $^{87}Sr/^{86}Sr$ values into their skeletal tissues. A skeletal population of 82 human samples from Central Europe were investigated and 51 individuals were identified as non-local (Price et al., 2004). One standard deviation from the mean for this population is 0.00129. This value is similar to that of elephants from South Africa.

Human populations with large standard deviations from the mean could indicate that the population moved within a large home range similar to that of elephants or other migratory animals. On the other hand it could also suggest a mixture of local and non-local people, as the study by Price and colleagues (2004) indicated. It is likely that the variation seen in the New Halos sample can be accounted for by a high number of non-local individuals within this population.

If we reject the arbitrary definition of 'local' based on sample standard deviation from the first method presented above and instead consider a second method that looks at the internal variation of the New Halos sample we can see that the New Halos sample can be divided into five groups. The lowest group (n=1) has a value of 0.70757. The low group (n=3) has a range between 0.70818 and 0.70858. The middle group (n=19) spans between 0.70863 and 0.70910. A high group (n=6) has a range of 0.70951-0.71028 and the highest group (n=2) has values from 0.71172 to 0.71190. The single animal value in this strontium analysis is a first molar that belongs to a sheep/goat and has a value of 0.71123. This places it between the high and highest groups.

Figure 5.2, p.100, is a geological map that shows the area around New Halos in Thessaly, Greece. New Halos is situated in the Pelagonian Zone and borders the Sub-Pelagonian Zone. Nafplioti (2011) determined that the Pelagonian Zone has a biologically available $^{87}Sr/^{86}Sr$ range of 0.70869 to 0.70927 while the Sub-Pelagonian Zone has a $^{87}Sr/^{86}Sr$ range of 0.70808 to 0.70869. Using the geological values from the Pelagonian and Sub-Pelagonian zones as endpoints, because the geological substrate will contribute to the biologically available strontium in the region, an estimated local $^{87}Sr/^{86}Sr$ range for the

New Halos area should fall between 0.70808 and 0.70927. The upper limit of this local range is similar to the $^{87}Sr/^{86}Sr$ value of 0.7092 for modern seawater.

Bentley (2006) indicated that the local strontium values of coastal areas are often influenced by sea spray and rain water that is derived from evaporated sea water. Coastal $^{87}Sr/^{86}Sr$ values of rainwater are similar to seawater values. The $^{87}Sr/^{86}Sr$ values of a region further inland are influenced by the incorporation of terrestrial $^{87}Sr/^{86}Sr$ sources, which will alter the original maritime signature. Strontium values will change the further inland a site is and with the different regional geological material (Veizer, 1989). There are many examples in the archaeological literature where coastal populations have $^{87}Sr/^{86}Sr$ values that approach values of seawater. Individuals from a Medieval Norwegian population who were considered to be fishermen had $^{87}Sr/^{86}Sr$ values similar to seawater strontium levels (Åberg et al., 1998). Additionally, a study that was done on the southwestern Cape of South Africa looked at $^{87}Sr/^{86}Sr$ values from both faunal and human skeletal material. The animals consuming a marine diet and terrestrial animals living on the coast had similar values to the seawater $^{87}Sr/^{86}Sr$ ratios. Similarly, the human samples from the coast had $^{87}Sr/^{86}Sr$ values approaching seawater strontium values (Sealy et al., 1991).

It can be seen that individuals from the middle group (n=19) have strontium values closest to modern seawater values. This group of individuals thus has $^{87}Sr/^{86}Sr$ values close to what we expect for soils and food resources in the immediate area, and can thus be argued to have grown up in the vicinity of New Halos. The four remaining groups represent 12 individuals above and below the modern seawater (coastal) value and the estimated geological range. It can be suggested that these 12 individuals likely grew up in other areas based on their different strontium values. The strontium values will be interpreted further in the following chapter using the geological estimates that were discussed in Chapter 5.

6.5 Summary

This chapter began by outlining the rationale for accepting or rejecting bone collagen samples for this research based on preservation quality indicators. Following this the chapter presented the stable carbon and nitrogen isotope data from bone collagen. The data were plotted by age, sex to determine if any dietary patterns emerged based on

these variables. Enamel carbonate data were also presented and their relationship with the collagen data was discussed. The results suggest some dietary variation within the New Halos population. The following chapter will discuss the dietary implications of these results for the population of New Halos.

Oxygen and strontium isotope data were also presented, and tentative suggestions were made about local and non-local individuals within the New Halos sample. Local ranges for both isotopes were proposed and individuals who appear to have been non-local were briefly discussed. The following chapter will discuss the use of strontium, oxygen and dietary signatures to form a robust interpretation of the composition of the New Halos population. These results provide exciting information about New Halos and Hellenistic populations.

Chapter 7 Discussion

7.1 Introduction

The faunal and human isotope data from New Halos presented in Chapter 6 will be discussed here. The discussion will include data exclusively from samples that passed the quality tests outlined in Chapter 5.6, Table 5.1, p.88. An archaeological analysis of domestic economy was previously conducted on the material from six excavated houses at New Halos; this included zooarchaeological studies on the recovered faunal material (Reinders and Prummel, 2003). The results of these projects will be considered during the interpretation of the isotopic data. Figure 7.1 is a map of the lower section of New Halos; it indicates where each excavated house was situated and where many artifacts were recovered during excavation seasons.

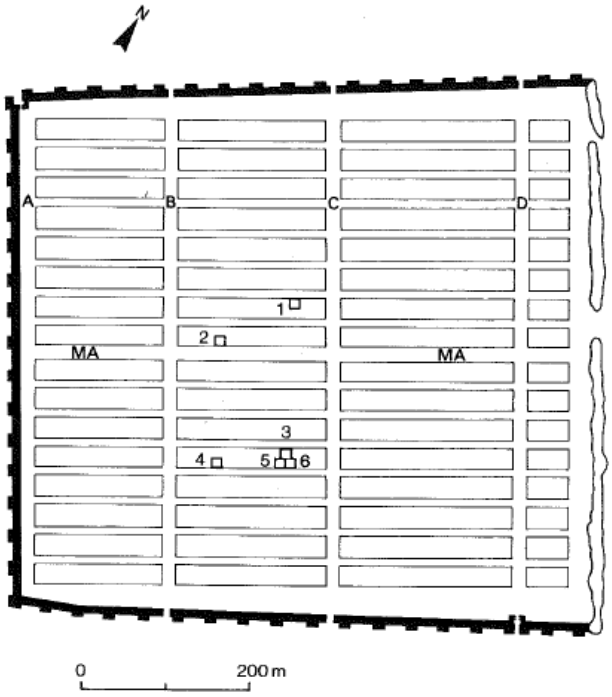

Figure 7.1 Plan of the lower section of the city of New Halos, showing the six excavated houses. 1: House of the Coroplast, 2: House of the Geometric Krater, 3: House of the Snakes, 4: House of the Amphorai, 5: House of the Ptolemaic Coins, 6: House of Agathon, MA: Main Avenue, A-D: Avenues (From Haagsma, 2010).

In addition to the archaeological material, the bone collagen data will be compared to data from other Greek and Mediterranean archaeological stable isotope studies and to reconstructed food values from various sites in the Mediterranean (Bourbou & Richards,

2007; Vika & Theodoropoulou, 2012). Understanding what foods were available near New Halos and their general isotopic ranges will provide a framework for reconstructing diet at the site.

To begin, a general interpretation of the human collagen values and the dietary trends will be presented and a suggestion for diets at New Halos will be offered. Following this, the four individuals with $\delta^{13}C$ and $\delta^{15}N$ values that fall away from the group mean, mentioned in the previous chapter, will be investigated in greater detail. Carbonate values and dietary spacing data will then be used to create an expanded interpretation of the diet at New Halos. As reviewed in prior chapters, carbonate $\delta^{13}C$ values reflect bulk diet and can be used in conjunction with collagen values to determine more subtle relationships between whole diet and dietary protein $\delta^{13}C$ than can be inferred from collagen alone.

Following the dietary analysis, population mobility will be assessed using the oxygen and strontium data. In Chapter 6, oxygen isotope values from the people of New Halos were converted into estimated drinking water values (see Figure 6.18, p.138) and those values were compared to the estimated regional drinking water values around New Halos. As well, individual strontium values were compared to local and regional strontium values to identify potential non-locally born individuals. A wider contextual comparison of the oxygen and strontium data will be done in this chapter in order to understand whether these two sets of data agree, followed by further discussion of the local and non-local individuals.

Lastly, the dietary information will be presented in terms of local and non-local individuals based on the results from the strontium and oxygen analysis to see if there are any apparent differences in diet between local and non-local individuals.

7.2 New Halos Human $\delta^{13}C$ and $\delta^{15}N$ Values Compared to New Halos Faunal $\delta^{13}C$ and $\delta^{15}N$ Values

Figure 6.10**,** p.129 shows the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values for the human and animal samples from New Halos. There are nine faunal samples that returned good quality collagen for analysis. The overall mean faunal value from New Halos (mean $\delta^{13}C$ = -20.8‰; mean $\delta^{15}N$ = 5.2‰) is comparable to Greek faunal samples with similar

species composition reported in some other studies and argued to have consumed a C_3 plant diet (Bourbou et al., 2011; Keenleyside et al., 2006; Vika, 2011). The small number of samples precludes much meaningful comment about inter-species differences. However, it is interesting that all four sheep/goat samples fall into the small central group circled in Figure 6.10, p.129.

There are four samples that fall on the outer margins of this faunal range (NHB-6, NHB-8, NHB-10, NHB-13). NHB-6, a sample taken from a cow, has slightly higher $\delta^{15}N$ (7.5‰) and lower $\delta^{13}C$ values (-21.6‰) than the rest of the faunal material. A total of 74 cattle bones were recovered from the excavated houses at New Halos (Prummel, 2003). Although this sample was assessed as a mature animal it is possible that it could still retain a nursing signature, explaining its relatively high $\delta^{15}N$ value compared to the two other cows sampled from the site. Another possible explanation is that manure was being used as fertilizer and as a result this animal was consuming plants with elevated $\delta^{15}N$ values. This could suggest that this animal had been traded into the area from another region with different agricultural practices and is reflecting isotopic values from that region. However these explanations for the $\delta^{15}N$ value for NHB-6 do not account for its low $\delta^{13}C$ values compared to the rest of the samples. Various studies in Greece have reported similarly low $\delta^{13}C$ values for some faunal samples (Bourbou et al., 2011; Keenleyside et al., 2006; Triantaphyllou et al., 2008). They attribute the values to variability within terrestrial C_3 herbivore diets.

NHB-13 is from a red deer; it has isotope values approaching the low range of the human collagen data ($\delta^{13}C$ = -20.5‰ and $\delta^{15}N$ = 7.3‰). With a sample size of only one it is difficult to say with certainty what a general value for red deer would be. Its value suggests that the New Halos individuals were not consuming a large amount of red deer, as that would raise their nitrogen values further above that of the red deer. Only 10 red deer bone fragments were recovered from four houses (House of the Snakes, Amphorai, Ptolemaic Coins, and Agathon) at New Halos compared to 322 bone fragments from domestic mammals found in all six houses (Prummel, 2003). This low count also suggests that red deer was not a commonly eaten resource at New Halos.

Two samples (NHB-8 and NHB-10) that represent a bird and a cow show low $\delta^{13}C$ and $\delta^{15}N$ values relative to the rest of the fauna. The lower end of the New Halos human

range falls about 1‰ and 4‰ above these two animals for $\delta^{13}C$ and $\delta^{15}N$, respectively. It is possible that the individuals at the low end of human values were consuming these types of animals with low $\delta^{13}C$ and $\delta^{15}N$ values.

Considering this is a very small sample size for faunal material it is possible that these four samples do not have odd isotopic values for the region but they are just on the edge of the overall regional signature. Perhaps with a larger faunal sample the individual values would be more evenly distributed and these four samples would not appear to be outliers.

The human collagen values suggest that most individuals at New Halos were eating a diet based on a combination of C_3 plants and terrestrial animal products. Human collagen values fall into a range of $\delta^{13}C$ = -17.9‰ to -20.3‰ and $\delta^{15}N$ = 7.3‰ to 11.1‰. The low end of these human $\delta^{13}C$ and $\delta^{15}N$ values fall a full trophic level above the lowest faunal samples and the human mean $\delta^{13}C$ and $\delta^{15}N$ values fall about a trophic level above the midpoint of the central cluster of faunal values. This supports the interpretation that terrestrial animal resources were important to the diet. The literature suggests that meat consumption was a rare occurrence in Greece during the Hellenistic Period and that it was mostly consumed during religious ceremonies (Jameson, 1988). Faunal analysis demonstrated that pig, horse, ass, cattle, goat, and sheep were eaten at New Halos (Prummel, 2003). Cattle, goat, and sheep remains are mostly from mature animals which suggests that their secondary products like milk and wool were of primary importance at New Halos (Haagsma, 2010; Prummel, 2003). Production of cheese and yogurt was a common activity in Ancient Greece and the domestic materials necessary for this process were simple and could be multi-purpose (Haagsma, 2010). Typically a large bronze pot called a *Kazania* was used for heating milk to make cheese; only small pots were found at New Halos so it has been proposed that cheese was made on a small scale in the home; it is also possible that expensive larger metal items were taken away after the destruction of the city erasing evidence of this industry at New Halos (Haagsma, 2010). These secondary animal products are the most likely cause of the high $\delta^{15}N$ values seen in this population because the archaeological record does not suggest that the population of New Halos were raising livestock for meat consumption (Haagsma, 2010).

As will be discussed further below, most of the $\delta^{13}C$ values for the New Halos population are quite low compared to other Greek populations. A possible explanation for this is that the bone collagen values from New Halos could reflect some participation from non-protein carbon coming from grain, other carbohydrates, oil, or the lipids of dairy products.

7.2.1 New Halos Human $\delta^{13}C$ and $\delta^{15}N$ Values Compared to Marine Resource Values

The faunal record at New Halos includes 504 mollusk shell and other shell fragments; using the number of identified specimens (NISP) this represent 59% of all identifiable animal remains (Prummel, 2003). This large amount makes a strong argument for the inclusion of shellfish in the diet (Reinders & Prummel, 2003). Although mollusks are well represented in the archaeological material it is important to remember that each mollusk shell represents a small amount of food compared to the amount of food represented by skeletal remains from a large mammal like a cow. Therefore it is possible that shellfish were not as important a dietary resource as their numbers may suggest (Prummel, 2003).

Only one fish vertebra was found during the excavations at New Halos so it was not possible to test for a local archaeological marine isotope signature. During the 1979 and 1993 excavations at New Halos some wet sieving was done. The sieving recovered small unidentifiable bone fragments and modern shells; the results did not reveal any new insights about faunal or cultural material at New Halos (Prummel, 2003). Poor preservation at New Halos may be responsible for the absence of small and fragile fish bones. This makes it difficult to determine if marine fish were included in the diet at New Halos; the archaeological record also did not provide material evidence (such as fishhooks) to suggest that fishing took place in the area. Interpreting the stable isotope evidence is complicated by the fact that local isotopic values for marine resources and shellfish at New Halos have not been determined. However, more general fish and shellfish isotope values can be used for comparison and as a starting point for interpreting isotopic values at New Halos. Studies of modern Mediterranean shellfish report wide $\delta^{13}C$ and $\delta^{15}N$ ranges of -20.1‰ to -12.9‰ and 6.3‰ to 10.7‰ respectively (Carlier et al., 2009; Pinnegar & Polunin, 2000). These vary by species and locale, and the

specific range at New Halos would likely have been narrower. An analysis of archaeological fish remains from Greece by Vika and Theodoropoulou (2012) reported very wide overall isotopic ranges. They present isotopic values from small marine fish from two coastal sites that might better represent resources available at New Halos. The $\delta^{13}C$ values from these two sites ranged from -12.16‰ to -7.3‰ and the $\delta^{15}N$ values had a range of 4.2‰ to 12.12‰. Considering the presence of a salt marsh near New Halos it is also relevant to note that Vika and Theodoropoulou (2012) also studied some euryhaline fish, and reported $\delta^{13}C$ values around -20‰ and $\delta^{15}N$ values as high as 12‰ for these organisms. Another study reported $\delta^{13}C$ and $\delta^{15}N$ values for modern fish from the Aegean and Adriatic Sea. Fish from this study had an average $\delta^{13}C$ value of -15.7‰ ± 2.0 and a $\delta^{15}N$ value of 9.7‰ ±3.9 (Bourbou et al., 2011). Sardines had average $\delta^{13}C$ and $\delta^{15}N$ values of -16.4‰ ± 0.4 and 6.7‰ ± 0.8 respectively; anchovies had average $\delta^{13}C$ and $\delta^{15}N$ values of -17.5‰ ± 0.8 and 6.3‰ ± 0.8 respectively (Bourbou et al., 2011). These values suggest that despite the wide range of isotopic values for marine resources published for the Mediterranean area, most marine resources available at New Halos would have had substantially higher $\delta^{13}C$ values than terrestrial domesticates; an exception is any euryhaline fish living in the nearby marshes. $\delta^{15}N$ values varied, and the low end would not have been distinguishable from terrestrial fauna.

The population at the low end of the New Halos distribution (around $\delta^{13}C$ = -20‰ and $\delta^{15}N$ = 7.5‰) does not appear to have consumed many marine resources. If marine items were a substantial part of the diet we would expect to see higher $\delta^{13}C$ and $\delta^{15}N$ values. At the high end of its distribution (around $\delta^{13}C$ = -19.5‰ and $\delta^{15}N$ = 10.5‰), $\delta^{15}N$ values are more consistent with marine resource use, especially low trophic level items. Substantial use of low trophic level marine resources would still be expected to cause higher $\delta^{13}C$ values if collagen carbon was coming largely from protein. Euryhaline fish use could raise $\delta^{15}N$ values without raising $\delta^{13}C$ values. It should be recalled, though, that what (if any) species were present in the marshes is unknown, and that there is no evidence for them in the faunal or archaeological record from the site.

There are four individuals who have $\delta^{15}N$ values similar to the rest of the population but have higher collagen $\delta^{13}C$ values (NH-45, NH-76, NH-78, NH-83). This suggests that small marine fish, shellfish, or a significant amount of C_4 grain were added to their diet. Given

that a seasonal freshwater source that could potentially have supported fish existed in the region north of New Halos, the possibility of freshwater fish was briefly considered. However, it is uncertain what fish would have been present in this small body of water and there were no fish hooks, net weights, or other artifacts associated with fishing found to support this as a common source of food (Haagsma, 2010). Therefore, freshwater fish are not considered a potential dietary resource in this reconstruction. From the faunal material and the abundance of shellfish remains, it appears that gathering mollusks was a more common task than fishing at New Halos. Millet would cause an individual's collagen $\delta^{13}C$ values to increase if it was consumed in significant amounts. However, it is important to recall that there is no evidence for millet cultivation at New Halos, though it is possible that millet was being brought in through trade networks. It is possible that both small marine fish and shellfish caused the distinctive $\delta^{13}C$ values of the four outlying individuals while keeping their $\delta^{15}N$ values similar to those of the rest of the population. The faunal record from the House of the Snakes included over 40 oyster shells that were found in the courtyard, proving that these kinds of resources were a significant dietary item for some of the individuals at New Halos and reminding us that not all households may have used them to the same degree (Prummel, 2003). We will come back to these four individuals when whole diet carbonate values are discussed in section 7.4.

Overall, the New Halos collagen values appear to reflect a diet predominantly based on C_3 plants and terrestrial C_3-fed animals and animal products. There is little evidence for C_4 plant resources (millet) in the diet for most individuals at New Halos, with the exception of some individuals with higher $\delta^{13}C$ values who may have consumed some millet. The entire population did not consume marine resources equally; at the low end of the isotopic range even small marine fish and shellfish are unlikely to have been consumed in quantity, while at the upper end of the distribution low trophic level marine resources may have been significant dietary items. There is not a distinct group of individuals consuming marine resources. Instead there is a gradual shift in dietary values throughout the population suggesting that people were consuming different quantities of marine resources, which affected individual isotopic values accordingly. In addition to this variation, four distinctive individuals appear to have consumed quite different diets including a significant marine or C_4 component.

7.2.2 Human Variation by Age and Sex

Figure 6.11 and Figure 6.12**,** p.130 show the New Halos collagen $\delta^{13}C$ and $\delta^{15}N$ values according to age and sex. As mentioned in Chapter 5.1, there are a large number of individuals who do not have an age or sex assessment because preservation did not allow an accurate estimate.

Looking at Figure 6.11, p.130 there is no obvious relationship between age categories and isotopic values. The age groups have such small sample sizes that no statistical testing was done because the results would not be reliable. Visual inspection of these groups does reveal that all six of the samples in the Old Adult (+ 50 years old) category have $\delta^{15}N$ values above the population mean. Skeletal samples taken from these individuals are as follows: four samples were taken from rib fragments, one sample from a phalanx, and one sample from a radius shaft. Therefore, five of the six bone samples represent approximately the last five years of life, while the sample from the radius shaft will represent a longer period of time because of its thicker cortical bone and slower turnover. Four of the six individuals were identified as male and the other two did not have the appropriate skeletal material for a sex determination. The higher $\delta^{15}N$ values for this group could indicate that their diet included more animal products, with less contribution from plant material. The addition of low trophic marine resources, such as small fish, to their diet could also be an explanation for the slightly higher $\delta^{15}N$ values. This is a very small sample group to make any clear conclusions about diet for older individuals in this population; however, all of their $\delta^{15}N$ values are above the average for the total sample, which is interesting and could cautiously suggest a different diet for older individuals. On the other hand they are not elevated above all samples, just the sample mean, so these values could easily be an artificial result because of the small sample size.

Figure 6.12**,** p.130 shows the New Halos human collagen values according to sex. A similar situation was encountered with this data as with the analysis of age where many individuals could not be given a sex estimation because of skeletal preservation. Table 6.4, p.131 shows the correlation values between $\delta^{13}C$ and $\delta^{15}N$ for the sex categories. There is a moderate correlation that is approaching significance for the whole population ($R^2 = 0.064$, p. = 0.048). The small female group shows a moderate but

significant correlation (R^2 = 0.449, p. = 0.03), however this sample size is very small and the reader is cautioned when interpreting these statistical values. Unequal variance t-tests were run for comparison of male and female $\delta^{13}C$ and $\delta^{15}N$ values. At the 95% confidence level neither $\delta^{13}C$ or $\delta^{15}N$ values showed any significant difference between males and females. This would indicate that the male and female samples are part of the same dietary group.

7.3 New Halos Bone Collagen Values in Comparison with Reconstructed Food Values

While interpreting stable isotope values, it is important to consider the local environment and attempt to establish regional dietary values for comparison to human values. Ecosystem $\delta^{13}C$ and $\delta^{15}N$ values can vary over time, and cultural practices can change the values in a region. Without an idea of the local isotope signature at the time in question, subtle differences in diet can go undetected. Unfortunately both the region of Thessaly and the Hellenistic time period have not been studied in the same detail as other regions and time periods. In order to interpret the local isotope signatures for New Halos we can use the faunal material sampled in this study to create part of the local dietary picture. We must also rely on data from other studies that represent other regions and time periods in Greece to fill in the gaps and complete the dietary picture.

In order to interpret the New Halos data, values from published studies in Greece were compiled to establish isotopic ranges for food resources that were available at New Halos. A theoretical diet based 100% on marine resources would have protein $\delta^{13}C$ values around -12‰ while a theoretical diet of only terrestrial animals consuming C_3 resources would have protein $\delta^{13}C$ values around -20‰ (Bourbou & Richards, 2007).

Figure 7.2 illustrates the ranges for various food resources that would have been available to the population of New Halos. The New Halos $\delta^{13}C$ and $\delta^{15}N$ human collagen values are plotted in Figure 7.2 for easy visual comparison to the food resource values. The collagen values were adjusted down by one trophic level in this figure. These adjustments allow the human collagen values to be considered in relation to the values of their food resources. For $\delta^{13}C$ that equals a -1‰ adjustment; 4‰ was subtracted for $\delta^{15}N$ values. The values for food resources were taken from Bourbou et al. (2011) who

compiled faunal data from Byzantine Greek sites. These ranges were then modified to accommodate a wider temporal range and to include marine values from the Mediterranean (Carlier et al., 2009; Garvie-Lok, 2001; Jennings et al., 1997; Vika & Theodoropoulou, 2012). All of the marine values were gathered from modern studies around the Mediterranean Sea and Greece (Garvie-Lok, 2001; Vika & Theodoropoulou, 2012). Plant values were determined using values from the literature.

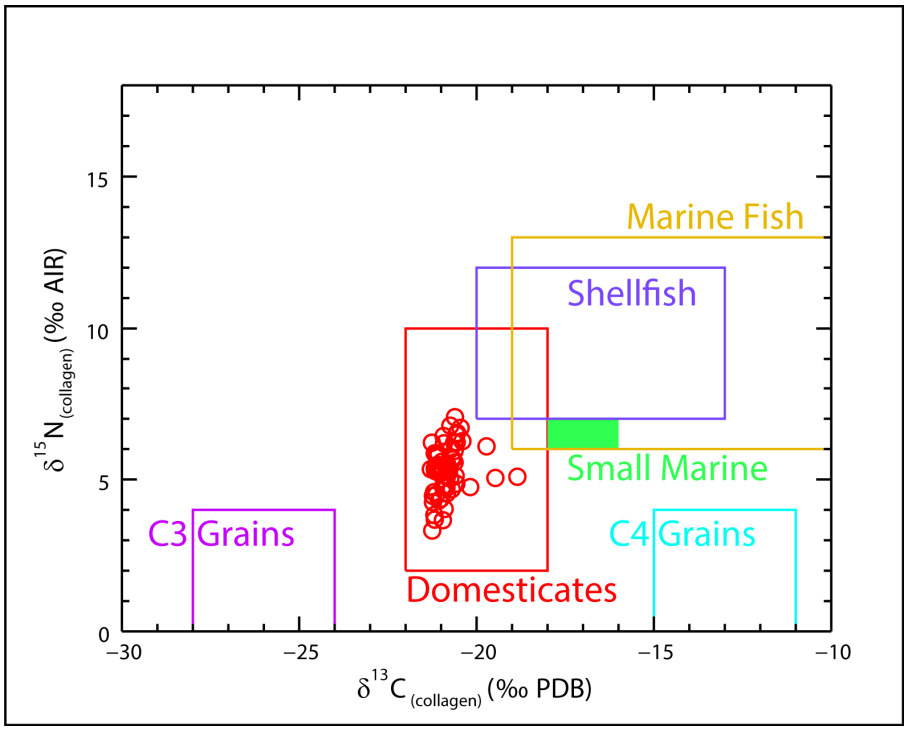

Figure 7.2: New Halos human collagen values adjusted by one trophic level ($\delta^{13}C$ = 1‰, $\delta^{15}N$ = 4‰) compared to reconstructed food resource values.

The human bone collagen values for $\delta^{13}C$ and $\delta^{15}N$ fall within the range for C_3 terrestrial animal dependence. This indicates that the diet was based primarily on staples like wheat and barley and on animals consuming these resources. All houses at New Halos had grinding equipment for grain which indicates that some grain processing was done at home and was not a specialized industry, but a domestic responsibility of each house (Haagsma, 2010). The archaeological analysis of the New Halos houses found that the population may have been dependent on the importation of grain because the land around New Halos was not conducive to agriculture and the soils were of moderate to low fertility (Haagsma, 2010). Thessaly was known for grain production, therefore New Halos was not far from grain sources that could be brought in to supplement the diet

(Haagsma, 2010). Moreover, the houses did not possess enough *pithoi* to store a full year's worth of grain, which further suggests that grain would have had to be brought into the city. The population was also likely gathering natural resources like rocket, asparagus, nettle, bulbs, and mushrooms from the area to supplement the diet (Haagsma, 2010), although given that many of these resources are high in fiber and trace nutrients but low in calories and protein, they would not likely be reflected in bone stable isotope values.

These human bone collagen $\delta^{13}C$ and $\delta^{15}N$ values are consistent with the literature that presents the diet as based on the C_3 staples of the Mediterranean Triad (wheat or barley, olive oil, and wine). In addition to the Mediterranean Triad this population relied on terrestrial meat and/or dairy products. There is a range in $\delta^{15}N$ values for this population. Individuals at the low end (converted $\delta^{15}N$ values of 3‰ to 5‰) fall a trophic level above the lowest faunal values for the site; they were likely using dairy products in addition to the staples of the Triad but are unlikely to have used any marine resources. People with converted $\delta^{15}N$ values above 5‰ could have been consuming more meat or secondary animal products, relying on animals whose $\delta^{13}C$ and $\delta^{15}N$ values fell closer to the sheep and goats in the sample, or adding some marine resources to their diet. The upper end of the general population distribution approaches the approximate range for shellfish and low trophic level marine resources, and is consistent with a diet that combined these resources with the terrestrial proteins the general population relied on.

The four individuals already mentioned (NH-45, NH-76, NH-78, NH-83) have higher $\delta^{13}C$ values than the rest of the population, which suggests a higher consumption of marine shellfish or small marine fish. This would account for the higher $\delta^{13}C$ values in the absence of higher $\delta^{15}N$ values because marine shellfish and small marine resources would not drastically increase the $\delta^{15}N$ values like a higher trophic marine animal would. C_4 resources would also affect $\delta^{13}C$ values without causing higher $\delta^{15}N$ values. Although C_4 resources are an obvious explanation for the higher $\delta^{13}C$ values of these four individuals it would be surprising because there is no clear evidence for C_4 resource use in the area. This point will be examined again when carbonate isotopes are considered.

7.3.1 Comparison of New Halos Collagen Data to Data from Other Stable Isotope Studies in Greece

Chapter 4.9 discussed many different Greek isotopic studies from various temporal and geographic areas. The sites discussed represent various dietary patterns in Greece and are useful comparisons to New Halos. Table 7.1 presents the average $\delta^{13}C$ and $\delta^{15}N$ values for the studies mentioned in Chapter 4.9. In this table it is apparent that New Halos has $\delta^{13}C$ values that are low compared to most other populations.

Table 7.1: Average $\delta^{13}C$ and $\delta^{15}N$ values from sites discussed in Chapter 4.9**.** The bolded sites are represented in Figure 7.4.

Site	**Time Period**	**Avg $\delta^{13}C$, ‰ (±1σ)**	**Avg $\delta^{15}N$, ‰ (±1σ)**	**Source**
New Halos	Hellenistic	-19.8 ± 0.42	9.3 ± 0.8	
Theopetra	Neolithic	-19.8 ± 0.86	7.4 ± 1.05	(Papathanasiou, 2003)
Tharrounia	Neolithic	-19.9 ± 0.22	8.0 ± 0.67	(Papathanasiou, 2003)
Kouveleiki	Neolithic	-19.8 ± 0.04	9.1 ± 0.98	(Papathanasiou, 2003)
Kalapodi	Bronze Age	-19.6 ± 0.3	8.5 ± 1.04	(Petroutsa & Manolis, 2010)
Apollonia	Classical	-18.5 ± 0.5	10.1 ± 0.8	(Keenleyside et al., 2006)
Thebes	Classical	-19.2 ± 0.4	10.7 ± 1.03	(Vika et al., 2009)
Thebes	Hellenistic	-19.6 ± 0.6	9.6 ± 0.7	(Vika, 2011)
Servia	Byzantine	-18.7 ± 0.3	8.7 ± 0.6	(Bourbou et al., 2011)
Stylos	Byzantine	-18.8 ± 0.7	9.4 ± 1.7	(Bourbou et al., 2011)
Kastella	Byzantine	-18.8 ± 0.3	9.1 ± 1.2	(Bourbou et al., 2011)
Soutara	Byzantine	-18.2 ± 0.3	9.5 ± 0.3	(Bourbou et al., 2011)
Eleutherna	Byzantine	-18.9 ± 0.6	8.2 ± 1.4	(Bourbou et al., 2011)
Messene	Byzantine	-19.2 ± 0.3	8.7 ± 0.6	(Bourbou et al., 2011)
Petras	Byzantine	-19.2 ± 0.3	9.5 ± 0.7	(Bourbou et al., 2011)
Nemea	Byzantine	-19.0 ± 0.3	8.7 ± 0.5	(Bourbou et al., 2011)
Helike	Byzantine	-18.7 ± 0.96	8.9 ± 0.66	(McConnan Borstad, 2013)

Figure 7.3 is a map of the Aegean area that highlights six comparative sites that are included in Figure 7.4 and are discussed below in this chapter. Figure 7.4 presents the mean collagen $\delta^{13}C$ and $\delta^{15}N$ values for seven Greek sites including New Halos. The sites in Figure 7.4 were chosen because they had similar isotopic values to New Halos. Even though most of the sites are not temporally or geographically similar to New Halos they are useful as dietary comparisons, with the understanding that social, technological, spatial, and temporal differences can greatly affect a population. However, knowledge

of the local resources at each site and the dietary conclusions reached in these studies can help interpret what the people at New Halos were consuming.

Figure 7.3: Map of the Aegean and comparative sites. 1: Apollonia, 2: Classical/Hellenistic Thebes, 3: Kalapodi, 4: Messene, 5: Petras, 6: New Halos (modified from (Einstein, 2006)).

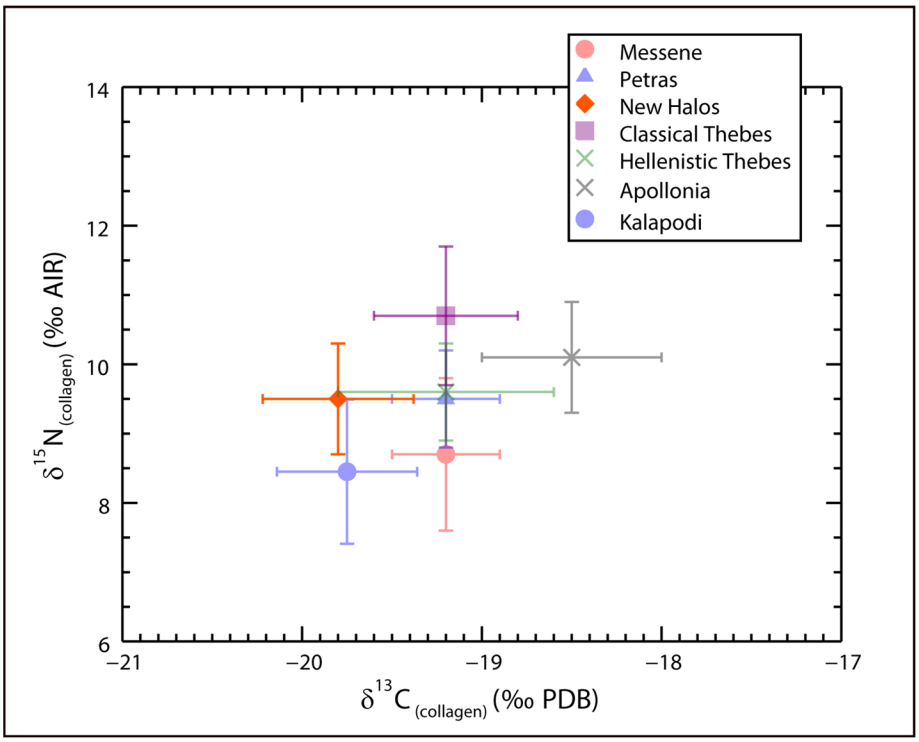

Figure 7.4: Comparison of mean $\delta^{13}C$ and $\delta^{15}N$ values (± 1sd) for New Halos and selected other Greek sites (Bourbou et al., 2011; Keenleyside et al., 2006; Petroutsa & Manolis, 2010; Vika, 2011).

Apollonia and Classical Thebes were both chosen because of their higher $\delta^{15}N$ values. Apollonia is a colonial (5th to 3rd century BC) population on the Black Sea in modern Bulgaria. It was founded by the city of Miletus in Asia Minor. The isotopic evidence indicated that the diet consumed at Apollonia resulted in slightly elevated $\delta^{13}C$ values and high $\delta^{15}N$ values. This was interpreted as a diet based on C_3 plants and C_3 terrestrial animals with a significant amount of dietary protein from marine sources (Keenleyside et al., 2006). The mean $\delta^{13}C$ and $\delta^{15}N$ values from the Apollonia population are higher than those of the New Halos population, especially for $\delta^{13}C$, suggesting that most individuals at New Halos did not consume a diet similar to that eaten at Apollonia. This supports the interpretation that high trophic level marine resources were not major contributors to the diet at New Halos.

During the Classical period (5th to 4th century BC), the city of Thebes reached the peak of its existence. This city was located in Boeotia and had a population of approximately 150,000 people (Vika, 2011). The $\delta^{13}C$ values for the site were interpreted by Vika (2011) as reflecting a diet based on C_3 plants with some animal product consumption. The

human $\delta^{15}N$ values from Classical Thebes were enriched by 4‰ above the faunal values from prehistoric Thebes. These $\delta^{15}N$ values were interpreted by Vika to suggest a C_3 plant diet that also included terrestrial animal protein, likely from meat and/or dairy products (Vika, 2011). In addition to this, Vika suggests that the nitrogen values were elevated by the consumption of freshwater fish. Freshwater fish usually have low $\delta^{13}C$ values but enriched nitrogen isotope values. Vika (2011) notes that manure used for fertilizer could be another possible explanation for the higher $\delta^{15}N$ values through the $\delta^{15}N$ elevation of staple grains, but notes that this suggestion may or may not be plausible depending on agricultural practices during the Classical period at Thebes.

The population of Classical Thebes declined to the size of a small village in Hellenistic times. This was a trend happening across mainland Greece as people moved East to new settlements looking for new opportunities (Vika, 2011). The population of Hellenistic Thebes shows $\delta^{13}C$ values that suggest a C_3 based diet. The average $\delta^{13}C$ value is slightly enriched compared to the New Halos average. The $\delta^{15}N$ values are lower than Classical Thebes, but similar to those of New Halos. It was suggested that during this time period the occupants at Hellenistic Thebes did not consume as much freshwater fish as Classical Thebes but would have still relied on C_3 plants and animal products (Vika, 2011). Vika (2011) proposes that this was a return to a 'rural' type diet where less animal products were consumed. Although geographically different, Hellenistic Thebes is one of the few contemporary comparatives to New Halos and Vika's study does suggest some interesting similarities in diet. For example, the people of Hellenistic Thebes may have consumed less aquatic resources than previous populations at Thebes, a parallel to the apparent low marine resource use of some individuals at New Halos.

Messene is a Byzantine (6^{th} to 15^{th} century AD) population from the Peloponnese whose population showed low $\delta^{15}N$ values in relation to New Halos and other Greek studies. These values have been interpreted as indicating a C_3 resource dependent diet with the addition of terrestrial animal products (Bourbou et al., 2011). The low $\delta^{15}N$ values suggest that marine resources were not a contributing factor in the diet at this site.

Petras, a coastal Byzantine population on the island of Crete, has similar $\delta^{13}C$ values to Messene but higher $\delta^{15}N$ values similar to those at New Halos. The higher nitrogen

values could be related to small amounts of marine consumption along with a diet based on C_3 plants and terrestrial animal protein (Bourbou et al., 2011).

Kalapodi and New Halos have the lowest $\delta^{13}C$ values of the seven sites considered here. The population at Kalapodi during the Late Bronze Age (3200 to 1200 BC) is argued to have consumed terrestrial animal protein or dairy products based on the $\delta^{15}N$ values. The $\delta^{13}C$ values suggest C_3 plant protein without any C_4 input (Petroutsa & Manolis, 2010). C_3 grain has a mean $\delta^{13}C$ value of -26.5‰, which would support the low dietary $\delta^{13}C$ values from Kalapodi if they were subsisting on large amounts of grain.

New Halos has the lowest mean $\delta^{13}C$ value of any of these populations. The sites used for comparison were chosen for their similarities to New Halos and do not represent all of the dietary variation reported in other Greek studies, and it is important to note that the mean $\delta^{13}C$ value for New Halos is low for Greek populations in general (see Table 7.1). Above, in Section 7.2, it was suggested that the people of New Halos were consuming a diet based on C_3 plants and terrestrial animal protein. However it was determined that all of the populations from Figure 7.4 were consuming a diet based on C_3 grains and terrestrial animal products. Therefore, it is necessary to explain why the people at New Halos have even lower $\delta^{13}C$ values than other Greek populations dependant on C_3 plants and terrestrial animal protein. These low $\delta^{13}C$ values could be the result of a diet in which overall protein consumption was lower or somewhat more calories were contributed by C_3 grains, olive oil, wine, or dairy product lipids. As mentioned in Chapter 4.3.2 collagen $\delta^{13}C$ preferentially reflects the protein sources in an individual's diet. However, some carbon from dietary carbohydrates and lipids is also included, and this can increase when protein consumption is low. If a higher than usual proportion of carbon from the carbohydrates and lipids of C_3 grains, olive oil, wine, or dairy products was being routed to bone collagen, this could account for the low $\delta^{13}C$ values at New Halos. As discussed in Chapter 4, the expected $\delta^{13}C$ value of C_3 grains is around -26.5‰. Samples of modern Greek olive oil have produced a mean $\delta^{13}C$ value of -28.7‰ (Royer et al., 1999). Wine also has low $\delta^{13}C$ values, with samples taken from France, Germany, Italy and Spain producing values ranging from -22.6‰ to -30‰ (Day et al., 1995; Giménez-Miralles et al., 1999; Rossmann et al., 1996). The lipid component of dairy products has a characteristic low $\delta^{13}C$ value that falls below dairy protein $\delta^{13}C$;

in one study, dairy lipids from animals grazing on C_3 pasture fell between -31‰ and -28‰ (Camin et al., 2008; Molkentin, 2009). If these staples did comprise a larger than usual portion of the diet and did lower the collagen $\delta^{13}C$ values as suggested, this could imply that the people of New Halos were eating less animal protein than the other comparative populations mentioned above. Carbonate values obtained from the New Halos samples also support a low overall dietary $\delta^{13}C$ value and the inclusion of non-protein carbon sources in the New Halos bone collagen. This is discussed further below in section 7.4.

The elevated $\delta^{15}N$ values at New Halos show that its inhabitants were not eating a diet similar to the land-based diet low in animal protein apparently consumed by individuals at Kalapodi, a population with similar $\delta^{13}C$ values. For some individuals this can be explained by the consumption of terrestrial animal products, but the highest human $\delta^{15}N$ values at New Halos are more than a trophic level above local fauna, suggesting another resource that further elevated their $\delta^{15}N$ values. Hellenistic Thebes and Petras have the most similar collagen $\delta^{15}N$ values to New Halos. But, as was mentioned before, the freshwater stream close to New Halos is not a likely source to explain the higher $\delta^{15}N$ values. Instead, the more likely explanation is that the people of New Halos were consuming shellfish, small marine fish, or euryhaline fish. These are all valid dietary items, however the simplest explanation would be that the abundance of shellfish remains at New Halos accurately reflects an important place in the diet at New Halos – an unusual pattern for an historical Greek population.

There are other dietary resources that could have been consumed at New Halos to account for the higher $\delta^{15}N$ values. Garum was a popular sauce used in Greek dishes that was produced by fermenting fish, often small fish such as sardines and anchovies. Based on residue analysis, a $\delta^{15}N$ value around 6.5‰ was reported for garum (Prowse et al., 2004). Garum was a well-known food item in the ancient Greek world (Curtis, 2005; Dalby, 1996; Garnsey, 1999). It was often considered a luxury item and was a sign of wealth or status (Garnsey, 1999; Keenleyside et al., 2006). Modern fish sauce produced in Southeast Asia uses methods that parallel the ones used in Greco-Roman times and produce a liquid that is protein rich that also contains many vitamins and minerals (Curtis, 2005). This fish sauce could have contributed to the $\delta^{15}N$ values at New Halos.

Another possibility is that the grains being consumed at New Halos had elevated $\delta^{15}N$ values because the fields they were grown in were fertilized with animal manure. In Chapter 3 it was mentioned that New Halos did not have suitable arable land to produce enough grain to support the population. Imported grain was the most likely source for New Halos; therefore, if the grain was not local it is unclear what methods were being used to grow the grain consumed at New Halos.

A stable isotope study examining an Early Iron Age population from Halos was very recently published (Panagiotopoulou et al., 2016). This is an excellent source of comparative data for New Halos; although it is not contemporary it is from a population that lived in the same area and would have had access to similar resources. Although the study appeared too recently to allow its data to be fully integrated into the discussion above, a brief examination and comparison of these data will be presented here.

The Early Iron Age in Greece (1100-700 BC) was a transitional phase between the end of the Mycenean Palatial phase and the beginning of the Archaic city-states (Panagiotopoulou et al., 2016). Two cemeteries, Kephalosi and Voulokaliva, were sampled for this study. The palaeodietary reconstruction considered diet by age, sex, and burial type in order to understand wealth and social status. The isotopic data from Early Iron Age Halos indicate a diet consisting of C_3 plant resources and terrestrial animal products, with no evidence of aquatic resource use (Panagiotopoulou et al., 2016). Panagiotopoulou and colleagues (2016) identify a number of individuals with higher $\delta^{13}C$ values, and suggest that these individuals were consuming some C_4 resources. They argue that individuals with $\delta^{13}C$ values of -18‰ or higher were likely regular consumers of these resources. Their values do not indicate a diet exclusively based on C_4 products, but they were consuming an amount large enough to affect their $\delta^{13}C$ values. Figure 7.5 compares the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from the New Halos population and the Early Iron Age Halos population.

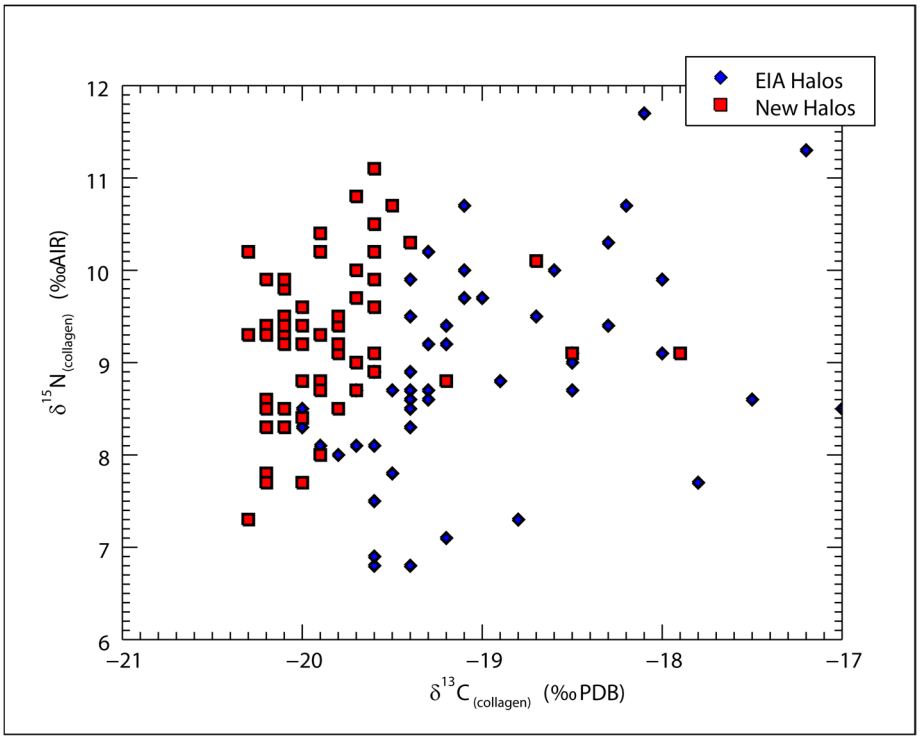

Figure 7.5: $\delta^{13}C$ and $\delta^{15}N$ bone collagen values from New Halos and Early Iron Age Halos

The range of $\delta^{15}N$ values for New Halos (7.3‰ to 11.1‰) and the Early Iron Age population (6.8‰ to 11.7‰) are very similar. The $\delta^{13}C$ values at New Halos have a range of -17.9‰ to -20.3‰, which is also similar to the range for the Early Iron Age population (-17‰ to -20‰). However, it is clear from Figure 7.5 that the distribution of the two groups within these overall ranges is quite different. Reflecting this, the mean values for these populations differ slightly.

The mean value for New Halos bone collagen $\delta^{13}C$ is -19.8‰ compared to a mean value of -19.0‰ for the Early Iron Age population. Overall, the two sets of values indicate that both populations were consuming diets dominated by C_3 plants and terrestrial animals. However the most enriched $\delta^{13}C$ values at New Halos have been interpreted to be a result of marine shellfish in the diet, whereas the highest $\delta^{13}C$ values at Iron Age Halos have been interpreted as indicating C_4 crop exploitation. As discussed below, the different interpretation for New Halos is based in part on carbonate $\delta^{13}C$ values.

The different mean values support the interpretation above that the individuals at New Halos were consuming a diet including both terrestrial animal products and marine

resources, in which more collagen carbon was derived from non-protein sources. Using the Early Iron Age Halos data as a comparison to New Halos is an excellent way to look at overall population similarities and differences. Despite the similar overall ranges, the data show that the Hellenistic population at New Halos was consuming a different diet than the Early Iron Age Halos population. This shows that although similar resources probably existed in the area in both periods the populations chose to utilize different resources, with diet at Iron Age Halos including C_4 grains and individuals at New Halos exploiting marine shellfish and depending more on non-protein sources of calories such as oil and wine.

7.3.2 New Halos Bone Collagen Data Sorted by Grave Date

As described in Chapter 5, the New Halos grave goods were used in past studies to assign a date to some of the excavated graves. A complete list of New Halos individuals and their grave dates can be found in Chapter 5, Table 5.1, p.88. Figure 7.6 presents the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values sorted by assigned grave date. The time period categories used for sorting the isotopic data were taken from the grave good analysis and modified so that overlapping date ranges were combined.

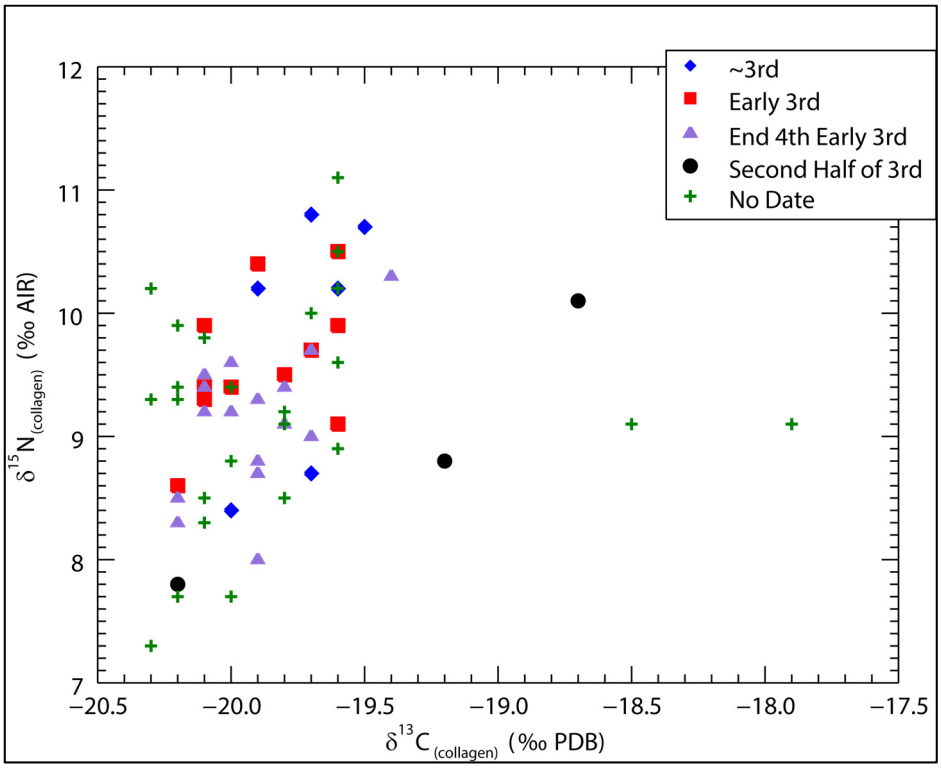

Figure 7.6: New Halos $\delta^{13}C$ and $\delta^{15}N$ bone collagen values sorted by grave date.

Correlations for the grave date groups were run to evaluate the $\delta^{13}C$ and $\delta^{15}N$ distributions when sorted by date. The 'End of the 4th, early 3rd century BC' category was the only one to produce a significant correlation between $\delta^{13}C$ and $\delta^{15}N$ ($r = 0.55$; $p < 0.05$), showing a trend in which $\delta^{13}C$ values increase along with $\delta^{15}N$ values. The low $\delta^{13}C$ and $\delta^{15}N$ values in this group point to a C_3 terrestrial diet while the higher $\delta^{13}C$ and $\delta^{15}N$ values suggest that food like marine resources were being consumed by some individuals. The '~3rd BC' and 'Early 3rd BC', categories did not produce significant correlations. Although the '~3rd BC' group is small it can be divided into two groups. The first group has two individuals with low $\delta^{13}C$ and $\delta^{15}N$ values that suggest a C_3 terrestrial diet. The second group has four individuals with high $\delta^{15}N$ values suggesting that marine resources could have been an addition to the diet. The small sample size for '~3rd BC' is most likely creating an artificial separation between dietary values during this time period. If more samples were analyzed it is likely that they would produce a similar distribution to the other time periods. The 'Early 3rd century BC' group showed a similar distribution as the 'End of the 4th, early 3rd century BC' group but did not produce a significant correlation. The 'Second half of the 3rd century BC' category had three sample therefore correlations were not calculated because of the small sample size. The correlation values can be found in Table 7.2. All of the sample groups are small, therefore the strength of the analysis should be considered with caution.

Table 7.2: Bone collagen $\delta^{13}C$ and $\delta^{15}N$ statistical data sorted by grave date

Time Period	**N**	**r-value**	**p-value**	**Average $\delta^{13}C$ (st dev)**	**Average $\delta^{15}N$ (st dev)**
End of 4th, early 3rd BC	17	0.55	< 0.05	-19.9 (0.2)	9.1 (0.6)
3rd BC	6	0.55	0.25	-19.7 (0.2)	9.8 (1.0)
Early 3rd BC	12	0.45	0.13	-19.9 (0.2)	9.6 (0.5)
Second half of 3rd BC	3	N/A	N/A	-19.4 (0.8)	8.9 (1.1)

The group from the 'Second half of the 3rd century BC' in Figure 7.6 shows the largest isotopic spread; however, there are only three individuals in this group. Two of the individuals (NH-45 and NH-76) have been identified previously as outliers; they are the two dated samples on the far right of Figure 7.6. These two individuals would have likely consumed a diet based on C_3 items with the addition of marine or shellfish resources. The $\delta^{13}C_{(carbonate)}$ value for NH-45 also indicates the presence of a substantial amount of

low-trophic marine resources in this individual's diet. Although C_4 resources could also influence the carbon and carbonate values, as mentioned before there is no evidence for C_4 grains in the area but trade could have brought these resources to the area. There is no carbonate data for NH-76 because this individual was only represented by a bone sample.

The NH-45 adult sample ($\delta^{13}C$ = -18.7‰; $\delta^{15}N$ = 10.1‰) has been identified as a non-local based on the strontium and oxygen data (See Figure 7.15). The isotope mobility data, which are discussed below in further detail, appear to suggest that this individual was originally from a higher altitude or a colder climatic area with metamorphic bedrock. An area near New Halos that fits these criteria includes the Vadar zone located to the northwest of New Halos outlined in Figure 5.1, p.97 (Nafplioti, 2011). The grave date assigned to this individual is associated with the end of New Halos' occupation and the re-occupation of the southeast gate. The different diet that this individual was consuming could be the result of different circumstances. The first possibility is that this non-local individual took steps to continue eating a diet similar to their place of origin while at New Halos causing a non-local isotopic signature. It could also be that this individual did not live at New Halos long enough for their bone content to turn over and incorporate a more typical New Halos dietary signature. Lastly, it is possible that diet at New Halos changed during this late period of occupation at the site and this individual is reflecting that change.

Unfortunately NH-76, the other collagen $\delta^{13}C$ outlier from the latest period at the site, was collected as a bone sample with no associated tooth to provide mobility information so it is unclear if this individual was local to New Halos. As an outlier with similar collagen values to NH-45 and being from the same time period, it is possible that this individual was also non-local and could be from a similar area. However this cannot be said with any certainty. The third individual in this late group (NH-75) has low $\delta^{13}C$ and $\delta^{15}N$ values compared to the total New Halos sample; the values are representative of a C_3 based diet, perhaps relying more on grains or olive oil and less on terrestrial protein.

The mean, standard deviation, and standard error of the mean for each time period were calculated. This information is illustrated in Figure 7.7. In addition, the t-value for

each pair of groups was calculated to determine if there were any statistically significant differences between the mean values for each group combination. The t-test values for $\delta^{13}C$ and $\delta^{15}N$ collagen values can be found in Table 7.3 and Table 7.4 respectively.

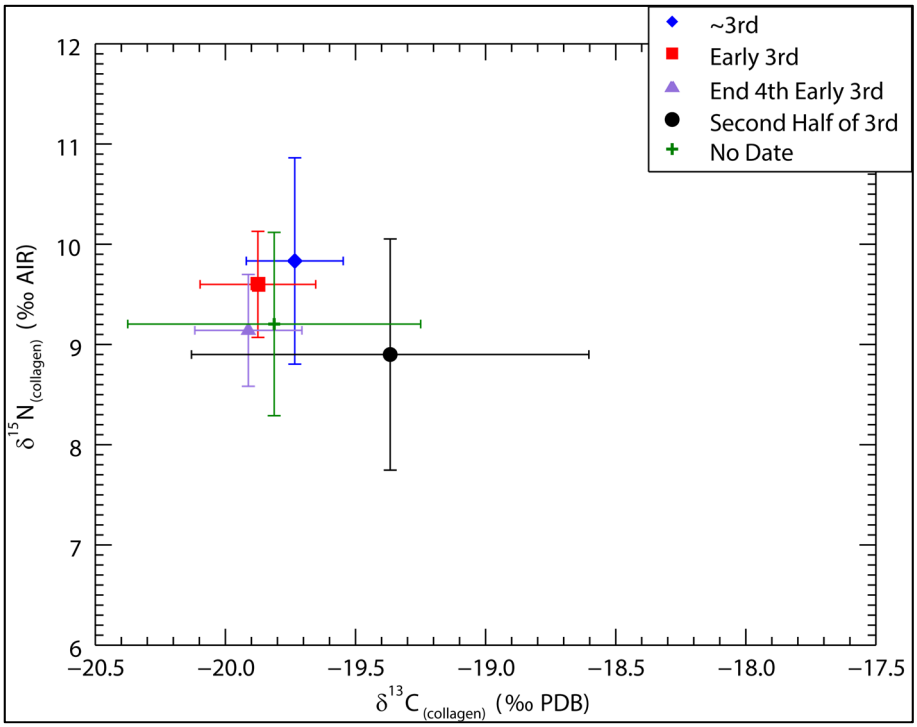

Figure 7.7: Group mean for $\delta^{13}C$ and $\delta^{15}N$ bone collagen values sorted by grave dates. (Lines indicate one st. dev.)

Figure 7.7 has replaced individual data points with group means and standard deviations in order to clarify inter-group differences. There is very little variation and there does not appear to be a relationship between $\delta^{13}C$ and $\delta^{15}N$ collagen values between time periods. The 'Second half of the 3rd century BC' group shows the biggest departure away from the other three time periods. This is because of the three individuals in this group two have been identified as outliers who had marine resources added to their diets which pulled their $\delta^{13}C$ values higher than the rest of the population.

Table 7.3: Results of T-test, $\delta^{13}C$ collagen for samples sorted by grave date.

	End 4th Early 3rd	~3rd	Early 3rd
End 4th early 3rd	----	----	----
~3rd	1.658	----	----
Early 3rd	0.416	1.575	----

T-values tested for significance at the 95% confidence level.

Table 7.4: Results of T-test, $\delta^{15}N$ collagen for samples sorted by grave date

	End 4th Early 3rd	~3rd	Early 3rd
End 4th early 3rd	----	----	----
~3rd	1.605	----	----
Early 3rd	2.098*	0.491	----

T-values tested for significance at the 95% confidence level. (*Indicates significance)

The values for these time periods do not show statistically significant differences, except for the $\delta^{15}N$ values between the 'End of the 4th early 3rd century BC' and 'Early 3rd century BC' groups (Table 7.3 and Table 7.4). Despite their significant difference, the two $\delta^{15}N$ means are so close that the validity of this statistic is debatable and there probably was not a dietary difference between the two periods. All of these test results are based on small sample sizes, weakening their validity.

7.4 Bulk Dietary Values from Enamel Carbonate

Enamel carbonate carbon is derived from all the food resources consumed by an individual. The stable carbon isotope values obtained from enamel carbonate samples represent an individual's whole diet or bulk diet. For a more complete explanation of carbonate and how it relates to bulk diet see Chapter 4. On their own, enamel carbonate data are useful in understanding what an individual was consuming. However, using enamel carbonate data in conjunction with bone collagen results can help by adding another dimension to the analysis. With enamel carbonate results it is possible to assess how the whole diet relates to the protein fraction of an individual's diet, which is called dietary spacing.

The $\Delta^{13}C_{(carb\text{-}coll)}$ value of an individual's skeleton assists in determining which macronutrients influenced the individual's diet. The $\Delta^{13}C_{(carb\text{-}coll)}$ value will change as protein, carbohydrates, and lipids with varying $\delta^{13}C$ values assume varying degrees of importance in different diets (Lee-Thorp et al., 1989). As detailed in Chapter 4, collagen carbon is primarily drawn from dietary protein, but with varying contribution from dietary lipids and carbohydrates. Because protein consumed in excess of protein synthesis needs will be used for energy, the protein in a diet will also contribute carbon atoms to both the carbonate and collagen fractions of bone (Lee-Thorp et al., 1989). When the isotopic composition of protein and energy sources in the diet are different

the collagen-carbonate spacing will also vary ($\Delta^{13}C_{(carb\text{-}coll)}$) (Ambrose & Norr, 1993). Understanding how this spacing relates to diet is helpful in reconstructing dietary patterns. For a complete discussion of dietary spacing and collagen-carbonate spacing refer to Chapter 4.3.2**.** The New Halos population has an average $\delta^{13}C_{(carbonate)}$ value of -11.62‰ with a range of -9.28‰ to -12.81‰. Using a 10‰ spacing between whole diet and enamel carbonate, these values suggest a mean whole diet value around -21.6‰, which in turn suggests that the people of New Halos were consuming a whole diet heavily influenced by C_3 plants and C_3-fed animals.

However, there is variation within the bulk dietary values that does suggest some individuals were consuming dietary items that increased their $\delta^{13}C_{(carbonate)}$ values. Dietary items most likely to do this are items that contribute significantly to bulk diet $\delta^{13}C$: high-calorie foods such as C_4 plants or large fatty marine fish. As was discussed above, the $\delta^{15}N$ values of the majority of the population do not support the inclusion of large marine fish in the diet. Although C_4 plants like millet were not commonly used during the Hellenistic period they could have been included in small amounts for some of the individuals at New Halos. Shellfish and small marine fish are another addition to the diet that might have caused $\delta^{13}C_{(carbonate)}$ values for some New Halos individuals to increase. Because shellfish are naturally low in fat and calories, individuals would have to consume a large amount of this resource in order to affect their $\delta^{13}C_{(carbonate)}$ values (Gopalakrishnan & Vijayavel, 2009). The faunal material collected from each excavated house showed that three houses had a large amount of mollusk shells. Of the number of identified faunal species in the House of the Snakes, 69% was from marine mollusks; the House of the Ptolemaic Coins had 66% of the faunal material from marine mollusks, and mollusk remains at the House of Agathon accounted for 72% of the identified material (Prummel, 2003). Prummel (2003) argues that the large quantities of marine shellfish found in the houses show that they were regularly consumed and he adds that many of the species recovered continue to be popular food today, solidifying the argument that the mollusk shells found in the houses represent the detritus from a meal.

Figure 7.8 compares the $\delta^{13}C_{(carbonate)}$ values to $\delta^{13}C_{(collagen)}$ values for the 26 individuals for whom both measures are available. The carbonate and collagen values are significantly correlated ($R^2 = 0.23$, p. = 0.012, $y = 0.86x + 5.14$). The collagen values vary with the

carbonate values, suggesting that as dietary protein $\delta^{13}C$ changes so does overall dietary $\delta^{13}C$. This would agree with the interpretation that some individuals were consuming shellfish and/or small marine fish because the $\delta^{13}C$ values for shellfish and small marine fish are higher than C_3 plant protein and terrestrial animal values.

Two individuals (NH-72, NH-88) have similar $\delta^{13}C_{(collagen)}$ values to the rest of the New Halos sample but their $\delta^{13}C_{(carbonate)}$ values are somewhat elevated. This suggests that these two individuals were consuming a C_4 resource – presumably millet – at a level sufficient to affect their bulk diet values, but not their dietary protein values, which are typical of a C_3 diet. This is a very interesting result because based on historical accounts and archaeological evidence millet was not thought to be used in the region in this era. Both of these individuals are non-local according to their $\delta^{18}O$ values, so it is possible that they came from another area where some millet was consumed. The other two (NH-45, NH-83) have both higher $\delta^{13}C_{(collagen)}$ and higher $\delta^{13}C_{(carbonate)}$ values compared to the rest of the sample. These isotope values indicate that these two individuals were consuming a food that elevated both their collagen and carbonate $\delta^{13}C$ - potentially, either millet consumed in a different dietary regime in which it contributed to both collagen and carbonate, or larger amounts of marine resources than others in the population. These two individuals fall outside of the main cluster when $\delta^{13}C$ and $\delta^{15}N$ collagen values are considered together, further reinforcing an interpretation of marine inclusion in their diets. NH-45 is classified as a non-local individual according to both the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values and NH-83 is considered a local individual by their $\delta^{18}O$ values while the $^{87}Sr/^{86}Sr$ values suggest a non-local origin.

The New Halos population values can be better understood using the method developed by Kellner and Schoeninger (2007) to reconstruct human diets using $\delta^{13}C$ values of collagen and carbonate that was outlined in Chapter 5.5.1.

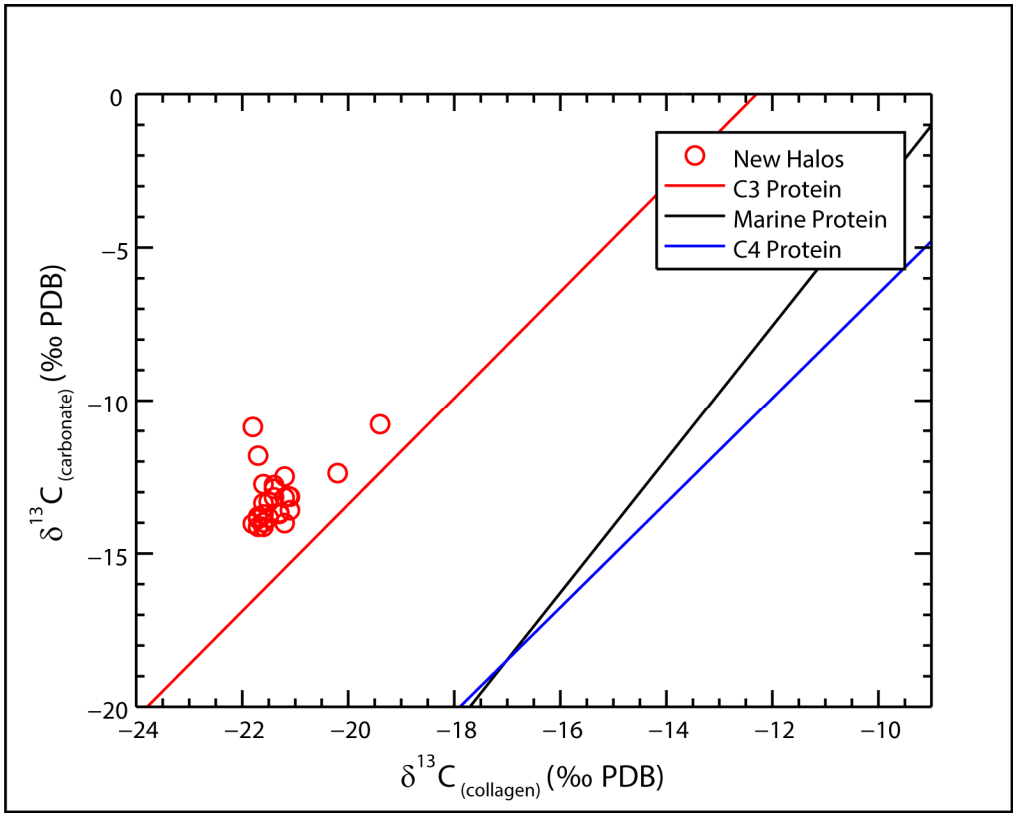

Figure 7.8: Kellner and Schoeninger model of carbonate and collagen values with the New Halos data.

According to Kellner and Schoeninger (2007), $\delta^{13}C_{(collagen)}$ values around -8‰ or between -20‰ and -22‰ can predict diets very accurately because they reflect essentially pure C_4 and C_3 diets, respectively. However, intermediate values (between -8‰ and -20‰) indicate that there is a mixture of C_3 and C_4 or marine food items involved in the diet and further methods of interpretation, including carbonate $\delta^{13}C$ analysis, are helpful in identifying the particular mixture in question. The dietary values from New Halos are plotted in Figure 7.8; as required for use by this model, they have been adjusted by -1.5‰ for today's atmospheric $\delta^{13}C$ values (Kellner & Schoeninger, 2007). Figure 7.8 supports the previous interpretation that the New Halos diet was based on C_3 protein sources. However, it also confirms that other factors were influencing the diet. The New Halos carbonate values fall uniformly above the C_3 regression line. Using the logic outlined by Kellner and Schoeninger, this could suggest an overall minor inclusion of C_4 energy in the diet affecting carbonate but not collagen values. Alternatively, it could reflect a situation in which collagen $\delta^{13}C$ was drawn down by the inclusion of a low $\delta^{13}C$ resource, shifting the position of the samples to the left. The Kellner and Schoeninger

model (2007) is most likely to hold true when dietary protein content is adequate. If the population of New Halos was not always getting enough protein, their $\delta^{13}C_{(collagen)}$ values would be pulled down because collagen carbon would be more heavily influenced by dietary carbon from carbohydrates and lipids. The documentary and historical evidence indicate that in ancient Greek diets, many of these carbohydrates and lipids would have come from dietary items such as dairy products, wine, olive oil and C_3 grains (Boardman et al., 1988; Casson, 1954; Dalby, 2003; Mee, 2011; Migeotte, 2009; Skiadas & Lascaratos, 2001). For the individuals at New Halos with low $\delta^{13}C_{(collagen)}$ and $\delta^{13}C_{(carbonate)}$ values in particular, we could suggest that some of these items were consumed in large enough amounts to pull the $\delta^{13}C_{(collagen)}$ values down (Royer et al., 1999). Environmental factors could also affect how this data is interpreted. The $\delta^{13}C$ values of the pure C_3 diets used in the feeding studies reviewed by Kellner and Schoeninger (2007) were based on foods grown in cooler climates. These values are extremely low in comparison to values reported in warmer climates like Greece (van Klinken et al., 2000). van Klinken and colleagues (2000) studied $\delta^{13}C_{(collagen)}$ values in Europe and determined that an environmental correction factor should be applied to values from warmer climates. Although we pay the most attention to the differences between C_3 and C_4 plants, plant $\delta^{13}C$ values also vary within each of these groups, and this is part of the basis for variation in the $\delta^{13}C$ signatures of humans consuming pure C_3 or C_4 diets. Overall temperature and humidity in an area can influence the $\delta^{13}C$ of plants and therefore introduce climate induced variation. van Klinken et al (2000) noted an apparent $\delta^{13}C$ variation of 2‰ to 4‰ between C_3 plants in warm and cool areas of Europe. Using a climatic correction factor could eliminate this environmental variability and allow human $\delta^{13}C$ values to be more realistically compared between different areas (van Klinken et al., 2000). This is an area for future study to determine if a correction factor could and/or should be applied to warmer climates.

The individuals with higher than average $\delta^{13}C_{(collagen)}$ and $\delta^{13}C_{(carbonate)}$ values for the New Halos population could have some marine or C_4 involvement in their diet. The archaeological faunal record at New Halos has an abundance of shellfish remains. It appears that the individuals at New Halos were putting forth an unusual effort to seek out shellfish compared to other populations living at coastal sites in Greece. Perhaps the

community was under stress and was forced to exploit every food resource available. This could support the idea that the New Halos diet was not always adequate in protein.

The $\delta^{13}C_{(carbonate)}$ and $\delta^{13}C_{(collagen)}$ values in Figure 6.13, p.132 are significantly correlated and show a trend that as collagen values increase so do carbonate values. This relationship is further reinforced when the two individuals who have high carbonate and low collagen values are removed. Also, when the $\delta^{15}N$ values are compared to the $\delta^{13}C_{(carbonate)}$ values in Figure 6.14, p.133 there is not a strong relationship until the two outliers with higher $\delta^{13}C_{(carbonate)}$ values are removed. When they are removed the trend shows that as $\delta^{15}N$ values increase so do $\delta^{13}C_{(carbonate)}$ values. The results from both figures support the idea that some individuals were consuming a larger proportion of marine resources than others in the New Halos population.

7.4.1 New Halos Collagen and Carbonate Values Sorted by Grave Date

The sample size for comparing collagen and carbonate values by grave date is small for two reasons. The first is that a bone and tooth pair was not selected for all individuals sampled because the skeletal material was not always complete. This limited the initial sample number collected for analysis. The second reason is that not all graves could be assigned a specific date because there was a lack of grave goods present. Statistical analysis was not done on the small resulting samples because the results would not return dependable results. The data for $\delta^{13}C_{(collagen)}$ and $\delta^{13}C_{(carbonate)}$ are presented in Figure 7.9 and $\delta^{13}C_{(carbonate)}$ and $\delta^{15}N$ values can be found in Figure 7.10.

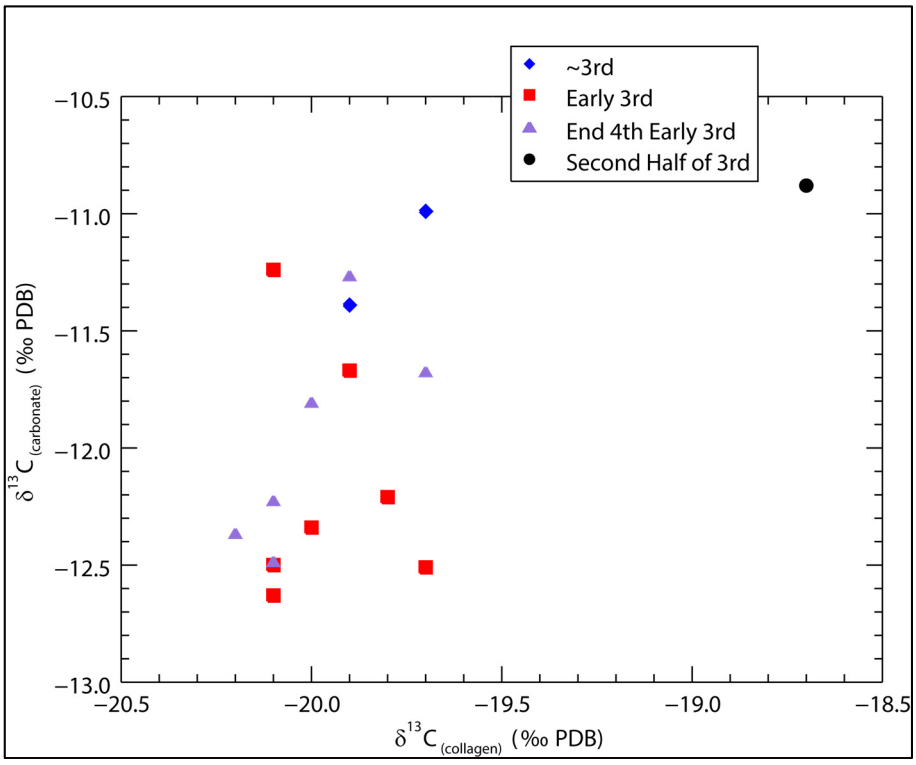

Figure 7.9: New Halos $\delta^{13}C_{(collagen)}$ vs. $\delta^{13}C_{(carbonate)}$ values sorted by grave date.

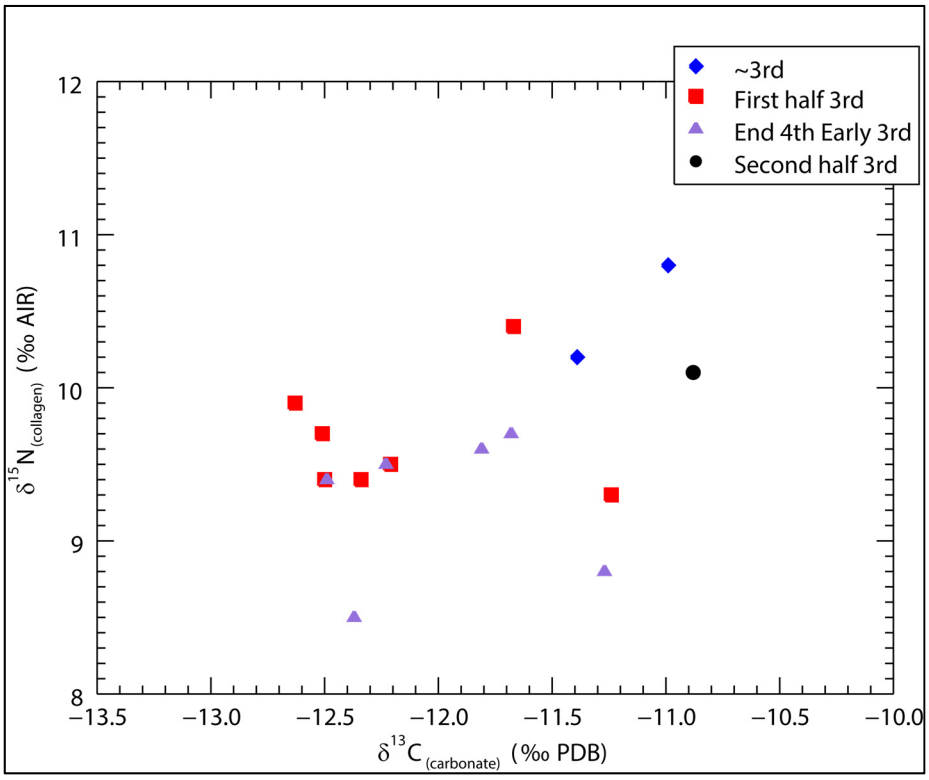

Figure 7.10: New Halos $\delta^{13}C_{(carbonate)}$ vs. $\delta^{15}N$ values sorted by grave date.

The small sample sizes in Figure 7.9 and Figure 7.10 make it difficult to reach any conclusions about changes in diet over time. Figure 7.9 has one outlying individual (NH-45) from the 'Second half of the 3rd century BC' group. Unfortunately there is only one individual in this group, so it is not possible to discuss if a diet that includes marine resources is representative of this time period. The rest of the samples do not show large separation between time periods and therefore do not suggest that diet was changing over time. In order for a more robust study, more samples would be necessary to provide a better picture of dietary change over time.

7.5 Oxygen Isotope Analysis

Oxygen isotope analysis was conducted on 50 enamel samples to evaluate population mobility by assessing whether the people interred at New Halos were potentially local to the area or came from further afield. Figure 6.17, p.137 presented data comparing enamel $\delta^{18}O$ to enamel $\delta^{13}C_{(carbonate)}$ in order to evaluate if dietary variation was linked to different climatic regions as defined by the $\delta^{18}O$ values. The correlation between these two variables is statistically significant. Lower $\delta^{18}O$ values tend to correspond with higher $\delta^{13}C_{(carbonate)}$ values. This suggests that people from higher altitudes or colder regions had slightly different diets than people from lower altitudes and warmer regions. Most of the individuals with very low $\delta^{18}O$ values (> 6‰) making them potentially non-local to the region show higher $\delta^{13}C_{(carbonate)}$ values.

In order to identify local and non-local individuals more precisely a local signature for New Halos had to be determined. Chapter 5 outlined the process used to convert $\delta^{18}O$ values to local drinking water values for each individual. Figure 6.18, p.138 presents these drinking water values along with the local New Halos range. The local range used for New Halos (-5.5‰ to -8.5‰) is based on the local drinking water range at New Halos of -6.5‰ to -7.5‰ (Dotsika et al., 2010), expanded on either side by 1‰ to account for the 2‰ variation normally found in a stationary population. The data from the $\delta^{18}O$ samples have a 6.5‰ spread, a value much greater than the 2‰ variation from a stationary population, indicating that the population is not composed wholly of local individuals.

This analysis identified 70% (n=35) of the analyzed samples as apparently local to New Halos, which means that 30% of the samples appear to be from non-locally born individuals. Chapter 5, Figure 5.3, p.104 represents the regional distribution of $\delta^{18}O$ values for precipitation in Greece.

New Halos is in an area with a reconstructed local drinking water $\delta^{18}O$ range of -6.5‰ to -7.5‰ indicated by the diamond on Figure 5.3. As mentioned above, the local range was expanded to -5.5‰ to -8.5‰ was expanded to reflect the fact that converted human $\delta^{18}O$ values in any one area tend to vary around 2‰ around their water source. 30% of the individuals appear to be non-local based on their $\delta^{18}O$ values. Four percent, or two individuals, have higher reconstructed drinking water $\delta^{18}O$ values than the estimated New Halos drinking water values. These individuals could have come from warmer areas, perhaps to the south of New Halos. There are 13 individuals (26%) who have reconstructed drinking water $\delta^{18}O$ values below the estimated New Halos drinking water range. These individuals most likely came from cooler areas or from higher altitudes.

The oxygen results from New Halos suggest that its population was a mixture of immediately local-born individuals, individuals who grew up in the surrounding area, and other individuals who were possibly not from Thessaly. The individuals with lower $\delta^{18}O$ values could reasonably have come from areas further inland or upland in the surrounding area. Those with the lowest $\delta^{18}O$ values could have come from the Othris mountain chain to the west of New Halos. Mount Pelion, located to the northeast of New Halos close to the modern city of Volos, is another possible point of origin for people with lower $\delta^{18}O$ values. As was discussed in chapters 2 and 3 there is very little written about small settlements in the Hellenistic period and how new cities were populated. However the city of Sikyon in the Peloponnese has a similar history to New Halos. A Classical iteration of the city was destroyed and a new Hellenistic city was built further inland on higher ground; the population was forced to move to the new location (Lolos, 2011). Stable $\delta^{18}O$ analysis has not been done on the population of Sikyon, so our understanding of the population's composition is only known from written and archaeological work. The establishment of New Halos follows a similar story to Sikyon because the Classical site of Halos was also destroyed and a new settlement was placed slightly further inland. What is interesting is that during the house excavations at New

Halos it was noted that there were cultural conventions that influenced how the domestic space was laid out and that based on the similar house plans and possible kinship ties to neighborhoods it was suggested that there was some social homogeneity within the population at New Halos (Haagsma, 2010). Even though the $\delta^{18}O$ values suggest some individuals were not originally local to New Halos, many do reflect values from within the region. The archaeological evidence paired with the oxygen isotope results suggests that there was some regional cohesion.

To refine the analysis of local and non-local individuals a little further, five samples from first molars (M1) were removed from the data set. The M1 samples were removed because, as mentioned in Chapter 4, M1s begin to form prior to weaning and can therefore retain an enriched $\delta^{18}O$ signature from breastfeeding depending on the age that weaning commenced. This could potentially give the M1 samples enriched $\delta^{18}O$ values that would change how they were interpreted. The removal of the M1 values did not affect the data. Of the five samples removed, two individuals had an apparently local signature, one had a higher value and two had lower values. These five samples can be seen in Figure 6.18, p.138 represented by the solid blue circles.

The New Halos population appears to have a large proportion of non-local individuals, many of whom apparently came from inland and from higher altitudes. This agrees with the regional topography of Thessaly, with the Orthris Mountains to the south and west of New Halos. It also agrees with the hypothesis that New Halos was quickly established and indicates that many of the people who make up the New Halos population grew up outside the immediate locality. In addition it offers an interesting hint that some people came from further away, as it appears that two individuals with higher $\delta^{18}O$ values originated from further to the south.

7.5.1 Oxygen Isotope Data Sorted by Grave Date

The grave date information that was assigned to each individual using grave good analysis was used with the oxygen isotope data and is presented below in Figure 7.11. The two dotted lines in Figure 7.11 indicate the local New Halos range for $\delta^{18}O_{(drinking\ water)}$ values.

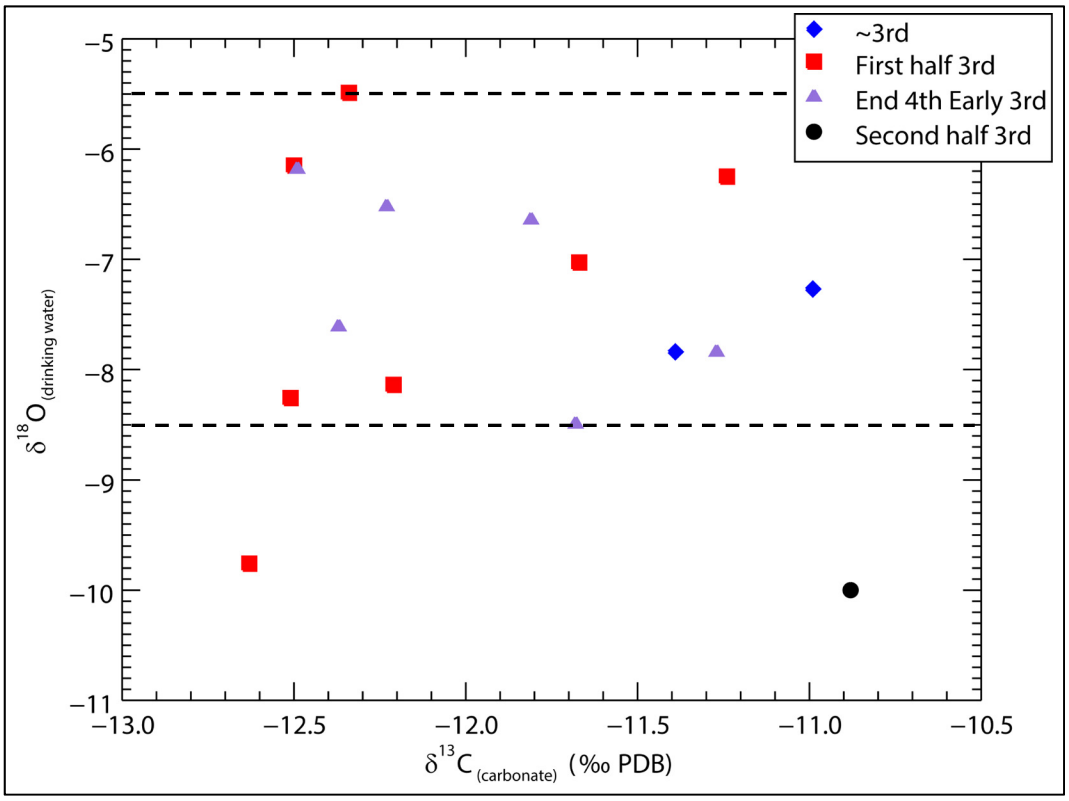

Figure 7.11 $\delta^{18}O_{(drinking\ water)}$ and $\delta^{13}C_{(carbonate)}$ values sorted by grave date. The two dotted lines represent the local drinking water range at New Halos.

The local $\delta^{18}O_{(drinking\ water)}$ range for New Halos is -5.5‰ to - 8.5‰. The entire "End of 4th early 3rd century BC' group in Figure 7.11 are local according to the drinking water range. This means that these individuals, buried in the earliest time period, were local to New Halos or from a climate similar to the New Halos area. This could possibly suggest that these individuals were part of the original founding population. The people interred at New Halos in the later time periods are from a range of different climates; some are local and some are not. There is only one individual from the 'Second half of the 3rd century BC' group; this individual has a non-local $\delta^{18}O$ value. With only one data point for this group it is impossible to say more about population composition during the final phases of the city of New Halos or the group that occupied the Southeast gate farmstead. Unfortunately sample sizes are small; although this is a good starting point for a study of population composition over time, more data are required to make better interpretations about the population of New Halos.

7.6 Strontium Analysis

Archaeological studies that include strontium isotope analysis have not been done extensively in Greece. Strontium isotope results are used to determine mobility patterns for populations and can identify possible locations of origin for individuals. They can also compliment archaeological work previously done at a site. The excavations at New Halos uncovered a small travellers coin hoard inside the city's southern wall (Haagsma, 2010; Reinders, 2003). As Reinders (2003) explains, similar coin hoards found at other sites in Thessaly often have more than half of their coins representing Hellenistic Kings. The coin hoard at New Halos only had two coins from Hellenistic Kings and the rest were from cities like Ephesos, Chalkis, Histiaia, and cities in Boetia (Reinders, 2003). The New Halos coin hoard has been dated to around the 4th century BC (Reinders, 2003). Demetrius Poliorcetes, the proposed founder of New Halos, visited many of the cities, represented by coins in the hoard, as he made his way north to meet Cassander in the Crocian plain. The coins are used as support for the argument that Demetrias was the founder of New Halos (See Chapter 3.1 for a discussion about the settling of New Halos). Additionally, the coins could also suggest that these cities had contact or a relationship with the people at New Halos.

There has not been a complete or specific regional strontium map created for the area of Thessaly where New Halos is located. Nafplioti (2011) published general strontium isotope values for broad geological areas of Greece based on animal enamel and snail shell values from sites on Euboea, in Attica, Corinthia, the Argolid, and on the island of Crete. Values from Nafplioti's study will be used to interpret the New Halos data with the understanding that they are not site specific. Additionally a discussion of local geological formations and their estimated strontium values will be used as a starting point for assessing the human strontium values at New Halos.

The strontium analysis was done on a subset of the enamel samples mentioned in the oxygen isotope section above. Thirty-six human enamel samples and one animal enamel sample are included in this data set. Figure 6.20, p.142 presented the data comparing strontium content in ppm to $^{87}Sr/^{86}Sr$ values. Creating a local baseline $^{87}Sr/^{86}Sr$ value based on biologically available strontium is a useful method for understanding human strontium signatures. As mentioned in Chapter 4.5 many factors affect the biologically

available strontium in an area, which is why using local archaeological faunal material is an effective strategy. Animals usually consume local foods and, therefore, their tissues will reflect an average $^{87}Sr/^{86}Sr$ value for the area that reflects the foods they are eating. Five animal samples were prepared for analysis but only a single animal value could be included in this study (due to delays in the analysis) to establish a local baseline signature for the region.

NHB-15 is an M1 sample from a sheep or goat with a $^{87}Sr/^{86}Sr$ value of 0.71123. This high value relative to the New Halos population, places this sample at the top range of the data set. Without a larger faunal sample set for comparison it cannot be stated with absolute confidence whether this animal reflects a local or non-local signature, however it is almost certainly not local. The underlying geological substrate at New Halos is dominated by recent alluvial deposits washed down from local bedrocks, most of which are limestone that should have a lower strontium value than this animal (Anders et al., 2006; Bentley, 2006). Also New Halos is a coastal site, so it is expected to have a strontium value closer to that of seawater. Very old rocks (>100 million years) such as old granites have higher strontium values similar to the NHB-15 faunal value (Bentley, 2006). It is possible that this animal was traded or brought in from somewhere with a different strontium signature. A local strontium range was not established based on this single animal value because it does not appear local and because one sample cannot be representative of an area. Future work will include a more robust animal sample to better develop a local signature. Since a faunal baseline strontium value could not be created for the New Halos area a different method has been employed to interpret the strontium data. This method uses the underlying bedrock strontium values to establish a local strontium signature for New Halos.

A visual inspection of the data identifies five groups of individuals based on their strontium values. These groups were outlined in Chapter 6. New Halos is situated so close to the coast that it is reasonable to predict that local individuals would have similar values to seawater (Bentley, 2006). The middle group with the most individuals (n=19) is closest to the modern seawater $^{87}Sr/^{86}Sr$ value of 0.7092 and they are considered local to New Halos. See Chapter 6.4 for a discussion on how coastal values are influenced by the sea.

New Halos is located in the Pelagonian zone as defined by Nafplioti (2011). Nafplioti (2011) measured two sites from this zone: Kitsos Cave in Attica had mean animal enamel $^{87}Sr/^{86}Sr$ values of 0.708940 and Manika on Euboea had mean animal enamel $^{87}Sr/^{86}Sr$ values of 0.708971. These two sites have $^{87}Sr/^{86}Sr$ values that fall within the 'middle' group's range at New Halos (0.70863-0.70910). Thus, the values published by Nafplioti (2011) also support the designation of the "middle group" at New Halos as locally born.

The sub-Pelagonian zone is west of and runs parallel to the Pelagonian zone and has a $^{87}Sr/^{86}Sr$ range of 0.70808 to 0.70869 (Nafplioti, 2011). The New Halos individuals from the low group (n=3) have a $^{87}Sr/^{86}Sr$ range of 0.70818 to 0.70858. These values suggest that this group of individuals may have grown up somewhere in the Sub-Pelagonian zone, perhaps in areas near the Othris Mountains.

There are six individuals in the high group, with a $^{87}Sr/^{86}Sr$ range of 0.70951 to 0.71028, and two samples (NH-95 and NH-121) in the highest group ($^{87}Sr/^{86}Sr > 0.71172$). The high and highest groups appear to be non-locally born based on their $^{87}Sr/^{86}Sr$ values. These higher strontium values suggest that these individuals grew up in areas with metamorphic or igneous bedrocks. Circum-Mediterranean granites generally show $^{87}Sr/^{86}Sr$ values above 0.7100; the Vadar geological zone, situated to the north west of New Halos, also has a $^{87}Sr/^{86}Sr$ range between 0.70926-0.71187 (Nafplioti, 2011). Given its relative proximity to New Halos, the Vadar zone is a possible original location for people in these groups (Bentley, 2006; Juteau et al., 1986; Nafplioti, 2011).

The single individual in the lowest group has a $^{87}Sr/^{86}Sr$ value of 0.70757. This value is below the lowest average strontium value of 0.70808 from the Pindos region (Central Argolid) reported by Napflioti (2011). Nafplioti (2011) did not publish a biological strontium value this low for Greece. It is difficult to suggest a location in which this individual grew up because a detailed strontium map with biologically available strontium values has not been completed, and it is possible that low values do exist but have not been sampled. However it does appear that this individual is likely not from the immediate New Halos area or the broader surrounding region. Presented below is a possible alternative explanation for this low strontium value using strontium values derived from bedrock.

The geological map presented in Chapter 5 (Figure 5.2, p.100) illustrated the bedrock near New Halos. It was previously mentioned that bedrock strontium could be used as a starting point to estimate biologically available strontium values for a region. Strontium values were estimated for marine derived bedrock in the New Halos area using the geological map and strontium results from Burke et al (1982) who created a curve of seawater $^{87}Sr/^{86}Sr$ values from the Late Cambrian to the Holocene. The area immediately around New Halos has a geological base of diluvium and alluvium deposits dating to the Quaternary period. These deposits should have a $^{87}Sr/^{86}Sr$ range of 0.7090 to 0.7091, which is very close to modern seawater strontium values. These values are in agreement with the values from the Pelagonian zone in Nafplioti's study (2011). This further reinforces the determination that individuals from the 'middle' group are originally from the New Halos area.

Of the identifiable geological regions near New Halos a small region located approximately 8 kilometers south-south-east of New Halos is composed of Neogene marls, clays, and sea deposits and has a $^{87}Sr/^{86}Sr$ range of 0.7080 – 0.7090. The individuals in the 'low' group (0.70818 – 0.70858) from New Halos have values within the range for this area. This area is within the Sub-Pelagonian zone that Nafplioti (2011) described. Although this area is too small to suggest that these individuals were eating exclusively from within it, it is still possible that they were from that area and grew up consuming foods grown in this area that influenced their strontium values. Additionally, bedrock of this type in the broader New Halos region is a good indication that these individuals could have been from the areas surrounding New Halos.

Although Nafplioti did not report strontium values similar to the individual in the 'lowest' group (0.70757) there are two bedrock types in the region that could produce low biologically available strontium values near New Halos. The first area consists of Middle Triassic – Jurassic dolomite and limestone deposits. It is estimated that these deposits have a $^{87}Sr/^{86}Sr$ range of 0.7070 – 0.7078 (Burke et al., 1982). This type of bedrock is found approximately 1 km west and approximately 2 km east of New Halos extending to the south. It would be difficult to make a living and eat exclusively from these small areas. Therefore they are not a likely place of origin for this individual. The second area with this type of bedrock is found is approximately 11 kilometers west of New Halos and

it is a larger area where an individual could have made a living. This individual could be from the surrounding New Halos area, however their $\delta^{18}O_{(drinking\ water)}$ value of -11.53‰ strongly suggests that they are not local to the region.

The 'high' and the 'highest' group values do not correspond with any of the geological areas near New Halos where a $^{87}Sr/^{86}Sr$ value from bedrock could be estimated. Both groups have $^{87}Sr/^{86}Sr$ ranges above the marine $^{87}Sr/^{86}Sr$ values reported by Burke et al. (1982). I would suggest, based on these values and Nafplioti's (2011) strontium map, that the individuals in these two groups could originally be from the Vadar zone north east of New Halos. It is difficult to predict a more specific location without a more comprehensive biologically available strontium map for this region or for Greece.

New Halos was a fortified city with towers built into the city walls and gates that controlled access in and out of the town suggesting a military presence like a garrison could have existed at some point during the city's use. Hellenistic garrisons often consisted of both Macedonian soldiers and mercenaries from elsewhere in the Greek world (Haagsma, 2010). It is possible that, if a garrison was stationed at New Halos, the soldiers would have married native women and settled down at New Halos (Haagsma, 2010). If New Halos were a garrisoned city and the soldiers did settle this could explain why certain individual tooth enamel samples represent a non-local signature from an earlier life period. The strontium results from New Halos appear to agree with archaeological work and literary sources that indicated rural settlements were disappearing and larger settlements were being established during the Hellenistic period (Alcock, 1996). The New Halos strontium results indicate that the majority of people living at New Halos were most likely from the surrounding area. There are some individuals who appear to be from further away, which is also in agreement with increased movement of peoples during the Hellenistic period.

7.7 Strontium and Oxygen Isotope Comparison of New Halos Mobility Patterns

The strontium and oxygen isotope results were compared with one another to visually evaluate trends within the data; this analysis is presented in Figure 7.12.

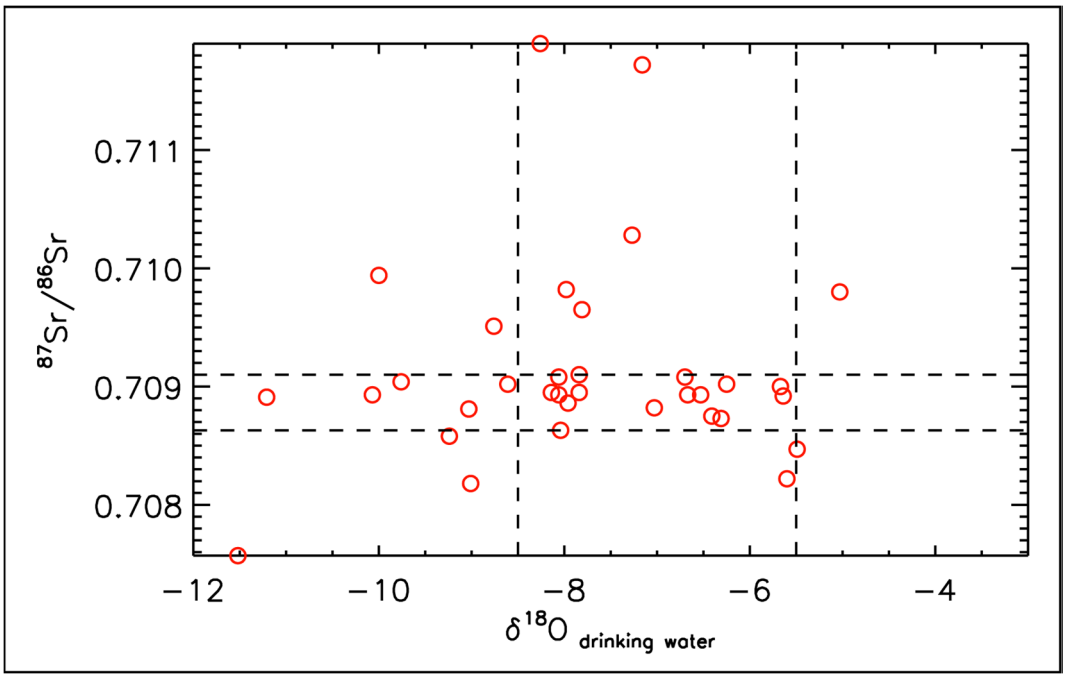

Figure 7.12: $^{87}Sr/^{86}Sr$ values compared with $\delta^{18}O_{(drinking\ water)}$ values. The rectangles indicate the local New Halos range for each isotope.

Of the 36 samples in Figure 7.12 there are 24 individuals identified as local by their $\delta^{18}O$ values. Of these 24 individuals, 18 also had $^{87}Sr/^{86}Sr$ values that suggested they were local. This is 50% of the individuals in this data set. Strontium and oxygen do not have to agree on whether an individual is non-local to an area because there are many strontium and oxygen isotope combinations that can potentially be reflected in an individual's isotopic signature depending on the bedrock and climate conditions where they lived at the time of their tissue formation. Six individuals have local strontium values but lower, non-local oxygen values. These individuals would have probably come from areas to the west of New Halos further inland or at a higher altitude, but from an area with similar bedrock. Seven individuals have local oxygen isotope values and strongly non-local strontium values. The oxygen values suggest that these people could have originated in another locale with a low altitude and warm climate similar to New Halos – but not likely a coastal location, which should, like New Halos, confer strontium isotope values similar to seawater. NH-77 has the lowest oxygen and strontium values in the sample. The oxygen values indicate that this individual was most likely born in a high altitude area or a colder climate. The strontium value was lower than all of the samples reported by Napflioti (2011); as mentioned above the geological map suggests that

there is an area inland to the west of New Halos with strontium values that are similar to this individual; however, the oxygen value is too low for this region suggesting that this individual was from further afield. NH-20 had the highest $\delta^{18}O$ value of -5.0‰ and a non-local strontium value of 0.70980 from the high group. It was suggested above that this group was from an area inland to the west of New Halos which still holds true, however for this individual the high oxygen isotope value would suggest that they are from a lower altitude area; together the two measures suggest a possible origin in one of Thessaly's many plains.

Figure 7.13 presents the mobility data divided by sex. Understanding movement of males and females in to or out of a population can provide information about cultural practices like marriage.

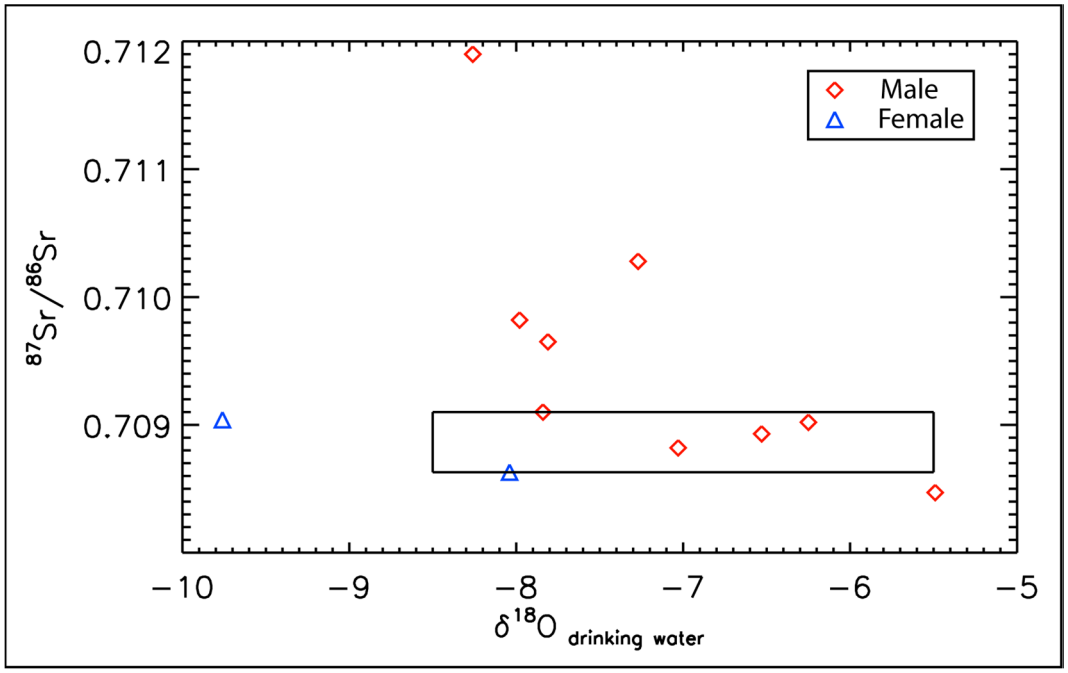

Figure 7.13: New Halos $^{87}Sr/^{86}Sr$ values and $\delta^{18}O$ drinking water values sorted by sex. The rectangle indicates the local $^{87}Sr/^{86}Sr$ values and $\delta^{18}O$ drinking water range for the area of New Halos

Unfortunately only 11 individuals with both oxygen and strontium values also had confident sex estimations, therefore the sample size is small and it is difficult to make inferences from this data. However, the current data do suggest that males were coming to New Halos from a variety of regions. It is difficult to suggest a pattern for female mobility with only two female samples. Although there are too few samples that can be

identified by sex for a strong analysis, mobility patterns for males and females are important to consider because they can provide a great amount of detail about population composition and cultural practices.

It was also possible to consider the local and non-local data sorted by grave date to determine if time period influenced a person's place of origin. As can be seen in Figure 7.14 there is no apparent pattern for these variables. However, NH-45, the individual from the 'Second half of the 3rd century BC' group has consistently been an outlier in many of the figures presented in this chapter and is considered non-local by both $\delta^{18}O$ value and $^{87}Sr/^{86}Sr$ values. The data indicates that this individual was originally from a different area and consumed a diet different from that at New Halos. The analysis of how time period influences local or non-local individuals at New Halos is limited because of the small sample size available. It is difficult to make any more conclusions with the data available. However this line of investigation is important to consider because it could have provided insight about population composition.

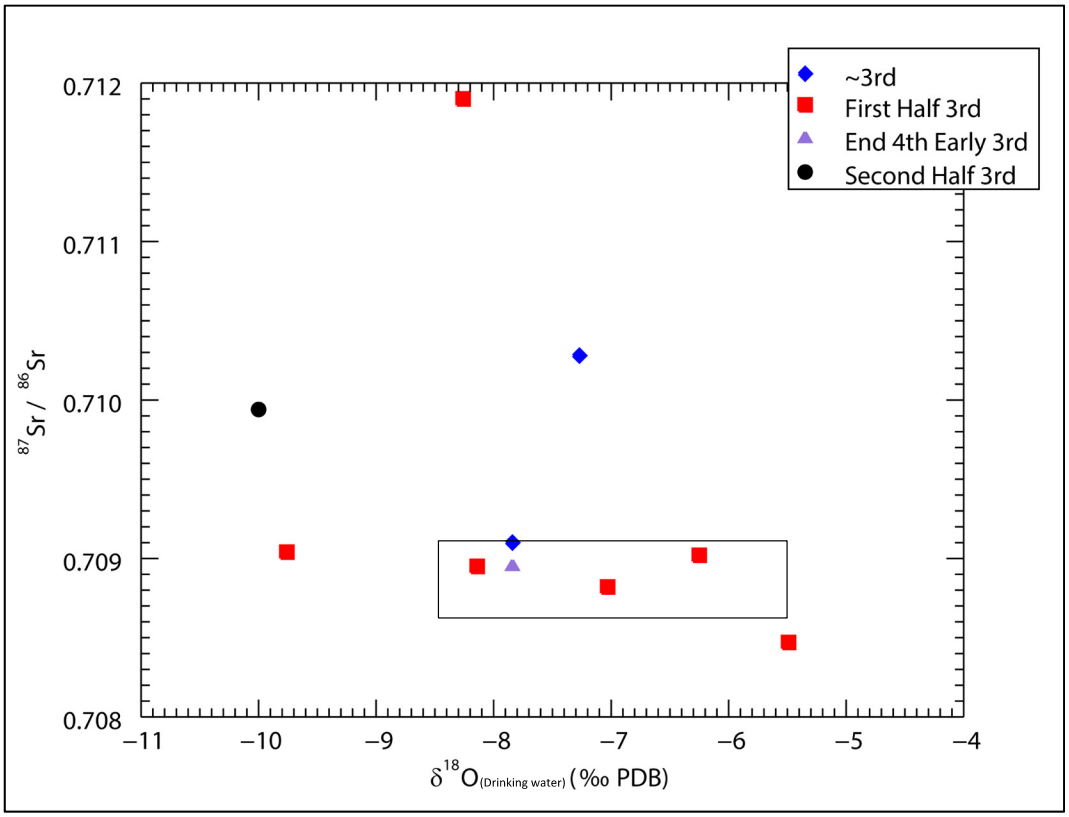

Figure 7.14: $\delta^{18}O_{(drinking\ water)}$ values and $^{87}Sr/^{86}Sr$ sorted by grave dates. The box indicates the local range for $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ at New Halos.

What is apparent from this comparison is that the population of New Halos is composed of individuals from a variety of regions in northern Greece and that oxygen and strontium isotope data, used together, do complement one anothers' results. Future work with archaeological animal samples will help refine the strontium local range at New Halos. This will aid with the analysis of local and non-local individuals and could help identify more non-local individuals who are on the edge of the current local range.

7.7.1 Dietary Values for Local and Non-Local Individuals at New Halos

The oxygen and strontium values have been used to determine local and non-local individuals. Figure 7.15 presents the $\delta^{13}C$ and $\delta^{15}N$ values for local and non-local individuals based on oxygen isotope results only.

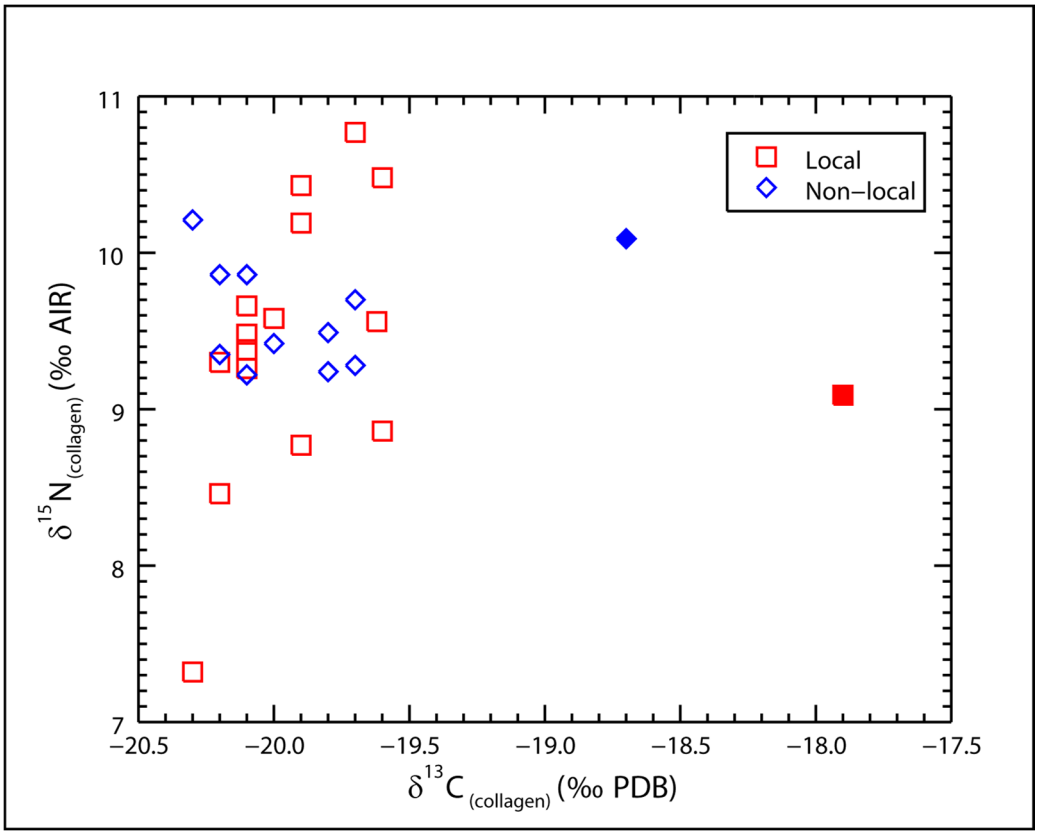

Figure 7.15: $\delta^{13}C_{(collagen)}$ and $\delta^{15}N_{(collagen)}$ dietary values from local and non-local individuals determined by oxygen isotope results. The local individuals have $\delta^{18}O_{(drinking\ water)}$ values between -5.5‰ and -8.5‰. These values include the immediate New Halos area. The solid red square indicates sample NH-84, the solid blue diamond indicates sample NH-45, both are mentioned in text.

Values from 16 local and 11 non-local individuals are presented in Figure 7.15. Surprisingly, based on oxygen isotope values alone, the locally-born individuals have a wider dietary variation than those who were non-locally born. This suggests that the locally born population was subsisting on all available resources at New Halos while those coming from elsewhere may have had a more uniform diet at a young age before coming to New Halos.

A similar analysis can be done using the five strontium groups that were outlined in Chapter 6 to evaluate $\delta^{13}C$ and $\delta^{15}N$ dietary signatures in terms of local and non-local individuals. Eighteen individuals had corresponding bone and tooth samples making it possible to evaluate their $\delta^{13}C$ and $\delta^{15}N$ values based on their $^{87}Sr/^{86}Sr$ values; these are portrayed in Figure 7.16.

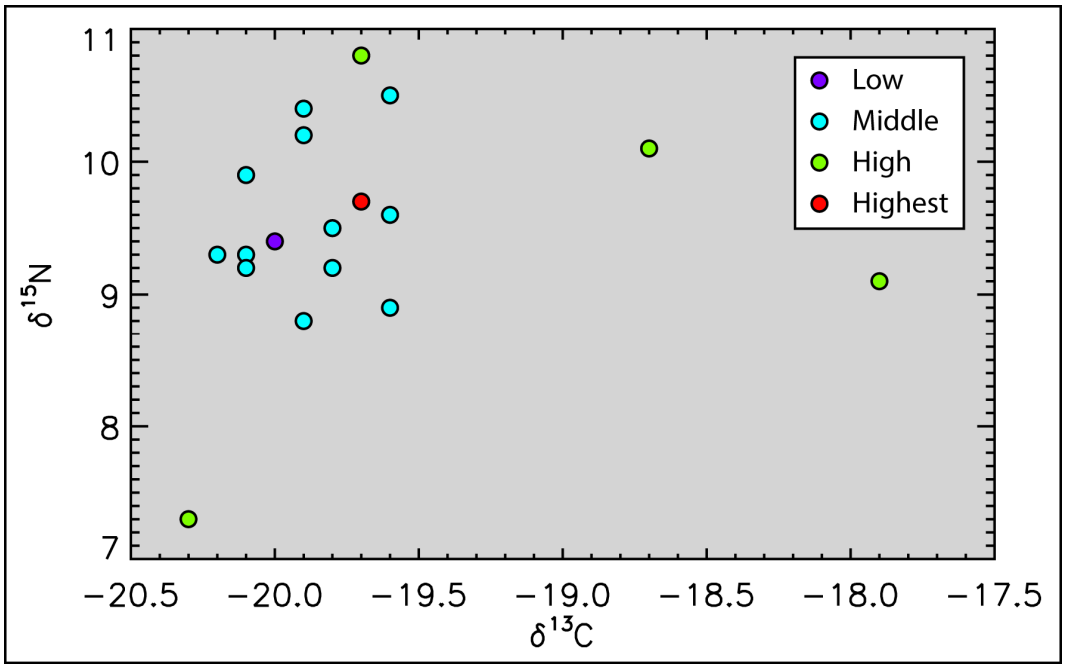

Figure 7.16: 7 $\delta^{13}C_{(collagen)}$ and $\delta^{15}N_{(collagen)}$ dietary values sorted by strontium groups. The middle group is considered to be local to New Halos.

Only four groups are represented in Figure 7.16 because the individual in the lowest group did not have a corresponding bone sample to provide dietary values. As reviewed above in section 7.6, the middle group is considered to be local to the immediate New Halos area. The sample sets are very small which limits the types and strength of inferences that can be made about these data. The four individuals in the 'high' group

have the most extreme dietary values and are on the outer limits of the plotted data points. As non-locals, having a different diet to people from New Halos is an expected result. The 'middle' and 'low' individuals have similar diets that could suggest that there was some level of connection within the region where people would have had access to similar resources.

In Chapter 6 four individuals were identified as being outliers based on their $\delta^{13}C$ and $\delta^{15}N$ collagen values. Only two of these individuals had corresponding enamel samples and are represented in Figure 7.15. NH-84 is represented by a solid red square and is only considered local based on $\delta^{18}O$ values. Their strontium value (0.70982) was not considered local; this individual fell in the 'high' group for strontium, suggesting that this individual is actually non-local and came from another region with similar precipitation values to New Halos. NH-45, the other outlier is represented by a solid blue diamond in Figure 7.15 and has $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values that both identify it as non-local. The dietary information for NH-45 suggests this person was consuming a diet different from most of the local New Halos individuals. This diet would have included C_3 plants and animal products along with the addition of shellfish, small marine fish, or small amounts of millet.

7.8 Summary

The discussion in this chapter has provided a dietary interpretation of the bone collagen and enamel carbonate data. The isotopic results from six spatially and temporally diverse sites were used as a comparison to the New Halos dietary information. What was noted is that the New Halos population had low $\delta^{13}C$ bone collagen values compared to other populations while the $\delta^{15}N$ values from New Halos suggest consumption of terrestrial animal protein for a portion of the population. The data suggest that most of the people at New Halos were consuming a diet based largely on C_3 staples and terrestrial animal products.

Low overall $\delta^{13}C_{(collagen)}$ values within the New Halos population may indicate that more bone collagen carbon was drawn from non-protein carbon sources such as dairy lipids, wine, grains or oil than was typical for Greek populations. Other individuals had slightly higher $\delta^{13}C_{(collagen)}$ values compared to the rest of the population. These individuals were

consuming shellfish and small marine fish but this was not a resource shared equally within the population. In addition, a few individuals appear to have consumed some millet. This is an interesting finding because the historical literature does not suggest that millet was commonly consumed in the Hellenistic period in Greece. Consumption of millet and the strontium and oxygen results indicate that some individuals were not originally from the New Halos region. Although plausible matches to the strontium and oxygen values were found within Greece, it is also possible that some of these individuals came from areas outside of Greece.

A newly published isotope study on an Early Iron Age population from Halos provided the opportunity to compare dietary results from a population that lived in the same area as the Hellenistic population from New Halos. Interestingly, the Early Iron Age population had generally lower $\delta^{15}N$ values and higher $\delta^{13}C$ values compared to Hellenistic New Halos. These comparative results indicate that the population of New Halos was utilizing the local resources differently than the Early Iron Age population. The low mean $\delta^{13}C$ collagen value at New Halos also indicates that the Hellenistic population was consuming foods like olive oil and/or wine in a quantity different than other Greek populations resulting in overall lower $\delta^{13}C$ value.

Enamel carbonate was also used for dietary analysis and these values also indicated that the population was consuming a diet heavily based on C_3 plant and C_3–fed animals. A small section of the population does appear to have consumed C_4 grains, shellfish or small marine resources. There were two people who had elevated $\delta^{13}C_{(carbonate)}$ values who were most likely consuming C_4 grains. Two other individuals had high $\delta^{13}C_{(collagen)}$ and high $\delta^{13}C_{(carbonate)}$ values indicating a diet that may have included marine resources. These two individuals also had higher $\delta^{15}N$ values, which also support the inclusion of marine resources in the diet. The dietary model developed by Kellner and Schoeninger (2007) was used in this study to interpret the New Halos data. The position of the New Halos values above the C_3-protein regression line suggests non-protein foods were contributing to collagen carbon. The individuals with low carbonate and collagen $\delta^{13}C$ values would have been eating a diet dominated by C_3 staples and terrestrial animal resources; people with higher carbonate and collagen $\delta^{13}C$ values would have likely had marine and/or C_4 resources included in their diets. It is possible that an environmental

correction factor is necessary for Greece when working with this model to reflect foods grown in warm climates, and this is a recommended area for future research.

Following the dietary analysis the oxygen and strontium isotope data were used to look into population mobility. It was shown that the population of New Halos is comprised of both locally born and non-locally born individuals. The oxygen isotope analysis revealed that 70% of the population had local signatures. Of the 30% who did not, two individuals were determined to be from an area with a warmer climate. The other 13 people had signatures consistent with areas near the Othris Mountains to the west or Mount Pelion to the North East.

The strontium isotope data indicated similar results to the oxygen data. Many people have strontium isotope values consistent with a local origin around New Halos while some individuals were originally from further away. Some of these non-local signatures are consistent with an origin in areas to the west of New Halos. There was a small subset of individuals that would have been from outside the region. It was suggested that a likely place of origin was near the modern city of Volos in the Vadar zone outlined by Nafplioti (2011). However it is also possible that these individuals came from further away.

Lastly, dietary information for local and non-local individuals was presented. Using results from the oxygen analysis, it appears that within the local individuals there is some dietary variation at New Halos and this variation was more than the variation within the non-local individuals. This could suggest that the individuals who grew up in the immediate New Halos area ate a diet of opportunity and needed to utilize all available resources while the people that grew up away from the site of New Halos were consuming a more homogeneous diet. Perhaps this was because of cultural ideas or a regional connection that influenced dietary norms. The strontium isotope results indicate that the local individual did not have a more varied diet but instead the most extreme dietary values belonged to non-local individuals. When considered together it is important to remember that the non-local individuals could have been living near by, for example in the Othris mountains, at higher elevations changing their $\delta^{18}O$ values but maintaining a strontium value similar to the local New Halos bedrock.

The data were also examined in the light of individual dates base on grave goods to investigate if diet changed over time or if population composition was affected by time. Unfortunately the sample sizes for this comparison were small and did not show any trends in dietary change over time. The same issue with sample size occurred for the mobility data and it was difficult to determine whether a trend occurred over time. However, the oldest group of individuals had mostly local $^{87}Sr/^{86}Sr$ values that could tentatively suggest that local people originally populated New Halos and that non-local people arrived later.

Overall, this discussion has provided valuable information about dietary habits and mobility patterns for New Halos, demonstrating that there is much that stable isotope analysis can offer when investigating a past population.

Chapter 8 Conclusions

8.1 Summary

There has been a great deal of research about Macedonian hegemony and the transition from the Classical to the Hellenistic period when Alexander the Great's generals took control and broke down his empire after his death (Ashley, 2004; Austin, 2006; Bengston, 1988; Billows, 1997; Chamoux, 2003; Chaniotis, 2005; Freeman, 2011; Habicht, 2006; Shipley, 2000). But there is little written about the impact of this volatile period on the daily lives of lower status individuals in both urban and rural settings during this time. The city of New Halos is an excellent source of information about life in the Hellenistic because it was occupied for a short period of time before it was destroyed; its archaeological remains and cemeteries shed important light on life in the early Hellenistic period.

This dissertation presented the isotopic profiles for individuals recovered from a Hellenistic cemetery associated with the site of New Halos in Thessaly, Greece. The skeletal sample set studied for this research included 62 human bone samples, 50 human teeth, and 15 faunal samples. The isotopic data from these samples provided evidence about diet and population composition at New Halos. The purpose of this chapter is to summarize the important findings of this research and to offer potential avenues for future work.

8.2 Diet at New Halos

This study presented a review of historical and archaeological sources concerning Hellenistic diets. Past studies have indicated that the "Mediterranean triad" of cereals, wine, and oils were staple foods in the diet, while animal products and marine resources varied in importance. Information in the literature often mentions foods available and eaten but does not discuss the proportions or who did or did not have access to these resources. Stable isotope analysis was used as a research strategy in this study to try and answer questions about diet in the Hellenistic period. Background information about stable isotopes was presented along with typical values for relevant food items. A brief discussion of collagen extraction methods and enamel preparation was presented and sample quality indicators were reviewed. Methodologies for inferring dietary stable

carbon and nitrogen isotope values from bone collagen were discussed, followed by a discussion of enamel carbonate carbon and how it can be used with bone collagen carbon to further our understanding of diet.

The stable isotope investigation at New Halos was designed to answer questions about diet composition and migration patterns. As the isotopes and their relation to one another were analyzed a complicated and exciting dietary pattern emerged. Human and animal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values were first compared to understand how human values related to the faunal values from the area. What was observed is that humans had isotopic values above the faunal samples indicating that meat or dairy products from terrestrial animals were important to this population's diet.

The human bone collagen $\delta^{13}C$ and $\delta^{15}N$ isotope values at New Halos were considered relative to local faunal values, other Greek populations, and to bulk diet carbonate values. The dietary evidence reflects a population who consumed a C_3 based diet, likely including the typical staple of grains, oil and wine as well as dairy foods. The individuals would have also consumed varying amounts of animal protein. The members of the population who had the lowest $\delta^{13}C$ and $\delta^{15}N$ values were consuming relatively low-protein diets whose protein came from terrestrial animal products. Other individuals would have been eating a combination of terrestrial animal protein and low-trophic marine resources. Shellfish are the most probable marine source because they are well represented in the archaeological record. People who consume these low trophic marine resources have enriched $\delta^{13}C$ values, usually falling above people consuming a C_3-based diet. However, C_4 grains can have a similar effect on an individual's collagen $\delta^{13}C$ values, making it very important to consult historical sources and the archaeological record for evidence of marine or C_4 resources at a site. There were four individuals with distinct diets; they had similar $\delta^{15}N$ values to the rest of the population but had higher $\delta^{13}C$ values. This was interpreted to mean that they were consuming an amount of C_4 grains, shellfish, or small marine fish greater than the rest of the population.

The New Halos dietary values were compared to reconstructed food values from Greece. The $\delta^{13}C$ collagen values at New Halos are low compared to values found for other isotopic studies in Greece. This was argued to indicate that low $\delta^{13}C$ items such as dairy lipids, grains, olive oil or wine made up a significant portion of the diet. This supported

the above interpretation that the majority of people at New Halos were consuming a diet based on C_3 staples with protein from terrestrial animal dairy products.

The enamel carbonate $\delta^{13}C$ values represent a whole diet signature and were compared to bone collagen $\delta^{13}C$ values. This comparison suggested that non-protein sources were influencing the bone collagen values, drawing them down relative to many other Greek populations. Enamel carbonate values show that the whole diet for the majority of the population was heavily based on C_3 resources and C_3-terrestrial animals. When the $\delta^{13}C_{(carbonate)}$ and $\delta^{13}C_{(collagen)}$ were compared the data showed that some individuals at New Halos were eating C_4 grains or marine resources. There were two people who had similar $\delta^{13}C_{(collagen)}$ to the rest of the population but elevated $\delta^{13}C_{(carbonate)}$. This suggests that they were eating millet that was affecting their bulk diet values and not their dietary protein values. This is an exciting find because millet was not considered to be in use in the area during the Hellenistic. There were two other individuals who appear to be eating a large amount of small marine fish and shellfish; this is reflected in their high $\delta^{13}C_{(collagen)}$ and high $\delta^{13}C_{(carbonate)}$ values.

When all of the isotopic data is considered it is clear that the people of New Halos were not eating a homogeneous diet. It is clear that C_3 resources and terrestrial animal products were staples in the diet for the individuals sampled, but there was variation in the amount of marine resources in the diet along with the overall amount of animal products people were eating.

8.3 Mobility Patterns at New Halos

The historical background research offered information about the political environment during the Hellenistic, which provided insights about how and why cities were formed and populated. The Hellenistic period was a time when many new cities were established. The literature is unclear about how these cities were populated. Was it forced or self-motivated migration? Did new inhabitants from local or distant regions move into the new urban setting? These questions are difficult to answer using only the historical literature, but stable isotope analysis provides researchers with new data directly from populations who lived during the time period in question. A second line of

investigation in this dissertation used stable oxygen and strontium isotopes to examine population composition at New Halos.

Mobility patterns at New Halos were investigated by establishing $\delta^{18}O$ values from enamel samples and determining a local drinking water range for the area. Individual $\delta^{18}O$ values were converted into drinking water values so they could be compared to the local range. Using a local $\delta^{18}O_{(drinking\ water)}$ range of -5.5‰ to -8.5‰ it was determined that 70% of the New Halos population could have grown up in the immediate surrounding area. Of the non-local individuals, two had $\delta^{18}O$ values above -5.5‰ indicating that they were from an area with a warmer climate. Thirteen people had $\delta^{18}O$ values below -8.5‰ and were most likely from areas either to the west of New Halos in the mountainous regions or from areas to the northeast near the Pindos mountain range.

Strontium isotope analysis was also used to evaluate population composition. It was possible to divide the samples into five groups. Estimated geological strontium values from the area and previously published biologically available strontium values for Greece were used to establish a local strontium range. Using this method 19 individuals were identified as potentially local to New Halos meaning that they could have grown up in the immediate surrounding area. The strontium values of samples that fall outside this range suggest that many people came from the west or north of New Halos. There was one individual with a strontium value lower than any previously reported values for Greece. While many areas of Greece have not yet been sampled and an origin in one of these areas is possible, it was also suggested that this individual might have been a foreigner that moved to Greece. For most individuals with both measurements, the strontium analysis suggests similar places of origin as the oxygen isotopes.

With the population mobility analysis complete and local and non-local individuals identified the data was used to compare local and non-local diets. When the bone collagen dietary values were separated according to local and non-local individuals according to the $\delta^{18}O$ data the people classified as local had a wider dietary range. Perhaps the local individuals were consuming a diet based on all available resources and did not have the luxury to choose specific foods. When the dietary data was sorted using the local and non-local strontium designations the data showed that non-local individuals were consuming a different diet than local New Halos individuals.

Age and sex were considered during the dietary and mobility analysis, but unfortunately the sample sizes were very small and did not allow for a strong analysis of the data. The data provided in this study did not indicate any obvious differences in $\delta^{13}C$ and $\delta^{15}N$ values between age categories or sex categories. No concrete conclusions about age and sex could be established.

The isotopic data were also considered in terms of grave date. It was attempted to determine if any changes in diet occurred over time or if different groups of people came to New Halos over time. As with the age and sex analysis, the sample sizes were once again too small for patterns or trends to be discerned.

The work at New Halos advances our understanding of population mobility patterns in Thessaly and the Hellenistic. New Halos was a newly established settlement and one question this study attempted to answer was where did the people come from. The mobility section demonstrated that many people from New Halos were local or immediately regional. This could suggest that a *synoikismos* occurred and that people from the area were brought to New Halos. The stable isotope results of this study provide us with a greater understanding about dietary habits at New Halos. It does not appear that New Halos was a wealthy population. The archaeological record did not reflect personal wealth and the dietary information suggests that this population was consuming a low-protein diet that may also indicate a less wealthy group of people. It also increased our understanding of populations within Thessaly, Greece. There continues to be a wealth of information to be gained from this region and time period and stable isotope analysis can continue to fill in the gaps.

8.4 Future Work

This study is the first of its kind in Thessaly. The inclusion of bone collagen data along with enamel carbonate values to recreate diet and assess mobility patterns offers a very complete picture of the people from Hellenistic New Halos. In the future there is more work that could be done to investigate aspects of this population's past. Establishing a larger faunal sample population for strontium analysis could be done in order to create a baseline for the New Halos region. This will help to refine the local New Halos strontium range.

A palaeopathological assessment of the skeletons to look for signs that the population was experiencing dietary stress during their lives will help to better understand living conditions at New Halos and whether people with different health status consumed different diets. Another possible avenue of study would be to look at the carbonate data in broader regional context, looking at data from other populations in varying environmental settings to investigate whether the environmental correction factor presented by van Klinken et al (2000) is a necessary step to take when dealing with skeletal samples from Greece.

A broader application would be to sample other skeletal populations in Thessaly to create a regional database that can be compared to the New Halos population for both dietary isotopes and mobility isotopes. Having a better understanding of how other populations in the surrounding geographic area survived would add to our understanding of life in that region. Similarly, assessing more Hellenistic populations in Greece will help us better understand this time period. There is a vast amount of future work to be done and the population of New Halos is just the beginning for understanding the Hellenistic period and the region of Thessaly.

Bibliography

Åberg, G., Fosse, G., & Stray, H. (1998). Man, nutrition and mobility: A comparison of teeth and bone from the Medieval era and the present from Pb and Sr isotopes. *The Science of the Total Environment*, *224*, 109–119.

Adam, E. (1999). Preliminary presentation of the Upper Palaeolithic and Mesolithic stone industries of Theopetra Cave, Western Thessaly. *British School at Athens Studies*, *3*, 266–270.

Alcock, S. E. (1996). *Graecia capta: the landscapes of Roman Greece*. Cambridge ; New York : Cambridge University Press.

Alcock, S. E., Gates, J. E., & Rempel, J. E. (2005). Reading the Landscape: Survey Archaeology and the Hellenistic Oikoumene. In A. Erskine (Ed.), *A Companion to the Hellenistic World* (pp. 354–372). Blackwell Publishing Ltd.

Alexakis, D., Sarris, A., Astaras, T., & Albanakis, K. (2011). Integrated GIS, remote sensing and geomorphologic approaches for the reconstruction of the landscape habitation of Thessaly during the neolithic period. *Journal of Archaeological Science*, *38*(1), 89–100.

Alt, K., Rosing, F., & Teschler-Nicola, M. (1998). *Dental Anthropology: Fundamentals, limits and prospects*. New York: Springer Wein.

Ambrose, S. H. (1986). Stable carbon and nitrogen isotope analysis of human and animal diet in Africa. *Journal of Human Evolution*, *15*(8), 707–731.

Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, *17*(4), 431–451.

Ambrose, S. H. (1991). Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science*, *18*(3), 293–317.

Ambrose, S. H., Butler, B., Hanson, D. B., Hunter-Anderson, R., & Krueger, H. W. (1997). Stable Isotopic Analysis of Human Diet in the Marianas Archipelago, Western Pacific. *American Journal of Physical Anthropology*, *104*, 343–361.

Ambrose, S. H., & Norr, L. (1993). Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In J. Lambert & G. Grupe (Eds.), *Prehistoric human bone: archaeology at the molecular level*. Berlin: Springer-Verlag.

Anders, B., Reischmann, T., Kostopoulos, D., & Poller, U. (2006). The oldest rocks of Greece: first evidence for a Precambrian terrane within the Pelagonian Zone. *Geology Magazine*, *143*, 41–58.

Anders, B., Reischmann, T., & Poller, U. (2002). Geochemistry and Geochronology of Basement Rocks from the Pelagonian Zone, Greece. *Geochimica et Cosmochimica Acta*, *66*, A19 (abstr.).

Andreou, S., Fotiadis, M., & Kotsakis, K. (1996). Review of Aegean Prehistory V: The Neolithic and Bronze Age of Northern Greece. *American Journal of Archaeology*, *100*(3), 537–597.

Andrianou, D. (2006). Chairs, Beds, and Tables: Evidence for Furnished Interiors in Hellenistic Greece. *Hesperia: The Journal of the American School of Classical Studies at Athens*, *75*(2), 219–266.

Aperghis. (2005). City Building and the Seleukid Royal Economy. In Z. Archibald, J. Davies, & V. Gabrielsen (Eds.). *Making, Moving and Managing*. Oxford: Oxbow Books.

Archibald, Z. (2001). *Hellenistic Economies*. London: Routledge.

Archibald, Z., Davies, J., & Gabrielsen, V. (2005). *Making, moving and managing: the new world of ancient economies, 323-31 BC*. Oxford: Oxbow Books.

Ashley, J. R. (2004). *The Macedonian Empire: The Era of Warfare Under Philip II and Alexander the Great, 359-323 B.C.* McFarland.

Austin, M. M. (1986). Hellenistic kings, war, and the economy. *Classical Quarterly*, 450–466.

Austin, M. M. (2006). *The Hellenistic World from Alexander to the Roman Conquest: A Selection of Ancient Sources in Translation*. Cambridge: Cambridge University Press.

Ayliffe, L. K., & Chivas, A. R. (1990). Oxygen isotope composition of the bone phosphate of Australian kangaroos: potential as a palaeoenvironmental recorder. *Geochimica et Cosmochimica Acta*, *54*(9), 2603–2609.

Beard, B., & Johnson, C. (2000). Strontium isotope composition of skeletal material can determine the birth place and geographic mobility of humans and animals. *Journal of Forensic Sciences*, *45*, 1049–1061.

Beestman-Kruyshaar, C. (2003). Chapter 3.1 Pottery. In H. R. Reinders & W. Prummel (Eds.). *Housing in New Halos: A Hellenistic Town in Thessaly, Greece*. Lisse: Swets and Zeitlinger.

Bell, L. S., Skinner, M. F., & Jones, S. J. (1996). The speed of post mortem change to the human skeleton and its taphonomic significance. *Forensic Science International*, *82*(2), 129–140.

Bengston, H. (1988). *History of Greece from the Beginnings to the Byzantine Era* (Vol. 3). Ottawa: University of Ottawa Press.

Bentley, A. (2004). Characterizing human mobility by strontium isotope analysis of the skeletons. In C. F. Higham & R. Thosarat (Eds.), *Khok Phanom Di: Summary and Conclusions* (pp. 159–166). Oxford: Oxbow Books.

Bentley, A. (2006). Strontium Isotopes from the Earth to the Archaeological Skeleton: A Review. *Journal of Archaeological Method and Theory*, *13*(3), 135–187.

Bentley, A., & Knipper, C. (2005). Geographical Patterns in Biologically Available Strontium, Carbon and Oxygen Isotope Signatures in Prehistoric SW Germany. *Archaeometry*, *47*(3), 629–644.

Bentley, R. A., Price, T. D., & Stephan, E. (2004). Determining the "local" 87Sr/86Sr range for archaeological skeletons: a case study from Neolithic Europe. *Journal of Archaeological Science*, *31*(4), 365–375.

Biers, W. R. (1996). *The archaeology of Greece: an introduction*. New York: Cornell Univ Press.

Billows, R. (1995). *Kings and Colonists: Aspects of Macedonian Imperialism*. New York: BRILL.

Billows, R. (1997). *Antigonos the One-Eyed and the Creation of the Hellenistic State*. California: University of California Press.

Bintliff, J. (2005). Human impact, land-use history, and the surface archaeological record: A case study from Greece. *Geoarchaeology*, *20*(2), 135–147.

Björkman, O., & Berry, J. (1973). High-efficiency photosynthesis. *Scientific American*, *229*(4), 80–93.

Blumner, H. (1966). *The home life of the ancient Greeks*. London: Cassell Publishing Co.

Boardman, J., Griffin, J., & Murray, O. (1988). *The Oxford History of Greece and the Hellenistic World, Jasper*. Oxford: Oxford University Press.

Bocherens, H., & Drucker, D. (2003). Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology*, *13*(1–2), 46–53.

Bocherens, H., Fogel, M., Tuross, N., & Zeder, M. (1995). Trophic Structure and Climatic Information from Isotopic Signatures in Pleistocene Cave Fauna of Southern England. *Journal of Archaeological Science*, *22*(2), 327.

Bocherens, H., Koch, P. L., Mariotti, A., Geraads, D., & Jaeger, J. (1996). Isotopic Biogeochemistry (^{13}C, ^{18}O) of Mammalian Enamel from African Pleistocene Hominid Sites. *PALAIOS*, *11*(4), 306–318.

Boehm, R. A. (2011). *Synoikism, Urbanization, and Empire in the Early Hellenistic Period* (PhD Thesis). University of California, Berkeley, Berkeley.

Bogaard, A., Heaton, T., Poulton, P., & Merbach, I. (2007). The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science*, *34*, 335–343.

Bookidis, N., Hansen, J., Snyder, L., & Goldberg, P. (1999). Dining in the Sanctuary of Demeter and Kore at Corinth. *Hesperia*, *68*(1), 1-54.

Bottema, S. (1988). A reconstruction of the Halos environment on the basis of palynological information. In H.R. Reinders & W. Prummel (Eds.). *New Halos, a Hellenistic Town in Thessalia, Greece* (pp. 216–226). Utrecht: HES Publishers.

Bourbou, C. (2010). *Health and Disease in Byzantine Crete (7th - 12th centuries AD)*. Surrey: Ashgate Publishing Ltd.

Bourbou, C., Fuller, B. T., Garvie-Lok, S. J., & Richards, M. P. (2011). Reconstructing the diets of Greek Byzantine populations (6th–15th centuries AD) using carbon and nitrogen stable isotope ratios. *American Journal of Physical Anthropology*, *146*(4), 569–581.

Bourbou, C., Fuller, B. T., Garvie-Lok, S. J., & Richards, M. P. (2013). Nursing mothers and feeding bottles: reconstructing breastfeeding and weaning patterns in Greek Byzantine populations (6th–15th centuries AD) using carbon and nitrogen stable isotope ratios. *Journal of Archaeological Science*, *40*(11), 3903–3913.

Bourbou, C., & Richards, M. P. (2007). The Middle Byzantine menu: palaeodietary information from isotopic analysis of humans and fauna from Kastella, Crete. *International Journal of Osteoarchaeology*, *17*(1), 63–72.

Brulé, P. (2003). *Women in Ancient Greece*. Edinburgh: Edinburgh University Press.

Brumfield, A. (1997). Cakes in the Liknon: Votives from the Sanctuary of Demeter and Kore on Acrocorinth. *Hesperia: The Journal of the American School of Classical Studies at Athens*, *66*(1), 147–172.

Bryant, D., Luz, B., & Froelich, P. (1994). Oxygen isotopic composition of fossil horse tooth phosphate as a record of continental paleoclimate. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *107*(3), 303–316.

Budd, P., Millard, A., Chenery, C., Lucy, S., & Roberts, C. (2004). Investigating population movement by stable isotope analysis: a report from Britain. *Antiquity*, *78*(299), 127–141.

Budd, P., Montgomery, J., Barreiro, B., & Thomas, R. G. (2000). Differential diagenesis of strontium in archaeological human dental tissues. *Applied Geochemistry*, *15*(5), 687–694.

Budd, P., Montgomery, J., Evans, J. A., & Chenery, C. (2001). Combined Pb-, Sr- and O-Isotope Analysis of Human Dental Tissue for the Reconstruction of Archaeological Residential Mobility. *Royal Society of Chemistry - Special Publication*, *267*, 311–326.

Buikstra, J., & Ubelaker, D. (1994). Standards for data collection from human skeletal remain: Proceedings of a seminar at the Field Museum of Natural History. Arkansas: Arkansas Archaeological Survey.

Burke, W., Denison, R., Hetherington, E., Koepnick, R., Nelson, H., & Otto, J. (1982). Variation of seawater $^{87}Sr/^{86}Sr$ throughout Phanerozoic time. *Geology*, *10*(10), 516–519.

Butzer, K. W. (2005). Environmental history in the Mediterranean world: cross-disciplinary investigation of cause-and-effect for degradation and soil erosion. *Journal of Archaeological Science*, *32*(12), 1773–1800.

Buzon, M. R., & Bowen, G. J. (2010). Oxygen and carbon isotope analysis of human tooth enamel from the New Kingdom site of Tombos in Nubia. *Archaeometry*, *52*(5), 855–868.

Buzon, M. R., Simonetti, A., & Creaser, R. A. (2007). Migration in the Nile Valley during the New Kingdom period: a preliminary strontium isotope study. *Journal of Archaeological Science*, *34*(9), 1391–1401.

Camin, F., Perini, M., Colombari, G., Bontempo, L., & Versini, G. (2008) Influence of dietary composition on the carbon, nitrogen, oxygen and hydrogen stable isotope ratios of milk. *Rapid Communications in Mass Spectrometry*, 22:1690-1696.

Carlier, A., Riera, P., Amouroux, J., Bodiou, J., Desmalades, M., & Grémare, A. (2009). Spatial heterogeneity in the food web of a heavily modified Mediterranean coastal lagoon: stable isotope evidence. *Aquatic Biology*, *5*, 167–179.

Casson, L. (1954). The Grain Trade of the Hellenistic World. *Transactions and Proceedings of the American Philological Association*, *85*, 168.

Chamoux, F. (2003). *Hellenistic Civilization*. Oxford: John Wiley & Sons.

Chang, C. (1994). Sheep for the ancestors: ethnoarchaeology and the study of ancient pastoralism. In P. Kardulias (Ed.), *Beyond the Site: Regional Studies in the Aegean Area*. Lanham: University Press of America. p. 354-370.

Chaniotis, A. (2005). *War in the Hellenistic world: a social and cultural history*. Malden: Blackwell Publishers.

Chenery, C. A., Pashley, V., Lamb, A. L., Sloane, H. J., & Evans, J. A. (2012). The oxygen isotope relationship between the phosphate and structural carbonate fractions of human bioapatite. *Rapid Communications in Mass Spectrometry*, *26*(3), 309–319.

Chenery, C., Müldner, G., Evans, J., Eckardt, H., & Lewis, M. (2010). Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. *Journal of Archaeological Science*, *37*(1), 150–163.

Chisholm, B. (1989). Variation in diet reconstructions based on stable carbon isotopic evidence. In T. D. Price (Ed.), *The chemistry of prehistoric human bone*. Cambridge: Cambridge University Press. p 10-37.

Chisholm, B., Nelson, D., & Schwarcz, H. P. (1982). Stable carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science*, *216*, 1131–1132.

Cohen, G. M. (1996). *The Hellenistic Settlements in Europe, the Islands, and Asia Minor*. University of California Press.

Comar, C. L., Russell, R. S., & Wasserman, R. H. (1957). Strontium-Calcium Movement from Soil to Man. *Science*, *126*(3272), 485–492.

Counihan, C. (1999). *The anthropology of food and body: gender, meaning and power*. London: Routledge.

Cox, G., & Sealy, J. (1997). Investigating identity and life histories: isotopic analysis and historical documentation of slave skeletons found on the Cape Town foreshore, South Africa. *International Journal of Historical Archaeology*, *1*(3), 207–224.

Craik, E. (1995). Hippokratic Diaita. In J. Wilkins, D. Harvey, & M. Dobson (Eds.), *Food in Antiquity*. Exeter: University of Exeter Press.

Curtis, R. (2005). Sources for production and trade of Greek and Roman processed fish. *Ancient Fishing and Fish Processing in The Black Sea Region*, *2*, 31–46.

Dalby, A. (1996). *Siren Feasts: A History of Food and Gastronomy in Greece*. New York: Routledge.

Dalby, A. (2003). *Food in the Ancient World from A to Z*. London: Routledge.

Dalby, A. (2013). *Siren feasts: a history of food and gastronomy in Greece*. London: Routledge.

D'Angela, D., & Longinelli, A. (1990). Oxygen isotopes in living mammal's bone phosphate: Further results. *Chemical Geology: Isotope Geoscience Section*, *86*(1), 75–82.

Daux, V., Lécuyer, C., Adam, F., Martineau, F., & Vimeus, F. (2005). Oxygen isotope composition of human teeth and the record of climate changes in France (Lorraine) during the last 1700 years. *Climatic Change*, *70*, 445–464.

Daux, V., Lécuyer, C., Héran, M. A., Amiot, R., Simon, L., Fourel, F., … Escarguel, G. (2008). Oxygen isotope fractionation between human phosphate and water revisited. *Journal of Human Evolution*, *55*(6), 1138–1147.

Davies, J. K. (2001). Hellenistic Economies in the post-Finley era. In Z. Archibald (Ed.), *Hellenistic Economies*. London: Routledge.

Day, M., Zhang, B. L., Martin, G. J., Asselin, C., & Morlat, R. (1995). Characterization of the region and year of production of wines by stable isotopes and elemental analyses. *Journal International des Sciences de la Vigne et du Vin (France)*.

Demoule, J. P., & Perlès, C. (1993). The Greek Neolithic: A new review. *Journal of World Prehistory*, *7*(4), 355–416.

DeNiro, M. J. (1985). Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, *317*, 806–809.

DeNiro, M. J. (1987). Stable Isotopes and Archaeology. *American Scientist*, *75*(2), 182–191.

DeNiro, M. J., & Epstein, S. (1978). Influence of diet on the distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta*, *42*(5), 495–506.

DeNiro, M. J., & Weiner, S. (1988). Use of collagenase to purify collagen from prehistoric bones for stable isotopic analysis. *Geochimica et Cosmochimica Acta*, *52*(10), 2425–2431.

Dotsika, E., Lykoudis, S., & Poutoukis, D. (2010). Spatial distribution of the isotopic composition of precipitation and spring water in Greece. *Global and Planetary Change*, *71*(3–4), 141–149.

Dupras, T. L., & Tocheri, M. W. (2007). Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition. *American Journal of Physical Anthropology*, *134*(1), 63–74.

Edward, J., Fossey, J., & Yaffe, L. (1984). Analysis by neutron activation of human bone from the Hellenistic cemetery at Asine, Greece. *Journal of Field Archaeology*, *11*(1), 37–46.

Einstein, N. (2006). *Aegean Sea map*. Retrieved from https://commons.wikimedia.org/wiki/File:Aegean_Sea_map_Urdu.png

Eleftheriadis, G., Castorina, F., Soldatos, T., & Masi, U. (2003). Geochemical and Sr-Nd isotopic evidence for the genesis of the Late Cainozoic Almopia volcanic rocks (Central Macedonia, Greece). *Mineralogy and Petrology*, *78*, 21–36.

Elias, R. W., Hirao, Y., & Patterson, C. C. (1982). The circumvention of the natural biopurification of calcium along nutrient pathways by atmospheric inputs of industrial lead. *Geochimica et Cosmochimica Acta*, *46*(12), 2561–2580.

Errington, R. (2008). *A history of the Hellenistic world: 323-30 B.C.* Malden: Blackwell Publishing.

Erskine, A. (Ed.). (2005). *A companion to the Hellenistic World*. Oxford: Blackwell Publishing.

Evans, J. A., Montgomery, J., Wildman, G., & Boulton, N. (2010). Spatial variations in biosphere $^{87}Sr/^{86}Sr$ in Britain. *Journal of the Geological Society*, *167*(1), 1–4.

Ezzo, J. A. (1994). Putting the "chemistry" back into archaeological bone chemistry analysis: modeling potential paleodietary indicators. *Journal of Anthropological Archaeology*, *13*(1), 1–34.

Ezzo, J. A., Johnson, C. M., & Price, T. D. (1997). Analytical perspectives on prehistoric migration: a case study from east-central Arizona. *Journal of Archaeological Science*, *24*(5), 447–466.

Fogel, M., Tuross, N., & Owsley, D. (1989). Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Carnegie Institution Year Book*, *88*, 111–117.

Francey, R., & Farquhar, G. (1982). An explanation of $^{13}C/^{12}C$ variations in tree rings. *Nature*, *297*, 28–31.

Freeman, P. (2011). *Alexander the Great*. New York: Simon and Schuster.

Froehle, A. W., Kellner, C. M., & Schoeninger, M. J. (2010). FOCUS: effect of diet and protein source on carbon stable isotope ratios in collagen: follow up to Warinner and Tuross (2009). *Journal of Archaeological Science*, *37*(10), 2662–2670.

Fry, B. (2006). *Stable isotope ecology*. New York: Springer.

Fry, B., & Sherr, E. (1984). $\delta^{13}C$ measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contributions in Marine Science*, *27*, 13–47.

Fuller, B., Fuller, J., Harris, D., & Hedges, R. (2006). Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. *American Journal of Physical Anthropology*, *129*, 279–293.

Gage, J., Francis, M., & Triffitt, J. (1989). *Collagen and dental matrices*. London: Wright.

Garant, P. (2003). *Oral cells and tissues*. Chicago: Quintessence Publishing Co.

Garland, R. (1998). *Daily life of the Ancient Greeks*. Westport: Greenwood Press.

Garnsey, P. (1999). *Food and Society in Classical Antiquity*. Cambridge: Cambridge University Press.

Garvie-Lok, S. (2001). *Loaves and fishes: a stable isotope reconstruction of diet in medieval Greece* (PhD Thesis). University of Calgary, Calgary.

Garvie-Lok, S. (2009). Population mobility at Frankish Corinth: Evidence from stable oxygen isotope ratios of tooth enamel. *Hesperia Supplements*, *43*, 245–256.

Garvie-Lok, S. (2009a). Human remains from the fortress of Mytilene. In J. Bintliff & H. Stoger (Eds.). *Medieval and Post-Medieval Greece: The Corfu Papers,* Oxford: Archaeopress, 115-120.

Garvie-Lok, S. (2013). Isthmia IX: The Roman and Byzantine Graves and Human Remains. The American School of Classical Studies at Athens. *American Journal of Physical Anthropology*, *151*(4), 668–669.

Garvie-Lok, S. (2014). Human Skeletal Remains. In G. Schaus (Ed.), *Stymphalos the Acropolis Sanctuary, Vol 1*. Toronto: University of Toronto Press.

Garvie-Lok, S. J., Varney, T. L., & Katzenberg, M. A. (2004). Preparation of bone carbonate for stable isotope analysis: the effects of treatment time and acid concentration. *Journal of Archaeological Science*, *31*(6), 763–776.

Gil, A. F., Neme, G. A., Ugan, A., & Tykot, R. H. (2014). Oxygen Isotopes and Human Residential Mobility in Central Western Argentina: Oxygen Isotopes and Mobility in Western Argentina. *International Journal of Osteoarchaeology*, *24*(1), 31–41.

Gilman, S. (2004). *Fat Boys*. London: University of Nebraska Press.

Giménez-Miralles, J. E., Salazar, D. M., & Solana, I. (1999). Regional origin assignment of red wines from Valencia (Spain) by (2)H NMR and (13)C IRMS stable isotope analysis of fermentative ethanol. *Journal of Agricultural and Food Chemistry*, *47*(7), 2645–2652.

Gopalakrishnan, S., & Vijayavel, K. (2009). Nutritional composition of three estuarine bivalve mussels, Perna viridis, Donax cuneatus and Meretrix meretrix. *International Journal of Food Sciences and Nutrition*, *60*(6), 458–463.

Grimes, V., & Pellegrini, M. (2013). A comparison of pretreatment methods for the analysis of phosphate oxygen isotope ratios in bioapatite. *Rapid Communications in Mass Spectrometry*, *27*(3), 375–390.

Grupe, G., Price, T. D., Schröter, P., Söllner, F., Johnson, C., & Beard, B. (1997). Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains. *Applied Geochemistry*, *12*(4), 517–525.

Grupe, G., Price, T. D., & Söllner, F. (1999). Mobility of Bell Beaker people revealed by strontium isotope ratios of tooth and bone: a study of southern Bavarian skeletal remains. A reply to the comment by Peter Horn and Dieter Müller-Sohnius. *Applied Geochemistry*, *14*, 271–275.

Haagsma, M. J. (2003). The Houses of New Halos. In *Housing in New Halos: A Hellenistic town in Thessaly, Greece* (pp. 37–79). Lisse: A.A. Balkema Publishers.

Haagsma, M. J. (2010). *Domestic economy and social organization in New Halos*. Groningen: University Library Groningen.

Haagsma, M. J., Karapanou, S., Harvery, T., & Surtees, L. (2011). An Ancient City and its Agora. Result of the Archaeological Project at the Kastro of kallithea, Greece. In E. Giannikouri (Ed.), *The Agora in the Mediterranean: from Homeric to Roman Times,* (pp. 197–209). Organized by the Archaeological Institute for Aegean Studies, the Hellenic Ministry of Economy, Competitiveness and Shipping and the Hellenic Ministry of Culture and Tourism.

Haagsma, M. J., Karapanou, S., & Surtees, L. (2015). The Greek-Canadian Archaeological Project at Hastro Kallithea. A report on the 2006-2011 seasons. *Αρχαιολογικό Έργο Θεσσαλίας Και Στέρεας Ελλάδας. Πρακτικά Επιστημονικής Συνάντησης 4. Βόλος.*, 245–249.

Habicht, C. (2006). *The Hellenistic monarchies: selected papers*. Ann Arbor: University of Michigan.

Halstead, P. (2007). Carcasses and commensality: investigating the social context of meat consumption in Neolithic and Early Bronze Age Greece. In C. Mee & J. Renard (Eds.), *Cooking up the past: Food and Culinary Practices in the Neolithic and Bronze Age Aegean*. Oxford: Oxbow Books.

Hamilakis, Y. (1999). The anthropology of food and drink consumption and Aegean archaeology. In S. J. Vaughan & W. D. E. Coulson (Eds.), *Palaeodiet in the Aegean*. Oxford: Oxbow Books.

Hanson, D. B., & Buikstra, J. E. (1987). Histomorphological alteration in buried human bone from the lower Illinois Valley: Implications for palaeodietary research. *Journal of Archaeological Science*, *14*(5), 549–563.

Heater, D. (2004). *A Brief History of Citizenship*. New York: New York University Press.

Hedges, R. E. M. (2003). On bone collagen-apatite-carbonate isotopic relationships. *International Journal of Osteoarchaeology*, *13*(1–2), 66–79.

Hedges, R. E. M., Clement, J. G., Thomas, C. D. L., & O'connell, T. C. (2007). Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. *American Journal of Physical Anthropology*, *133*(2), 808–816.

Hedges, R. E. M., & Millard, A. R. (1995). Bones and groundwater: towards the modelling of diagenetic processes. *Journal of Archaeological Science*, *22*(2), 155–164.

Higgins, M., & Higgins, R. (1996). The Geological Background. In *A Geological companion to Greece and the Aegean*. London: Cornell Univ Press.

Hillson, S. (1996). *Dental Anthropology*. Cambridge: Cambridge University Press.

Hobson, K. A., Alisauskas, R. T., & Clark, R. G. (1993). Stable-Nitrogen Isotope Enrichment in Avian Tissues Due to Fasting and Nutritional Stress: Implications for Isotopic Analyses of Diet. *The Condor*, *95*(2), 388–394.

Hoefs, J. (2009). *Stable isotope geochemistry 6th edition*. Berlin: Springer.

Hoppe, K. A., Koch, P. L., & Furutani, T. T. (2003). Assessing the preservation of biogenic strontium in fossil bones and tooth enamel. *International Journal of Osteoarchaeology*, *13*(1–2), 20–28.

Howland, M., Corr, L., Young, S., Jones, V., Jim, S., van der Merwe, N. J., … Evershed, R. (2003). Expression of the dietary isotope signal in the compound-specific $\delta^{13}C$ values of pig bone lipids and amino acids. *International Journal of Osteoarchaeology*, *13*, 54–65.

IGSR, (Institute for Geology and Subsurface Research). (1957). Geological Map of Greece (Domokos, Anavra and Almyros sheets). Kallithea (Athens).

Isager, S., & Skydsgaard, J. (1992). *Ancient Greek Agriculture*. London: Routledge.

Jahns, S. (1993). On the Holocene vegetation history of the Argive Plain (Peloponnese, southern Greece). *Vegetation History and Archaeobotany*, *2*(4), 187–203.

Jameson, M. (1988). Sacrifice and Animal Husbandry in Classical Greece. In C. Whittaker (Ed.), *Pastoral Economies in Classical Antiquity* (Supplementary Vol 14, pp. 87–119). Cambridge: Cambridge Philological Society.

Jameson, M. (1990). Domestic Space and the Greek city-state. In S. Kent (Ed.), *Domestic Architecture and the Use of Space* (pp. 92–114). Cambridge: Cambridge University Press.

Jans, M. M. E., Nielsen-Marsh, C. M., Smith, C. I., Collins, M. J., & Kars, H. (2004). Characterisation of microbial attack on archaeological bone. *Journal of Archaeological Science*, *31*(1), 87–95.

Jennings, S., Renones, O., Morales-Nin, B., Polunin, N., Moranta, J., & Coll, J. (1997). Spatial variation in the ^{15}N and ^{13}C stable isotope composition of plants, invertebrates and fishes on Mediterranean reefs: implications for the study of trophic pathways. *Marine Ecology Progress Series*, *146*, 109–116.

Jim, S., Ambrose, S. H., & Evershed, R. (2004). Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen, and apatite: implications for their use in palaeodietary reconstruction. *Geochimica et Cosmochimica Acta*, *68*, 61–72.

Jones, J. E., Graham, A. J., & Sackett, L. H. (1973). An Attic Country House below the Cave of Pan at Vari. *The Annual of the British School at Athens*, *68*, 355–452.

Jones, J. E., Sackett, L. H., & Graham, A. J. (1962). The Dema house in Attica. *The Annual of the British School at Athens*, *57*, 75–114.

Jørkov, M. L., Heinemeier, J., & Lynnerup, N. (2007). Evaluating bone collagen extraction methods for stable isotope analysis in dietary studies. *Journal of Archaeological Science*, *34*, 1824–1829.

Juteau, M., Michard, A., & Albarded, F. (1986). The Pb-Sr-Nd isotope geochemistry of some recent circum-Mediterranean granties. *Contributions to Mineralogy and Petrology*, *92*, 331–340.

Katzenberg, M. A. (1989). Stable Isotope Analysis of Archaeological Faunal Remains from Southern Ontario. *Journal of Archaeological Science*, *16*, 319–329.

Katzenberg, M. A. (1992). Advances in stable isotope analysis of prehistoric bones. In S. R. Saunders & M. Katzenberg (Eds.), *Skeletal biology of past peoples: Research methods.* (pp. 105–120). New York: Wiley-Liss.

Katzenberg, M. A. (2008). Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In M. Katzenberg & S. Saunders (Eds.), *Biological Anthropology of the Human Skeleton* (pp. 411–441). John Wiley & Sons, Inc.

Katzenberg, M. A., & Harrison, R. G. (1997). What's in a bone? Recent advances in archaeological bone chemistry. *Journal of Archaeological Research*, *5*(3), 265–293.

Katzenberg, M. A., & Lovell, N. (1999). Stable Isotope Variation in Pathological Bone. *International Journal of Osteoarchaeology*, *9*, 316–324.

Katzenberg, M. A., McKenzie, H. G., Losey, R. J., Goriunova, O. I., & Weber, A. (2012). Prehistoric dietary adaptations among hunter-fisher-gatherers from the Little Sea of Lake Baikal, Siberia, Russian Federation. *Journal of Archaeological Science*, *39*(8), 2612–2626.

Katzenberg, M. A., & Saunders, S. R. (2000). *Biological Anthropology of the Human Skeleton*. New York: Wiley-Liss.

Katzenberg, M. A., Schwarcz, H. P., Knyf, M., & Melbye, F. J. (1995). Stable Isotope Evidence for Maize Horticulture and Paleodiet in Southern Ontario, Canada. *American Antiquity*, *60*(2), 335–350.

Katzenberg, M. A., & Weber, A. (1999). Stable isotope ecology and palaeodiet in the Lake Baikal region of Siberia. *Journal of Archaeological Science*, *26*, 651–659.

Keenleyside, A., Schwarcz, H. P., & Panayotova, K. (2011). Oxygen isotopic evidence of residence and migration in a Greek colonial population on the Black Sea. *Journal of Archaeological Science*, *38*(10), 2658–2666.

Keenleyside, A., Schwarcz, H., & Panayotova, K. (2006). Stable isotopic evidence of diet in a Greek colonial population from the Black Sea. *Journal of Archaeological Science*, *33*(9), 1205–1215.

Kellner, C. M., & Schoeninger, M. J. (2007). A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology*, *133*(4), 1112–1127.

Knudson, K. J. (2009). Oxygen isotope analysis in a land of environmental extremes: the complexities of isotopic work in the Andes. *International Journal of Osteoarchaeology*, *19*(2), 171–191.

Knudson, K. J., Price, T. D., Buikstra, J., & Blom, D. (2004). The use of strontium isotope analysis to investigate Tiwanaku migration and mortuary ritual in Bolivia and Peru. *Archaeometry*, *46*, 5–18.

Knudson, K. J., Tung, T., Nystrom, K., Price, T. D., & Fullagar, P. (2005). The origin of the Juch'uypampa Cave mummies: strontium isotope analysis of archaeological human remains from Bolivia. *Journal of Archaeological Science*, *32*, 903–913.

Kohn, M. J. (1996). Predicting animal $\delta^{18}O$: Accounting for diet and physiological adaptation. *Geochimica et Cosmochimica Acta*, *60*(23), 4811–4829.

Kravaritou, S. (2011). Synoecism and religious interface in Demetrias (Thessaly). *Kernos. Revue Internationale et Pluridisciplinaire de Religion Grecque Antique*, (24), 111–135.

Krueger, H. W. (1991). Exchange of carbon with biological apatite. *Journal of Archaeological Science*, *18*(3), 355–361.

Krueger, H. W., & Sullivan, C. (1984). Models for carbon isotope fractionation between diet and bone. In J. Turnlund & P. Johnson (Eds.), *Stable Isotopes in Nutrition*. Washington: American Chemical Society Symposium Series.

Kyparissi-Apostolika, N. (2003). The Mesolithic in Theopetra Cave: new data on a debated period of Greek prehistory. *British School at Athens Studies*, *10*, 189–198.

Laffoon, J. E., Rojas, R. V., & Hofman, C. L. (2013).Oxygen and carbon isotope analysis of human dental enamel from the Caribbean: Implications for investigating individual origins: Analysis of human dental enamel from the Caribbean. *Archaeometry*, *55*(4), 742–765.

Landis, W. J. (1995). The strength of a calcified tissue depends in part on the molecular structure and organization of its constituent mineral crystals in their organic matrix. *Bone*, *16*(5), 533–544.

Lê, M. (2006). *Frankish conqueror or acculturated Greek? Investigating Birthplace and Cultural Integration at a 13th century cemetery in Corinth using strontium isotope analysis* (MA Thesis). University of Alberta, Edmonton.

Lee-Thorp, J. A. (2008). On isotopes and old bones. *Archaeometry*, *50*, 925–950.

Lee-Thorp, J. A., Sealy, J. C., & van der Merwe, N. J. (1989). Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science*, *16*(6), 585–599.

Leslie, B. G. (2012). *Residential Mobility in the Rural Greek Past: A strontium isotope investigation* (MA Thesis). University of Alberta, Edmonton.

Loftus, E., & Sealy, J. (2012). Technical note: interpreting stable carbon isotopes in human tooth enamel: an examination of tissue spacing from South Africa. *American Journal of Physical Anthropology*, *147*, 499–507.

Lolos, Y. (2011). *The Town Planning of Hellenistic Sicyon*. Archaologischer Anzeiger.

Longin, R. (1971). New Method of Collagen Extraction for Radiocarbon Dating. *Nature*, *230*(5291), 241–242.

Longinelli, A. (1984). Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta*, *48*(2), 385–390.

Longrigg, J. (1998). *Greek medicine: From the heroic to the Hellenistic Age: A source book*. London: Duckworth.

Lyngstadaas, S. (1995). *On the molecular biology of tooth formation: biomineralization, structure, evolution and genetics of calcified dental tissues*. University of Oslo, Oslo.

Malakasioti, Z. (1985). Almiros. *Archaiologikon Deltion, Chronika*, *40*(1), 184–185.

Malakasioti, Z. (1992). Platanos Almirou. *Archaiologikon Deltion, Chronika*, *47*(1), 228–234.

Malakasioti, Z. (1993). Platanos Almirou. *Archaiologikon Deltion, Chronika*, *48*(1), 238–240.

Malakasioti, Z. (2001). Voulokaliva. *Archaiologikon Deltion, Chronika*, *56–59*, 487–489.

Malakasioti, Z. (n.d.). *Halos: Cemeteries of the Hellenistic city (Unpublished PhD dissertation and cemetery catalogue)*. Greece.

Malakasioti, Z., & Rondiri, V. (1990). Platanos Almirou. *Archaiologikon Deltion, Chronika*, *45*(1), 203–204.

Manville, P. B. (2014). *The Origins of Citizenship in Ancient Athens*. New Jersey: Princeton University Press.

McConnan Borstad, C. A. (2013). *After the earthquake: dietary resource use during the Hellenistic, Roman and Byzantine periods at Helike, Greece* (MA Thesis). University of Alberta, Edmonton.

Mee, C. (2011). *Greek Archaeology: A Thematic Approach*. Malden: Wiley-Blackwell.

Meeks, J. C., & Elhai, J. (2002). Regulation of Cellular Differentiation in Filamentous Cyanobacteria in Free-Living and Plant-Associated Symbiotic Growth States. *Microbiology and Molecular Biology Reviews*, *66*(1), 94–121.

Migeotte, L. (2009). *The economy of the Greek cities: from the archaic period to the early Roman Empire*. Berkeley: University of California Press.

Miller, E. (1984). Chemistry of the collagens and their distribution. In K. Piez & A. Reddi (Eds.), *Extracellular Matrix Biochemistry*. New York: Elsevier.

Miller, F. (2012). Aristotle's Political Theory. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Fall 2012).

Minagawa, M., & Wada, E. (1984). Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between $\delta^{15}N$ and animal age. *Geochimica et Cosmochimica Acta*, *48*, 1135–1140.

Molkentin, J. (2009). Authentication of Organic Milk Using $\delta^{13}C$ and the α-Linolenic Acid Content of Milk Fat. *Journal of Agriculture and Food Chemistry*, 57, 785-790.

Montgomery, J. (2010). Passports from the past: Investigating human dispersals using strontium isotope anlysis of tooth enamel. *Annals of Human Biology*, *37*(3), 325–346.

Montgomery, J., Evans, J. A., Powlesland, D., & Roberts, C. A. (2005). Continuity or colonization in Anglo-Saxon England? Isotope evidence for mobility, subsistence practice, and status at West Heslerton. *American Journal of Physical Anthropology*, *126*(2), 123–138.

Morris, I., & Powell, B. B. (2010). *The Greeks: history, culture, and society*. Upper Saddle River, NJ: Prentice Hall.

Nafplioti, A. (2008). "Mycenaean" political domination of Knossos following the Late Minoan IB destructions on Crete: negative evidence from strontium isotope ratio analysis ($^{87}Sr/^{86}Sr$). *Journal of Archaeological Science*, *35*(8), 2307–2317.

Nafplioti, A. (2011). Tracing population mobility in the Aegean using isotope geochemistry: a first map of local biologically available $^{87}Sr/^{86}Sr$ signatures. *Journal of Archaeological Science*, *38*(7), 1560–1570.

Nardo, D. (2000). *Women of Ancient Greece*. San Diego: Lucent Books.

Nevett, L. (1995). Gender relations in the classical Greek household. The archaeological evidence. *The Annual of the British School at Athens*, pp. 363–381.

Nevett, L. (1999). *House and society in the ancient Greek world*. Cambridge: Cambridge University Press.

Nielsen, I. (1994). *Hellenistic palaces: tradition and renewal*. Aarhus: Aarhus University Press.

Nowell, G.M, & Horstwood, M.S.A. (2009) Comments on Richards et al., Journal of Archaeological Science 35, 2008 "Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS". *Journal of Archaeological Science*, 36, 1334-1341.

Ogden, D. (Ed.). (2002). *The Hellenistic world: new perspectives*. London: Classical Press of Wales.

O'Leary, M. (1981). Carbon isotope fractionation in plants. *Phytochemistry*, *20*, 553–567.

Palagia, O. (1992). Cult and allegory: The life story of Artemidoros of Perge. In J. Motyka Sanders (Ed.), *Philolakon: Lakonian Studies in Honour of Hector Catling* (pp. 171–177). London: The British School at Athens.

Panagiotopoulou, E., van der Plicht, J., Papathanasiou, A., Voutsaki, S., Nikolaou, E., & Tsiouka, F. (2016). Isotopic (^{13}C, ^{15}N) investigation of diet and social structure in Early Iron Age Halos, Greece. *Journal of Archaeological Science: Reports*, *10*, 212–220.

Papathanasiou, A. (2003). Stable isotope analysis in Neolithic Greece and possible implications on human health. *International Journal of Osteoarchaeology*, *13*(5), 314–324.

Pellegrini, M., Lee-Thorp, J. A., & Donahue, R. (2011). Exploring the variation of the δ^{18}Op and δ^{18}Oc relationship in enamel increments. *Palaeogeography, Palaeoclimatology, Palaeoecology*, *310*, 71–83.

Pemberton, E. G. (1985). Ten Hellenistic Graves in Ancient Corinth. *Hesperia*, *54*(3), 271.

Pennycook, C. (2008). *A stable isotope reconstruction of Byzantine and Frankish Greek diet in the Valley of Stymphalos* (MA Thesis). University of Alberta, Edmonton.

Peoples, M., Herridge, D., & Ladha, J. (1995). Biological nitrogen fixation: an efficient source of nitrogen for sustainable agriculture production? *Plant and Soil*, *174*, 2–28.

Petroutsa, E. I., & Manolis, S. K. (2010). Reconstructing Late Bronze Age diet in mainland Greece using stable isotope analysis. *Journal of Archaeological Science*, *37*(3), 614–620.

Pfeiffer, S., & Varney, T. L. (2002). Quantifying Histological and Chemical Preservation in Archaeological Bone. In S. H. Ambrose & M. A. Katzenberg (Eds.), *Biogeochemical Approaches to Paleodietary Analysis* (pp. 141–158). Springer US.

Pfeiffer, S., Williamson, R., Sealy, J. C., & Smith, D. (2014). Stable dietary isotopes and mtDNA from Woodland period southern Ontario people: results from a tooth sampling protocol. *Journal of Archaeological Science*, *42*, 334–345.

Pinnegar, J. K., & Polunin, N. V. C. (2000). Contributions of stable-isotope data to elucidating food webs of Mediterranean rocky littoral fishes. *Oecologia*, *122*(3), 399–409.

Pomeroy, S. B. (1995). *Goddesses, Whores, Wives, and Slaves: Women in Classical Antiquity*. Random House LLC.

Pomeroy, S. B. (1997). *Families in Classical and Hellenistic Greece: representations and Realities*. Oxford: Clarendon Press.

Postgate, J. (1981). Microbiology of the free-living nitrogen-fixing bacteria, excluding cyanobacteria. In A. Gibson & W. Newton (Eds.), *Current perspectives in nitrogen fixation* (pp. 217–228). Amsterdam: Elsevier/North-Holland Biomedical.

Preziosi, D., & Hitchock, L. (1999). *Aegean Art and Architecture*. Oxford: Oxford University Press.

Price, T. D., Blitz, J., Burton, J., & Ezzo, J. A. (1992). Diagenesis in prehistoric bone: Problems and solutions. *Journal of Archaeological Science*, *19*(5), 513–529.

Price, T. D., Burton, J. H., & Bentley, R. A. (2002). The characterization of biologically available strontium isotope ratios for the study of prehistoric migration. *Archaeometry*, *44*(1), 117–135.

Price, T. D., Knipper, C., Grupe, G., & Smrcka, V. (2004). Strontium Isotopes and Prehistoric Human Migration: The Bell Beaker Period in Central Europe. *European Journal of Archaeology*, *7*(1), 9–40.

Price, T. D., Mansanilla, L., & Middleton, W. (2000). Immigration and the ancient city of Teotihuacan in Mexico: A study using strontium isotope ratios in human bone and teeth. *Journal of Archaeological Science*, *27*, 903–913.

Price, T. D (1989). *The Chemistry of prehistoric bone*. Cambridge: Cambridge University Press.

Prowse, T.L., Schwarcz, H.P., Saunders, S.R., Macchiarelli, R., & Bondioli, L. (2004). Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science*. 31, 259-272.

Prummel, W. (2003). Animal Husbandry and mollusk gathering. In H. Reinders & W. Prummel (Eds.), *Housing in New Halos: a Hellenistic Town in Thessaly, Greece* (pp. 175–223). Lisse: A.A. Balkema Publishers.

Reinders, H. R. (1986). Hellenistic New Towns on the Pagasitic Gulf. *Bulletin Antieke Beschaving*, *61*, 34–40.

Reinders, H. R. (1988a). *New Halos: A Hellenistic Town in Thessalia, Greece*. Utrecht: HES Publishers.

Reinders, H. R. (1988). The investigation of the Hellenistic city of Halos, 1987 campaign. *Netherlands Institute at Athens. Newsletter*, *1*, 24–27.

Reinders, H. R. (2003). Coins. In H. R. Reinders & W. Prummel (Eds.), *A Hellenistic Town in Thessaly, Greece*. Lisse: Swets and Zeitlinger.

Reinders, H. R. (2003a). Beginning and end of the occupation of New Halos. In *Housing in New Halos: A Hellenistic town in Thessaly, Greece* (pp. 231–247). Lisse: A.A. Balkema Publishers.

Reinders, H. R. (2003b). New Halos in Achaia Phthiotis. In *Housing in New Halos: A Hellenistic town in Thessaly,Greece* (pp. 7–35). Lisse: A.A. Balkema Publishers.

Reinders, H. R. (2004). *Prehistoric Sites at the Almirós and Soúrpi Plains (Thessaly, Greece)*. Koninklijke Van Gorcum.

Reinders, H. R. (2009). The Hellenistic City of New Halos: A Creation of Demetrios Poliorketes? *AETHSE (Greek)*, *2*, 369–379.

Reinders, H. R., Bergmans, M., Malakasioti, Z., & Tsouka, F. (2011). The excavation of the House of the Tub in Hellenistic Halos. Prelimenary report on the 2007-2009 field seasons. *Pharos*, *17.2*, 83–106.

Reinders, H. R., & Bottema, S. (1983). Investigations at Halos and Zerelia. Preliminary report 1982. *Bulletin Antieke Beschaving*, *58*, 91–100.

Reinders, H. R., & Prummel, W. (2003). *Housing in New Halos: A Hellenistic Town in Thessaly, Greece*. Lisse: Swets and Zeitlinger.

Reinders, H. R. (2014). *The City of New Halos and its Southeast Gate*. Barkhuis.

Reinders, H. R. (1983). Halos, a Hellenistic Town in Thessaly. In D. Keller & D. Rupp (Eds.), *Archaeological Survey in the Mediterranean Area* Oxford: BAR. (pp. 217–218).

Reinders, H. R., Fijma, P., Malakasioti, Z., & Rondiri, V. (2000). An archaeological survey of the Sourpi plain (Thessaly, Greece). *Pharos*, *8*, 83–92.

Richards, M., Harvait, K., Grimes, V., Smith, C., Smith, T., Hublin, J., … Panagopoulou, E. (2008). Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS. *Journal of Archaeological Science*, *35*, 1251–1256.

Richards, M. P., & Hedges, R. E. M. (2008). Stable isotope evidence of past human diet at the sites of the Neolithic cave of Gerani; the Late Minoan III cemetery of Armenoi;... In *Archaeology Meets Science: Biomolecular Investigations in Bronze Age Greece* (pp. 220–230). Oxbow Books.

Rosenthal, H. L., Cochran, O. A., & Eves, M. M. (1972). Strontium content of mammalian bone, diet and excreta. *Environmental Research*, *5*(2), 182–191.

Rossmann, A., Schmidt, H. L., Reniero, F., Versini, G., Moussa, I., & Merle, M. H. (1996). Stable carbon isotope content in ethanol of EC data bank wines from Italy, France and Germany. *Zeitschrift Für Lebensmittel-Untersuchung Und Forschung*, *203*(3), 293–301.

Royer, A., Gerard, C., Naulet, N., Lees, M., & Martin, G. J. (1999). Stable isotope characterization of olive oils. I-Compositional and carbon-13 profiles of fatty acids. *Journal of the American Oil Chemists' Society*, *76*(3), 357–363.

Runnels, C. (1988). A Prehistoric Survey of Thessaly: New Light on the Greek Middle Paleolithic. *Journal of Field Archaeology*, *15*(3), 277–290.

Runnels, C., & Murray, P. (2001). *Greece Before History: An Archaeology Companion and Guide*. Stanford: Stanford University Press.

Rupp, D. (2007). The Fieldwork of the Canadian Institute in Greece. *Mouseion*, *7*(2), 140–145.

Ruxton, G. (2006). The unequal variance t-test is an underused alternative to Student's t-test and the Mann-Whitney U test. *Behavioral Ecology*, *17*(4), 688–690.

Schoeninger, M. J., & DeNiro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, *48*, 625–639.

Schoeninger, M. J., DeNiro, M. J., & Tauber, H. (1983). Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science*, *220*(4604), 1381–1383.

Schoeninger, M. J., & Moore, K. (1992). Bone stable isotope studies in archaeology. *Journal of World Prehistory*, *6*(2), 247–296.

Schoeninger, M. J., Moore, K., Murray, M., & Kingston, J. (1989). Detection of bone preservation in archaeological and fossil samples. *Applied Geochemistry*, *4*, 281–292.

Schroeder, H. (1991). *Oral structural biology*. New York: Thieme.

Schroeder, H. A., Tipton, I. H., & Nason, A. P. (1972). Trace metals in man: Strontium and barium. *Journal of Chronic Diseases*, *25*(9), 491–517.

Schurr, M. (1997). Stable isotopes as evidence for the age of weaning at the Angel site: a comparison of isotopic and demographic measures of weaning age. *Journal of Archaeological Science*, *24*, 919–927.

Schwarcz, H., Melbye, F., Katzenberg, M., & Knyf, M. (1985). Stable isotopes in human skeletons of Southern Ontario: reconstructing palaeodiet. *Journal of Archaeological Science*, *12*, 187–206.

Schwarcz, H. P., White, C., & Longstaffe, F. J. (2010). Stable and radiogenic isotopes in biological archaeology: some applications. In J.B. West, G.J. Bowen, T.E. Dawson and K.P. Tu (Eds.). *Isoscapes* (pp. 335–356). Netherlands: Springer.

Sealy, J. C. (1989). The Use of Chemical Techniques for Reconstructing Prehistoric Diets: A Case Study in the South-Western Cape. *Goodwin Series*, *6*, 69–76.

Sealy, J C., Johnson, M., Richards, M., & Nehlich, O. (2014). Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing whole bone demineralization with gelatinization and ultrafiltration. *Journal of Archaeological Science*, *47*, 64–69.

Sealy, J. C., Merwe, N. J. van der, Hobson, K. A., Horton, D. R., Lewis, R. B., Parkington, J., … Schwarcz, H. P. (1986). Isotope Assessment and the Seasonal-Mobility Hypothesis in the Southwestern Cape of South Africa [and Comments and Replies]. *Current Anthropology*, *27*(2), 135–150.

Sealy, J. C., van der Merwe, N. J., Sillen, A., Kruger, F. J., & Krueger, H. W. (1991). $^{87}Sr/^{86}Sr$ as a Dietary Indicator in Modern and Archaeological Bone. *Journal of Archaeological Science*, *18*, 399–416.

Shearer, G., Kohl, D., & Chien, S. (1978). The nitrogen-15 abundance in a wide variety of soils. *Soil Science Society of America Journal*, *42*, 899–902.

Shin, J. Y., & Hedges, R. E. M. (2012). Diagenesis in bone and enamel apatite carbonate; the potential of density separation to assess the original composition. *Journal of Archaeological Science*, *39*(4), 1123–1130.

Shipley, G. (2000). *The Greek world after Alexander, 323-30 BC*. London ; New York : Routledge.

Sillen, A. (1986). Biogenic and Diagenetic Sr/Ca in Plio-Pleistocene Fossils of the Omo Shungura Formation. *Paleobiology*, *12*(3), 311–323.

Sillen, A., Sealy, J. C., & van der Merwe, N. J. (1989). Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity*, *54*(3), 504–512.

Skiadas, P. K., & Lascaratos, J. G. (2001). Dietetics in ancient Greek philosophy: Plato's concepts of healthy diet. *European Journal of Clinical Nutrition*, (7), 532.

Smith, B. (1972). Natural abundance of the stable isotopes of carbon in biological systems. *Plant Physiology*, *47*, 380–384.

Snodgrass, A. M. (1987). *An archaeology of Greece: the present state and future scope of a discipline*. Berkeley: University of California Press.

Spencer, N. (1995). *Time, tradition, and society in Greek archaeology: bridging the "great divide."* New York : Routledge.

Sponheimer, M., & Lee-Thorp, J. A. (1999). Oxygen Isotopes in Enamel Carbonate and their Ecological Significance. *Journal of Archaeological Science*, *26*(6), 723–728.

Stissi, V., Kwak, L., & de Winter, J. (2004). Early Iron Age. In H. R. Reinders (Ed.). *Prehistoric sites at the Almiros and Sourpi Plains (Thessaly, Greece)* (pp. 94–98). Koninklijke Van Gorcum: Assen.

Tarn, W. W., & Griffith, G. T. (1961). *Hellenistic civilisation*. Cleveland: World Publishing Co.

Tieszen, L. L. (1991). Natural variations in the carbon isotope values of plants: Implications for archaeology, ecology, and paleoecology. *Journal of Archaeological Science*, *18*, 227–248.

Tieszen, L. L., & Fagre, T. (1993). Effect of diet quality and composition on the isotopic compostion of respiratory CO_2, bone collagen, bioapatite, and soft tissues. In J.B. Lambert and G. Grupe (Eds.). *Prehistoric human bone: archaeology at the molecular level* (pp. 121–155). Berlin: Springer-Verlag.

Tieszen, L. L., Senyimba, M., Imbamba, S., & Troughton, J. (1979). The distribution of C3 and C4 grasses and carbon isotope discrimination along an altitudinal and moisture gradient in Kenya. *Oecologia*, *37*, 337–350.

Tremba, E. L., Faure, G., Katsikatsos, G. C., & Summerson, C. H. (1975). Strontium-isotope composition in the Tethys Sea, Euboea, Greece. *Chemical Geology*, *16*(2), 109–120.

Trentmann, F. (2012). *The Oxford Handbook of the History of Consumption*. OUP Oxford.

Triantaphyllou, S., Richards, M. P., Zerner, C., & Voutsaki, S. (2008). Isotopic dietary reconstruction of humans from Middle Bronze Age Lerna, Argolid, Greece. *Journal of Archaeological Science*, *35*(11), 3028–3034.

Turner, B. L., Kamenov, G. D., Kingston, J. D., & Armelagos, G. J. (2009). Insights into immigration and social class at Machu Picchu, Peru based on oxygen, strontium, and lead isotopic analysis. *Journal of Archaeological Science*, (2), 317.

Tziafalias, A., Haagsma, M. J., Karapanou, S., & Gouglas, S. (2006). Scratching the Surface: A Preliminary Report on the 2004 and 2005 Seasons from the Urban Survey Project at Kastro Kallithea ("Peuma"), Thessaly. *Mouseion*, *6*(2), 91.

van der Merwe, N. J., Sealy, J. C., & Yates, R. (1987). First accelerator carbon-14 date for pigment from a rock painting. *Current Anthropology*, *83*, 56–57.

van Klinken, G. J. (1999). Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science*, *26*(6), 687–695.

van Klinken, G. J., Richards, M. P., & Hedges, R. E. M. (2000). An overview of causes for stable isotopic variation in past European human populations: Environmental, ecophysical and cultural effects. In S. H. Ambrose & Katzenberg, MA (Eds.),

Biogeochemical Approaches to Paleodietary Analysis (pp. 39–64). New York: Kluwer Acedemic/ Plenum Publishers.

Veizer, J. (1989). Strontium isotope in seawater through time. *Annual Review Earth Planet Science*, *17*, 141–167.

Vika, E. (2011). Diachronic dietary reconstructions in ancient Thebes, Greece: results from stable isotope analysis. *Journal of Archaeological Science*, *38*, 1157–1136.

Vika, E., Aravantinos, V., & Richards, M. P. (2009). Aristophanes and stable isotopes: a taste for freshwater fish in Classical Thebes (Greece)? *Antiquity*, *83*(322), 1076–1083.

Vika, E., & Theodoropoulou, T. (2012). Re-investigating fish consumption in Greek antiquity: results from $\delta^{13}C$ and $\delta^{15}N$ analysis from fish bone collagen. *Journal of Archaeological Science*, *39*, 1618–1627.

Voerkelius, S., Lorenz, G. D., Rummel, S., Quétel, C. R., Heiss, G., Baxter, M., … Ueckermann, H. (2010). Strontium isotopic signatures of natural mineral waters, the reference to a simple geological map and its potential for authentication of food. *Food Chemistry*, *118*(4), 933–940.

Welles, C. B. (1934). *Royal correspondence in the Hellenistic period: a study in Greek epigraphy*. Chicago: Ares Publishers.

Westlake, H. D. (1969). *Thessaly in the fourth century B. C.* Methuen & Co., Ltd.

White, C. D., Longstaffe, F. J., & Law, K. R. (2001). Revisiting the Teotihuacan connection at Altun Ha. *Ancient Mesoamerica*, *12*(1), 65–72.

White, C. D., Spence, M. W., Longstaffe, F. J., & Law, K. R. (2000). Testing the Nature of Teotihuacán Imperialism at Kaminaljuyú Using Phosphate Oxygen-Isotope Ratios. *Journal of Anthropological Research*, *56*(4), 535–558.

White, C. D., Spence, M. W., Longstaffe, F. J., & Law, K. R. (2004). Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. *Journal of Anthropological Archaeology*, *23*(4), 385–403.

White, C. D., Spence, M. W., Longstaffe, F. J., Stuart-Williams, H., & Law, K. R. (2002). Geographic Identities of the Sacrificial Victims from the Feathered Serpent Pyramid, Teotihuacan: Implications for the Nature of State Power. *Latin American Antiquity*, *13*(2), 217–236.

White, T. D., & Folkens, P. (2005). *The Human Bone Manual*. Academic Press.

Whitley, J. (2001). *The Archaeology of Ancient Greece*. Cambridge: Cambridge University Press.

Wilkins, J. (2005). Fish as a source of food in antiquity. In T. Bekker-Nielsen (Ed.), *Ancient fishing and fish processing in the Black Sea region* (pp. 21–30). Aarhus : Aarhus University Press.

Wright, L. E. (2013). Examining childhood diets at Kaminaljuyu, Guatemala, Through stable isotopic analysis of sequential enamel microsamples. *Archaeometry*, *55*(1), 113–133.

Wright, L. E., & Schwarcz, H. P. (1998). Stable carbon and oxygen isotopes in human tooth enamel: Identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology*, *106*(1), 1–18.

Wright, L. E., & Schwarcz, H. P. (1999). Correspondence Between Stable Carbon, Oxygen and Nitrogen Isotopes in Human Tooth Enamel and Dentine: Infant Diets at Kaminaljuyú. *Journal of Archaeological Science*, *26*(9), 1159–1170.

Wright, P. A. (1995). Nitrogen excretion: three end products, many physiological roles. *Journal of Experimental Biology*, *198*(2), 273–281.

Young, P. (1992). Phylogenetic classification of nitrogen-fixing organisms. In G. Stacey, H. Evans, & R. Burris (Eds.), *Biological nitrogen fixation* (pp. 43–86). New York: Chapman and Hall Inc.

Zazzo, A., Lecuyer, C., & Mariotti, A. (2004). Experimentally-controlled carbon and oxygen isotope exchange between bioapatites and water under inorganic and microbially-mediated conditions. *Geochimica et Cosmochimica Acta*, *68*(1), 1–12.

Zeder, M. A. (2008). Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences*, *105*(33), 11597–11604.