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Multi-Isotope Analysis to Reconstruct Dietary and Migration Patterns of an Avar Population from Sajópetri, Hungary, AD 568-895

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Multi-Isotope Analysis to Reconstruct Dietary and Migration Patterns of an Avar Population from Sajópetri, Hungary, AD 568-895

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts Department of Anthropology College of Arts and Sciences University of South Florida

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Dedication

To my husband, Matthew, and daughter, Maddox, for their never ending moral support, encouragement, understanding, and inspiration.
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Abstract

The Avar were nomadic people from Central Asia who migrated into the Carpathian Basin in Central-Eastern Europe during the mid to late Migration Period (AD 568 – 895). Archaeological evaluation of grave goods and documentation of mortuary practices have been the primary means of understanding the Avar. However, this approach has largely neglected skeletal and biochemical analysis, in particular as these approaches relate to the biological variation, ancestry, and dietary patterns of the Avar.

There remains debate as to whether disparities existed among the socially stratified Avar population of ancient Hungary. It is argued by some that these disparities existed and were the result of differential access to nutritional resources. This hypothesis was tested using the unique properties of isotopes and their chemical signatures. In so doing, the qualitative work on the grave goods was augmented by an additional, quantifiable line of evidence.

To investigate social stratification among the Avar population, the techniques of chemical multi-isotope and osteological analysis were employed. Multi-isotopic analyses can be done on stable isotopes (carbon, nitrogen, and oxygen) and on the heavy isotopes (strontium and lead). The particular stable isotopes examined were carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$), and oxygen ($\delta^{18}O$). The heavy isotopes analyzed were strontium ($^{87}Sr/^{86}Sr$) and lead ($^{206}Pb/^{204}Pb$). Stable isotope analysis as well as ratio analysis of the heavy isotopes strontium ($^{87}Sr/^{86}Sr$) and lead ($^{206}Pb/^{204}Pb$) are well-established analytical chemistry methods for examining diverse aspects of diet and
mobility through specific geographic regions. The analysis was performed on samples derived from well-preserved tooth enamel and bones.

Reconstructing migration and dietary patterns at the Sajópetri cemetery site has helped estimate variability among social groups and between sexes in this population at the time of the Migration Period. Results of the heavy isotope analysis revealed that the Avar population were non-locals to the region, and the stable isotope analysis demonstrated that there was little variation between social groups with slightly higher variation between sexes. This research provides an empirical and analytical framework for further research into migration patterns and social class dynamics of late prehistoric Hungry. This study also adds existing research possibilities to the on-going biogeochemical studies conducted throughout Europe.
Chapter One
Introduction

The primary research objective of this project was to examine the ways and extent to which social stratification can be measured through the use of multi-isotopic analysis. This work focused on individuals that lived during the Migration Period. The research used isotope signatures from bone and enamel samples from twenty-seven individuals (n=27) collected from a historic cemetery in Sajópetri, Hungary. The results were compared to known geographic isotope values to gain insight into the subsistence and settlement patterns of the nomadic people of the northeast region of the Carpathian Basin.

The Avar were nomadic people from Central Asia who migrated into the Carpathian Basin during the mid to late Migration Period (6th to 9th century AD). This migration was precipitated due to a drought in Asia and accessibility to fertile land for agriculture (Lengyel, 1958; Kontler, 2002; Makoldi, 2011; Radovčić, 2011). This region is identified as East-Central Europe with current day Hungary positioned in the lowlands of the basin. The surrounding countries that include the Carpathian mountain range include: Slovakia, Ukraine, Romania, Serbia, Croatia, Slovenia, and Austria. The mountain range offered a geographic barrier and protection for the fertile lowlands of Hungary. Other incoming ethnic groups battled for this territory during the early Migration Period (1st to 5th century AD), but the Romans still had precedence and governance over this territory (Vida, 2003; Todd, 2002; Radovčić, 2011). Originally the Romans named this region the Pannonian Basin, but the region has also been
referred to as the Carpathian Basin. The two names have been used interchangeably in the historic and archaeological literature. This paper will use the descriptor of Carpathian Basin, as this is the more common usage in contemporary studies.

During the mid-Migration Period, the Roman Empire lost territorial power due to invasions of surrounding ethnic groups into the area. This was a result of poorly fortified exterior boundaries (Vida, 2003; Radovčić, 2011). The Avar population has historically been described as one of the most violent and aggressive of the invaders. More nuanced opinions, however, describe the Avar groups as important warriors who integrated with the local population, demonstrating the resiliency and adaptability of the Hungarian people. Scholars have also credited the Avar groups for playing a large part in gaining independence from the Romans (Vida, 2003, Radovčić, 2011).

Research Objectives

Stable and heavy isotope analysis can be used to investigate whether or not these are the remains of the Avar who migrated from Central Asia. Isotope analysis is the chemical analysis of different isotopes. Isotopes are forms of a specific element that have an additional neutron in the nucleus and occur normally in nature. Stable isotopes refer to nonradiogenic forms of isotopes of a specific element and heavy isotopes are generally radiogenic forms of isotopes with a decay rate that can be measured. The values or ratios of isotopes can be measured with specialized mass spectrometry. Differing amounts of atomic isotopes are found in varied geographic regions. By looking at the ratios of isotopes it is possible to make an estimation of geographic origins, dietary habits, and migration patterns of human populations (Kamenov, 2008; Giblin, 2011).
This variation also helps to delineate differences in diet and migration patterns of the assorted socio-economic groups within the Avar (Ambrose, 1990, 1991, 1993; Tykot, 2004, 2006).

Stable isotope analysis can also be utilized to identify the major agricultural crop consumed by the individual and population. Various agricultural crops grow better in certain regions due to the environment and climate. Utilizing the inherent isotope variety in crops from differing regions allows for placement of an individual via diet, as the isotopes of a geographic region will be absorbed in an individual from his or her diet (Ambrose, 1993; Tykot, 2004, 2006).

The skeletal remains and artifacts are currently housed at the Herman Ottó Múzeum in Miskolc, Hungary. Sajópetri is located only 15.6 km (9 miles) southeast from Miskolc, a city 183 km (113 mi) northeast from Budapest.(Figure 1.1) In modern times, the northeast region of the Carpathian Basin in Hungary is also referred to the Borsod-Abaúj-Zemplén (BAZ) region (Figure 1.2). The excavation of the historic Avar cemetery in Sajópetri was initiated due to the impending construction of the current interstate M30, southwest of the town (Makoldi, 2011). Figure 1.3 displays a map with the surrounding borders of Sajópetri. Figure 1.4 displays the Avar cemetery map with the burial plots that were sampled from the individual graves.

Several investigative methods were applied to complete the study: a) the documentation of the mortuary artifacts was examined to contextualize the burials in terms of social status; b) osteological analysis was performed to estimate the sex of the individuals. This was then used to determine the demographic structure of the sample population and compare biological profiles within the sampled population; c) stable and heavy isotopic ratios (n=54) were compared to identify dietary and migration patterns among the social groups.
Figure 1.1. Map of Hungary situated in the central eastern region of Europe. A) The town of Sajópetri is approximately 15.6 km (9 miles) from the city of Miskolc; B) The skeletal remains from the Sajópetri cemetery are located in Miskolc at the Herman Otto Museum (Google Maps, 2011).

There are well-documented archeological and cultural changes of the Hungarian Migration Period, but there is a shortage of bioarchaeological and biogeochemical research on the area. The main hypothesis states there is significant variation between the stable isotope ratios of carbon ($\delta^{13}$C), nitrogen ($\delta^{15}$N), and oxygen ($\delta^{18}$O) among the social classes and between sexes. This is due to disparities of nutritional resources available to individuals.
Figure 1.2. Map of Hungary’s county boundaries, Borsod-Abaúj-Zemplén (BAZ) region is located in the Northeast region of Hungary. Sajópetri is located 9 km southeast of Miskolc (CIA, 1994).

The secondary hypothesis states that the Avar were non-locals and estimates their location of origin to be likely the central Asia region. This will be demonstrated via analysis of the heavy isotope ratios ($^{87}\text{Sr}/^{86}\text{Sr}$) and ($^{206}\text{Pb}/^{204}\text{Pb}$). This research builds upon earlier works that
Figure 1.3. Google map (2012) of current Sajópetri, Hungary and its surrounding boundaries. The impending construction of the interstate M30 to the west of Sajópetri prompted the excavation of the Avar cemetery by the county’s archaeologists from the Herman Ottó Múzeum in 2005. The Google map (2012) represents the location of Sajópetri and the town’s surrounding border.

aims to understand processes underlying human behavior, and in particular, how skeletal remains provide evidence of events during the life of the individual and population (Gamble et al. 2001;
Figure 1.4. TÉRKÉP (Map of Sajópetri Cemetery, Modified from Makoldi, 2011)
The map includes the high status equestrian burials indicated in colored rectangles. The key below displays the chronological order of these burials (Modified from Makoldi, 2011).

**Key**
Red dashed circles: Burial number, tooth and bone sample collected for isotope analysis
- Yellow: Group I. A (AD 650-675)
- Green: Group I. B (AD 675-700)
- Pink: Group II. A (379.sir) (AD 720/725-750)
- Lilac: Group II. B (AD 720/725-750)
- Blue: Group III (AD 750-775/780)
- Light blue: Group IV (AD 775/780-820/830)
- Brown: Group V (AD 820-830-850/860)
Larsen, 2006; Leatherdale, 2013). The results of this study demonstrate local variation in the region but can also be used as a model for examining socially stratified groups in the archaeological record. Biogeochemical data from this cemetery excavation gives a broader insight into how socially stratified groups of the past had a diversity of diets due to differential access to resources. This differential access to resources was examined in the context of a widening social status that accompanied political stability later seen in the Conquering Period. This social stratification was evident during the Migration Period, and social classes identified include the nobility caste, warrior caste, and the “common folk” (Daim, 1984; Molnar, 2001). Differences in power among the populations likely inhibited some groups from accessing resources. The results of the study demonstrate significant variation found in the isotopic ratios among the social classes and between sexes due to possible differences in nutritional resources available to the individuals. Analyses of grave-goods interred with the burials were considered in conjunction with the isotope analyses to produce additional lines of supporting evidence of the socio-economic statuses of the individuals identified in this cemetery population (Pearson, 2000; Makoldi, 2011; Le Juray and Schutkowski, 2005; Buikstra and Scott, 2009). The dataset supports the hypothesis asserting that social status and sex are determinants of dietary variation. There are variables that could contribute to social stratification or economic class struggles among past and present populations. The investigation of social stratification involves a historic and political examination of power struggles that existed among the people. A political economy perspective is utilized as a framework to better understand how social stratification existed in the prehistoric Hungarian population during the transition from the early to late Migration Period (AD 568-895). Political economy theory incorporates the cultural history of the people, the class struggles
and conflicts, ethnicity, gender, culture as well as the politics of the population under investigation (Goodman and Leatherman, 1998; Carrier, 2012).

The Avar population was believed to have migrated into the Carpathian Basin in the 5th century AD, during the downfall of the Roman Empire. There were different ethnic populations that occupied the Carpathian Basin during that time period, and the political situation had become more complex with the advent of more groups migrating into the region. The use of a political-economy perspective will help situate how the incoming Avar population may have been affected by the outside forces, specifically the populations (or ethnic groups) that occupied the Hungarian region. The use of a political economy perspective can help situate and contextualize the biochemical and georeferencing data within a broader social framework: “it acknowledges that science cannot be separate from the people it studies and their conditions. It involves critical self-reflection, inclusion of social history and regional context, and exploration of social relations” and people or systems in power (Martin, 1998: 179).

A central view in political economy is that a “mode of production” and economic history what has shaped societies (Robotham, 2012). Historically, there are numerous scholars who have contributed to political economy theory, but Karl Marx has been noted as one of most influential founders for this theory (Roseberry, 1988). Marx’s theories on class conflict, interpretation of historic development, and how modes of production are related to labor forces have been issues anthropologists and scholars alike have addressed in their research (Roseberry, 1988). Firth (1975) had described some American anthropologists as ‘gut Marxists’ because of their concerns of “Western economic and political dominance of lesser developed societies”; the significance of migratory labor for a colonial system, of the origin of working class consciousness, of the political role of poverty, of class character and challenges (Firth, 1975; 25). The application of
political economy theory has been instrumental in understanding the economic and social impact of colonialism, such as how British colonialism impacted South Africa countries through mining: “the transformation of the land tenure...the breakdown of ‘tribal cohesion’, the rise of large-scale labor migration and its associated urbanization,” which has caused civil wars and changed the course of world history (Robotham, 2012).

Political economy is also helpful in looking at a pre-capitalist economy, more so for understanding the “modes of production” in a society and how it is impacted over time as it transitions into a capitalist economy (Robotham, 2012). In anthropology, the theoretical perspective has been used as an explanatory framework, as it inter-relates to social class conflict, gender issues, political systems, and cultural history (Roseberry, 1988). According to Robotham (2012) another important concept related to the ‘means of production’ is the ‘forces of production’, or the ‘objects of labor’, which includes the land, the raw materials (e.g. crops/agriculture), tools and technology. Although, the most important force of production is the “labor theory of value,” the actual human labor power and exploitation (Robotham, 2012; 44). He described economy as characterized by classes and a “characteristic form of the extraction of the surplus,” but the production of the regular surplus has led to class divisions. Historically, the transformation of kinship dominated economies transform into political societies and further onto the rise of the state (Robotham, 2012).

With a political economy perspective, I have addressed and contextualize the variation observed with the stable isotope value results in relation to possible gender role differences and social stratification. The Avar migrated into the Carpathian Basin in need of fertile land to farm and raise livestock in order to expand to survive and prosper. The Avar cemeteries, grave goods interred with the burials, and mortuary behavior has led to the interpretation that distinct social
classes had existed among their population (Kovrig, 1975; Young, 1978; Vida, 2003; Makoldi, 2011).

In Chapter Two, literature was selected which highlights previous bioarchaeology research that investigated how cultural and social factors can affect the biology of an individual and their community. More importantly, how social status, the sex of the individual, or traditional roles can play a major role in one’s health status and possible inequalities. The following chapter will also highlight stable and heavy isotope research from prehistoric populations that have aided in the reconstruction of dietary and migration patterns. These studies have enlightened our understanding of how social stratification has affected variation in isotope values within local populations. Chapter Two explains the different types of isotope analysis, and how to interpret isotope values to reconstruct dietary and migration patterns.

Chapter Three explains the Materials and Methods utilized for this research study. Chapter Four displays the stable and heavy isotope results for the Avar population recovered from the Sajópetri cemetery. Chapter Five discusses the results from the isotope analysis, possible interpretations, and compares the data to other regions throughout Europe. The comparison of data to other isotope research throughout Europe reveals differences and similarities in diet and migration patterns over time. In the last chapter, the Conclusion, a summary of the findings is given as well as suggestions for future work.
Chapter Two

Historical and Technical Perspectives

Previous Archaeological and Bioarchaeological Research

Bioarchaeology uses a holistic approach to understand how cultural and social factors of the past have affected the biology of the individual. Bioarchaeology combines biological data from skeletal remains within archaeological contexts to examine cultural and social adaptations of historic populations, activity and survival patterns, effects of nutrition on past populations and its effects on health and well-being (Stojanowski and Schillaci, 2006). Stojanowski and Schillaci (2006) utilized metric and non-metric traits of skeletal remains within cemetery contexts to investigate the degree of relatedness, families or social groups to create ideas about social structure. From kinship analysis, it is possible to describe burial practices, reconstruct mating patterns, identify the manner in which social families were created, and recreate the nature of attributed inequality in reference to social classes (Stojanowski and Schillaci, 2006).

Similar research had been completed by Gamble et al. (2001) in which they investigated the Chumash social organization during the late Middle Period through bioarchaeological data to better understand genetic relationships, health status, and activity. Gamble and colleagues coupled the bioarchaeological data with artifacts excavated within the burial context and ethnohistorical documents and ethnographic accounts. Through these multidisciplinary sources of data, it was possible to interpret the social significance of a ranked society within the hereditary elite of the Chumash society (Gamble et al., 2001). Gamble (2001) noted, with a
processual archaeology perspective, cemetery analysis emphasized the importance of the interplay between mortuary behavior and social structure (Gamble et al., 2001; Pearson, 2000). Pearson’s (2000) review of Klavs Randsborg and Colin Renfrew’s research on the social differentiation in Bronze Age Denmark linked correlations of metal grave goods with social status and gender. Pearson (2000) discussed that burial orientation, sex, and age of the individual tended to correspond with the wealth of grave goods. These researchers recognized that patterns in the mortuary practices of the deceased could provide them with valuable information about the social relations of the living. In the past, archaeologists have used this approach to make inferences about social organization and have explored the interpretive value of grave goods in association with bioarchaeological data on genetic relationships, health or biological fitness, and past occupational patterns for research on the social significance of burial practices (Gamble et al., 2001).

DeFrance (2009) discussed the use of animals as markers of social inequality and how it denotes social status among a population. Her research in zooarchaeology utilized the theory of political economy as a foundation to examine how societies have manipulated animal husbandry practices to provide food, but in turn can be used to denote high status and power. Animals have been used for the accrual of capital and wealth, social power, and to enhance monetary gain or other forms of economic compensation for political advantages (DeFrance, 2009). The presence of equestrian burials within the Avar Sajópetri cemetery is an example that highlights social hierarchy among the Avar population. The equestrian burials consistently had more grave goods located with the adjacent male individual and decorated horse accessories. The horses are seen as symbols of power and wealth. Women of elite status were also buried with large animals such as cows or pigs, and children were sometimes buried with small animals. In these cases, animals
interred with the burial can denote social status but are also symbolic ritual sacrifices and offerings (DeFrance, 2009; Makoldi, 2011).

The bioarchaeology research of Martin (1998) involved skeletal analysis of the precontact Native Americans in the American Southwest. Martin utilized a political economic perspective, which helped link studies of their past with current concerns of violence and inequalities of the Native American people in the present. Martin provided data and found patterns of violence and poor health conditions in the skeletal remains (La Plata Valley population) with higher frequencies among the women from the La Plata burial sites versus the men. The frequency of healed cranial trauma among women had a threefold increase (42.8 percent versus 14.2 percent) over men, and post-cranial trauma was twice as frequent among women as men (35.7 percent versus 14.2) (Martin, 1998). Health related infections observed in the skeletal remains were also disproportionately female (30.7 percent versus 6.2 percent). Martin noted that some of these skeletal infections could be by-products of the skeletal trauma. Enamel hypoplasias were more prevalent with the female remains, which is an indicator of childhood growth disruption due to malnutrition or illness. The use of a political-economic perspective can help situate and recognize how scientific data can complement possible trends, conditions and patterns of the people it studies. A political economic perspective involves the knowledge of social history, regional context, and explorations of fields of power and social relations for the population we wish to study (Martin, 1998).

Martin further delves into the possible factors for the wide discrepancy in trauma and infections between males and females. She noted that the upper arm bones of women exhibited the most occupational stress markers and trauma. The women were responsible for grinding the corn into meal and storing it for rations throughout the year. The corn grinding would take eight
to nine hours a day at the grindstone, and as the population increased so did the preparation and production of corn meal. A sexual division of labor for the Pueblo people existed where the women were responsible for domestic duties that included: gathering wood, building and mending the homes, baskets, pottery making, clothing, and gathering of wild foods. The men were responsible for occasional hunting, farming, and religious ceremonies and activities (Martin, 1998). Over time, as more people moved into the La Plata Valley, food production had to increase, but women may have been exploited and “caught in the struggle for control over labor, production, and resources,” which is seen in the trauma evident on the skeletal remains (Martin, 1998:184).

Martin presented her findings to the current Pueblo women, who are still negotiating for equality and access to formal political power in their communities today. The Pueblo Laguna women have never held elected offices nor had an equal voice in political decisions made at the level of the tribal council or government office. Women have been allowed to participate in supportive roles concerning land use, some ritual practices or matrilineal practices that dictate marriage patterns. However, Laguna men have made the final decisions for political, economic, health, and resource issues for their communities (Martin, 1998).

Current work in the Borsod-Abaúj-Zemplén (BAZ) region includes the excavation of Karos Eperjessog and other smaller sites in Hungary. Multiple structures have been excavated at these other sites, but there have been fewer archaeological excavations involving skeletal analysis (Gerevich, 1977; Vertes, 1975; Marcsik and Pap, 2000). This work will exploit this as of yet largely untouched store of information, as this current Sajópetri skeletal collection has not been researched. There have been numerous excavations in the BAZ region since the 1960s, but according to Marcsik and Pap (2000), it was not until the 1990s that the research has been more
interdisciplinary. Unfortunately, looting has occurred in many cemeteries, and preservation of cultural material and heritage are crucial before more loss or damage occurs.

There are several bioarchaeology studies that have investigated pathology and trauma in Hungary, but all have either focused on one aspect or the other (Szathmary, 2000). Few studies have focused on ethnic identity, gene flow or genetic drift (migration) during the Migration Period. The current isotope analysis compliments the traditional archaeological analysis of grave goods and mortuary practices to offer insights into the subsistence and migration patterns of the Avar population as well as insight as to how they were affected by social stratification. Isotope studies supplement these types of studies given the great political and cultural transition of the time (Szathmary, 2000).

The migration of groups into the Carpathian Basin contributed to the gene flow and admixture of the Hungarian population. Socioeconomic and cultural factors have a huge impact on the growth and development of the individual, which in turn has an impact on the health and well-being of the community (Miekle et al., 2004; Larsen, 1987, 2002). This may be the result of changing kinship patterns or alliances that were built over time (Larsen, 2006). According to Knudson and Stojanowski, “[b]iodistance analysis is not simply about who is related to whom, but how those relationships change through time and the potential significance of increasing or decreasing biological integration from a social perspective (2008:405).” Social stratification has an effect on marginalized groups because the divide between classes can grow over time. This inequality can progress to conflict and difficulty in accessing resources for the lower classes; therefore, health disparities increase for those in the lower classes (Knudson and Stojanowski, 2008; Barbalet, 1998).
During the Hungarian Migration Period, it may have been more imperative for the warrior caste to have more nutritional resources, as they were responsible for invading other territories and protecting their khaganate (kingdom) (Steckel, 2005). There is a power differential that prohibits some social classes from accessing resources more so than others. The nobility (khagans) and warrior caste reigned over the local commoners (Steckel, 2005). Goodman (1993) points out that more research is necessary to understand markers of social status, such as those who benefited and who were disadvantaged possibly during times of agricultural intensification. Goodman notes that a “population-level decline in health could be due to the expansion in size of the underclass”, which would also lead to the increase of the mean ill-health of the population (Goodman, 1993:285).

Previous bioarchaeology research in craniometric studies, conducted by Hollo et al. (2008), studies craniometric variation in different ethnic groups that migrated into the Great Hungarian Plain, which dated from the Sarmatian age (AD 1st- 4th century) to the Arpadian age (AD 1000-1301). Hollo noted that the greatest variation was observed during the Avar Period, and that the female group differed from the earlier and later populations, leading to the conclusion that females changed more gradually over time than males (Hollo et al, 2008). Hollo (2008) noted how the Avar were considered more aggressive and violent conquerors than the Huns or the local Hungarians, and they eventually drove the Langobards (Western Germanic groups) out of the Carpathian basin (Hollo et al., 2008).

Previous archaeological excavations of Avar cemeteries and analysis have identified three distinct social classes based on grave goods and burial practices during the Avar Period (AD 568 - 895). However, it has also been suggested each social class was a distinct ethnic group as well (Hollo et al., 2008). Past skeletal analysis of the Avar cemeteries throughout
Hungary have documented that the “elite” class exhibited Asian (Mongoloid) cranial traits, while the “commoners” exhibited European traits that include the Germanic groups and eastern European nomads (Vida, 2003). In the osteological analysis by Szathmary (2000), he described the three layers of society as the “overloads” (nobility), the middle layer or “warriors” layer, and the “common folk” of the conquering Hungarians. Szathmary (2000) discovered through skeletal analysis that taller individuals made up the nobility and warrior caste, which could be a direct correlation to hereditary traits, admixture, or it could mean direct correlation to better nutrition over their lifetime due to social stratification (Steckel, 2005; Relethford, 2005). This research could identify the dietary patterns among the Avar population and determine if there was a correlation to a specific diet associated with the higher status group verses the lower status group.

Previous research in the northeastern Borsod-Abaúj-Zemplén (BAZ) region of Hungary has yielded cemetery sites that date back to the Migration and Conquering Period. The opportunity to examine the skeletal remains from the Sajópetri cemetery for dietary and migration patterns gave us insight into the past social life of Hungarians and will be novel for this region. Recent work in the southwestern region has included the excavation of Karos and Pecs, and other historic cemeteries in Hungary. Grave good analysis has been conducted at these other sites, but there has been less bioarchaeological analysis (Gerevich, 1977; Vertes, 1975; Young, 1978; Marcsik and Pap, 2000). Numerous sites in the Pecs region (south-west Hungary) that dated to the early Avar Period are also located in the southern Carpathian Basin and were excavated during 1904 to 1968. Unfortunately, the skeletal remains from cemeteries in the Pecs region were only partially excavated; at that time, a biological anthropologist was not consulted and these skeletal remains were not properly examined.
Kiss (1977) compiled a book with documented maps of the excavated cemeteries in the Pecs region. These maps include documentation of grave goods, burial positions, and the sexes of the cemetery population. As a reference for mortuary behavior these maps were useful for the proposed research in assessing the social status for the current study (Kiss, 1977). Previous excavations and analysis also revealed high status burials of military leaders and high-ranking individuals in small family graveyards in the center of their settlement territory or within the center of larger cemeteries with their extended family and clan (Kovrig, 1975; Vida, 2003; Makoldi, 2011). The burials at the Sajópetri cemetery were found to be primarily from the middle to late Avar period, where the family burials surround the nobility and their adjacent equestrian burials, while the commoners were buried on the further borders of the cemetery (Makoldi, 2011).

The research of Ilona Kovrig (1975) distinguished three main chronological Avar groups. From her analysis of burials from the Alattyán cemetery she determined that the first Avar populations arrived in AD 568, the second Avar groups joined the previous population approximately AD 670-680, and the last large migration of Avar was approximately AD 700-720. Burial customs of the first group of Avar observed include grave goods of spears and horse harnesses burnt with the deceased on funerary pyres in shallow pits, which parallels the burial customs of Inner Asia and Turkic territories. The nomadic elites were often buried with their horse or there would be an adjacent equestrian burial. There were numerous burials recorded at the Zalakomár cemetery (Vida, 2003), where the horse was skinned and the skull, along with the foot bones and equestrian accessories, (i.e. harness, stirrups, bridle, reins, girth buckle) were wrapped into the hide. The nobility elite would have been buried with their weapons (i.e. bow,
spear, war axe, swords) and ornately decorated belts with varying lengths of bronze or gold belt ornaments or implements.

There were numerous equestrian burials recorded within the Sajópetri cemetery, where the horse was buried with various accessories and the individual also exhibited nobility belt accessories and weapons. However, there were no recorded cases of the horse skeletal remains disarticulated at Sajópetri. In this instance the horse remains were recovered articulated in situ (Makoldi, 2011). Offerings of food, which included meat and wine, were also placed in special pottery vessels, for their journey into the afterworld (Vida, 2003). An example of belt accessories for a male elite or nobility burial is pictured in Figure 2.1. The accessories were found at the Zamárdi cemetery dating to the early Avar Period. The belt accessories included the belt buckle, main strap end and seven side strap ends. There were rolled silver mounts of the cross guard of a sword and the matching sheath interred with the burial. The accompanying horse was buried at the foot of the male individual (Steakley, 2013).

Burial 153 of the Sajópetri cemetery pictured in Figure 2.2 was a male individual of high status and his accompanying horse (Makoldi, 2011). The male and the horse had numerous burial accessories, which cannot be seen in this image, but included a griffin body buckle, simple belt, a knife, and bronze and iron decorative plates for a belt. The burial depth of the accompanying horse was consistently at a shallow burial compared to the male individual throughout the Sajopétri cemetery (Makoldi, 2011). Archaeologists have proposed that the depth of the burial also reflects a sign of high status of the individual because of the energy expenditure invested in the preparation of the burial (Pearson, 1999; Makoldi, 2011). Throughout the Sajópetri cemetery, Makoldi (2011) observed and documented the male elite burials were at a consistently deeper burial with postholes, and their accompanying horses were interred at a shallower burial.
There were very few burials within the Sajópetri cemetery that contained the golden yellow round burial (jug) vessel associated with the high status burials, and the burials with this specialized pottery were regarded as most likely the nobility elite within the Sajópetri cemetery population (Makoldi, 2011). The elite women were buried with ornate jewelry, which included bronze and gold necklace beads and pearls, earrings with bead pendants, pottery, faunal remains of birds, and a few pottery vessels. Children were usually buried with faunal remains. The commoners were usually buried with one knife or sickle type tool, a small decorative pin, or without any grave goods (Makoldi, 2011).

Figure 2.1. Belt accessories from an ‘elite’ male burial from the Zamárdi cemetery dating back to the 6th – 7th century AD, the early Avar Period (Steakley, 2013).
Cultural Historic Background

The Migration Period (AD 375-900) in Hungary’s history was a significant and critical point in time for this region because of the influx of ethnic cultures that migrated into the Carpathian Basin region. Numerous nomadic groups migrated into Hungary due to of climate changes, the advantageous geographic position of the Carpathian Basin and the proximity to the Danube River (Molnar, 2001). The Basin also offered fertile lands for the following: game hunting as well as space for the domestication of cattle and pigs and extending agriculture. This also allowed for exporting sheep, goats and cereals to the Balkans. Additionally, the Carpathian Basin provided a strategic geographic boundary that afforded protection from rival groups (Hollo
et al., 2008; Molnar, 2001). The surge of incoming people from the north and east caused a change in the political and social structure, which shaped the Hungarian history.

These sociopolitical changes during the Migration Period were a precursor to the Hungarian Conquering Period (AD 895-1000), in which groups later united together to conquer territory in Western Europe. The Avar Period (AD 568-895) was positioned in the Middle to Late Migration Period and marks the transition before the Conquering Period. The people of the Carpathian Basin during the Avar invasion were ethnically diverse groups. These different ethnic groups banded together to form military alliances along with the Avar (Hollo et al., 2008). Hollo and co-authors (2008) argue that the Avar were able to unify these groups in the territories of Transdanubia, the Great Hungarian Plain, and Transylvania into an empire (Figure 2.3). Table 2.1 displays the Hungarian historic timeline and the invading ethnic groups involved during the Hungarian Migration Period, which was also the time period the Roman Empire had started to decline and Christianity became more widespread throughout this region (Radovčić, 2011).

To gain a better understanding of how the Avar migration influenced Hungary’s history, a brief background of the existing groups before the Avar arrived needs to be addressed. Historic conquests before the Avar include: the Sarmatians (Iranian Clans), the Huns (Asian groups), Gothic-Hun-Alan groups (Ostrogoths /Germanic groups), and Langobards (West Germanic groups) (Kontler, 2002; Todd, 2002).

There were two groups that were considered Sarmatians, the Iazyges and Roxolani groups who were known as the nomadic steppe people who occupied the Carpathian Basin region as early as the AD 200 (Todd, 2002). Along with the Sarmatian groups, the Slavs were considered the local Romanized populations during the Migration Period that also occupied areas of the Carpathian (Pannonian) Basin (Todd, 2002; Kontler, 2002; Vida, 2003).
Table 2.1. Hungarian Historic Timeline: Time periods and Invading Ethnic Groups

<table>
<thead>
<tr>
<th>Period or Epoch</th>
<th>Time Frame</th>
<th>Ethnic Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarmatian/Alan Period</td>
<td>AD I-IV Centuries</td>
<td>Jazygian and Roxolani Groups (Iranian origin)</td>
</tr>
<tr>
<td>(Beginning of Migration Period)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hun and Gepidic Epochs</td>
<td>AD 420-455</td>
<td>Central Asia/ Germanic Groups</td>
</tr>
<tr>
<td></td>
<td>AD 455-567</td>
<td></td>
</tr>
<tr>
<td>Early Avar Period</td>
<td>AD 568-670</td>
<td>Western Germanic/Asian Roots</td>
</tr>
<tr>
<td>Langobards and the Avar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(End of Migration Period)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Avar Period</td>
<td>AD 670-680</td>
<td>Asian Roots</td>
</tr>
<tr>
<td>Late Avar Period</td>
<td>AD 700-895</td>
<td></td>
</tr>
<tr>
<td>(Conquering Period)</td>
<td>AD 895-1000</td>
<td>Magyars-Hungarians</td>
</tr>
<tr>
<td>Hungarian Conquest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(new Christian state)</td>
<td>AD 1000-1301</td>
<td>Hungarian Troops</td>
</tr>
<tr>
<td>Arpadian Age</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(adapted from Vida, 2003; Hollo et al., 2008)

Figure 2.3 Map of the Pannonian Basin and also referred to as the Great Hungarian Plains and Carpathian Basin. The Carpathian Mountain range surrounds the lowlands of the basin, and Sajópetri is located in the northeast region (BAZ) of Hungary (adapted from Dolton, 2006).
Other Hunnish rulers later migrated into the Carpathian Basin during the mid-4th century AD, which included Ruga, Bleda, and Attila the Hun. The Hun’s legacy instilled universal fear throughout Europe due to their violent and aggressive conquering, but their reign was short lived. The Langobards (Western Germanic roots) then migrated to the Carpathian Basin (Pannonian) region after AD 510, and continued onward to conquer regions into northern Italy. The earliest account of an Asian Avar khagan (king), Bayan, who arrived to the Carpathian Basin was in AD 568, and over the next century an Avar Empire was established (Radovčić, 2011; Vida, 2003).

Khagan Bayan of the Avar is recognized for unifying Transdanubia, the Great Hungarian Plain and Transylvania regions (Figure 2.1) into one state (Kontler, 2002). The local steppean population also joined the Avar. Between AD 568-626, the Avar continued to combat the Byzantium border forts and towns in the Lower Danube, region and taking captives back with them and requiring solidi (gold coins as the annual subsidy) from Byzantium to be paid to them to ensure peace (Vida, 2003). In AD 626, the Avar then attempted to conquer Constantinople, with the help of the Gepids, Slavs, and Bulgars, but the siege failed. It was this defeat that marked a weakening of the Avar Empire. However, the Avar were well integrated among the other European groups occupying the Carpathian Basin. Over the next decade, the Bulgars (Turkish decent) of the eastern borders of the Avar Empire created their own khaganate (kingdom) and the Slavs of Carinthia and Dalmatia also demanded independence (Vida, 2003). Archaeological records confirm Avar settlements did extend to the Vienna Basin and southern Slovakia, and by AD 680 the Avar occupied Lauriacum (Lorch, Austria). A peace treaty was signed in AD 692 with the Franks to demarcate the border of the Avar khaganate (kingdom) (Vida, 2003). According to Tivadar Vida (2003), Byzantine written documents indicate the Avar spoke a Turkic language, and the leaders also spoke Mongolian. Early archaeological work
mistakenly documented Avar artifacts to the Hun period but further research indicated this was not the case. Byzantine gold coins dating back to AD 566-670, the pottery, mortuary grave goods, weapons, and burial customs were indicative of the Asian Avar (Kontler, 2002; Vida, 2003; Radovčić, 2011).

As the Avar migrated into the Carpathian Basin during the Migration Period, the political and cultural dynamics of the region integrated and admixture occurred among the European and Hungarian groups (Kontler, 2002). Radovčić (2011) described the Avar as a group that originated from Central Asia, but as the Avar dominated other ethnic groups, these groups joined them in their movements because they gained protection under the Avar khaganate. She also noted the “tribes” that populated the Carpathian Basin were not considered a “water-tight reservoir” population, rather, these groups were “short-lived federations of clans” based on the reputation of a leader and his credibility in promising benefits for members of the group (Radovčić, 2011:88). The Avar who first migrated into the Carpathian Basin were a very different ethnic group than the Avar of the 9th century due to admixture. Towards the end of the 9th century AD, the people of the Carpathian Basin transitioned into the Conquering Period (10th and 11th century AD), and socio-political disparities increased between the social classes. The surge of incoming people from the north and east during the Migration Period caused changes in political and social structures that shaped the Hungarian culture. The social history and regional context, exploration of social relations, and fields of power are the forces that have shaped the people of the Avar Period (Morfin, 1998). The division of social classes was due to division of labor and primarily due to the incoming conquests of foreign powers (Molnar, 2001; Szőke, 2003; Martin, 1998; Goodman and Leatherman, 1998; Vida, 2003).
**Definition and Types of Isotope Analysis**

Larsen (2002) notes that with diet reconstruction in archaeological contexts, evidence is often based on the plant and faunal remains suggesting the presence of a particular food or groups of foods. However, the presence of a particular food groups does not necessarily give the quantity or quality of foods in one’s diet or assist with the interpretation of the health and nutrition of the individual or population. Bone chemistry provides a robust method for documenting and quantifying the biochemical intake of carbon and nitrogen in one’s diet over an individual’s lifetime. Stable isotope analysis is a form of bone and enamel tissue chemistry.

Chemical elements have known atomic masses, properties, and characteristics that differentiate them from one another. Atomic masses are the sum of the weights of an atom’s subatomic particles: the protons, neutrons and electrons. The protons, neutron, and electrons are sub-atomic particles that create the specific element. Chemical elements have naturally occurring corresponding isotopes, in which the element’s number of neutrons will differ (McMurray and Fay, 2001). For example, carbon has the atomic number 6 and has two stable isotopes, $^{12}\text{C}$ and $^{13}\text{C}$. This means that $^{13}\text{C}$ has an additional neutron (7 neutrons) when compared to $^{12}\text{C}$ (6 neutrons). Standard isotope notation utilizes the $(\delta)$ delta value and $0\%$ (ppt) unit, with the isotope atomic mass in the upper left superscript position (Dawson and Siegwolf, 2007).

Chemical analysis of the stable isotopes, carbon $(\delta^{13}\text{C})$, nitrogen $(\delta^{15}\text{N})$ and oxygen $(\delta^{18}\text{O})$ are an effective and well-established scientific method to examine diverse aspects of diet and mobility. Carbon, nitrogen, and oxygen have stable isotopes, which are not radioactive (do not undergo radioactive decay) (McMurray and Fay, 2001).

Isotope analysis utilizes mass spectrometry, a process by which the chemical sample of interest ($\sim 1$ mg) is vaporized and the diluted gas (elutant) is exposed to high-energy electrons.
This chemical reaction produces positively charged ions as the energy forces some atoms to lose electrons. Some of these ionized molecules survive and some fragment into smaller ions. The gases travel through numerous columns under the influence of a strong magnet and an electric field. Depending on the atomic mass and the charge of the ion, the particle will reach a detector either sooner or later than other ions within the sample. By comparing the prevalence of each particle to known standards it is possible to determine the presence and relative abundance of the isotope within the sample. A numerical output is available for the isotope mass for the element(s) under investigation (McMurray and Fay, 2001).

The carbon, nitrogen, and oxygen isotope results for this study were reported in standard delta notation relative to the standard Vienna Pee Dee Belemnite (VPDB). The output data for the carbon, oxygen, and nitrogen isotope analysis was compiled into Microsoft Excel spreadsheets which display the numeric values for percentile yields in parts per thousand (‰) for each of the specific elements. These were then plotted to compare the variability between individuals and social groups.

These elements are found in different types of food and water sources that are ingested and metabolized throughout one’s lifetime, creating a biochemical profile for the individual’s diet or migration pattern. Isotope analysis of paleodiets and migration has been a well-established scientific method in archaeology and anthropology since the 1970s, and is currently used in modern forensic anthropology to reconstruct food sources and migration patterns for unidentified individuals (Juarez, 2008; Gorman, 2012). This study primarily investigated stable isotopes $\delta^{13}C$ and $\delta^{15}N$. $\delta^{13}C$ is found in the enamel and apatite of bone, while $\delta^{15}N$ isotope is seen in collagen. By evaluating their relative abundance it is possible to reconstruct the dietary sources of the Avar.
The bone was analyzed for both hydroxyapatite and collagen, which contain levels of carbon and oxygen isotopes embedded in the hydroxyapatite of the mineral portion of bone. The collagen of bone also has carbon and nitrogen isotopes in its structure. The bone is constantly remodeling at a very slow and steady rate, so it can give the chemical signature of these stable isotopes for the individual’s last seven to ten years of life (Ambrose, 1993). Carbon and oxygen isotopes are generally analyzed in dental tissue; therefore the enamel represents the diet at the time of enamel crown formation and development. For example, the enamel for central incisors will not remodel after the enamel crown has completed development after early childhood (< 6 years old) (Hillson, 1996). The permanent tooth enamel develops in early childhood, while bone remodels between seven to ten years. Hence, the enamel can be used to determine the biochemical record of the individual’s early childhood to compare with the later years of life. The permanent (adult) anterior teeth and the first molars are generally used in research for isotope analysis to investigate the contrasting isotope values between the tooth and bone to identify if there are changes in diet or migration patterns (Ambrose, 1998; Tykot, 2006).

Stable isotopic analysis of carbon and nitrogen ratios within tooth enamel and bones can assist in distinguishing diet diversity: marine diets from terrestrial and riverine/lacustrine diets of inland inhabitants, as well as hunting-and-gathering diets from agricultural diets. In this way diet diversity can be assessed. Additionally, isotope analysis can be used to determine the amount of certain crops, such as millet, in the diet (Tykot, 2006).

Stable isotope studies have also included research into identifying weaning ages of populations as well as nutritional and health disparities. These disparities are often linked to elevated levels of stress and infectious disease (Larsen, 2002). In previous isotope analysis studies, it has been observed that there has been greater variability between the social classes and
sexes as populations transitioned into socially stratified societies (Ambrose et al., 2003; LeHuray and Schutkowski, 2005; Murray and Schoeninger, 1988). In this study, the stable isotope values from the enamel were compared to the isotope values of the bone to identify if there are any similarities or differences within the individual’s lifetime. The stable isotope values were then compared to one another within this population to identify any statistically significant differences in dietary patterns between the social classes and the sexes.

Isotopes are incorporated into the bones and enamel of organisms throughout their lifetime. By understanding how plants and animals integrate isotopes through different metabolic pathways it is possible to understand what values derived from bone analysis mean. Carbon is the most abundant element in life, and it is this ubiquity that makes it useful to track food intake.

Plants can be differentiated via their metabolic pathways as C3 (Calvin cycle), C4 (Hatch-Slack) pathway, or CAM (Crassulacean Acid Metabolism) plants. The differing pathways are due to the number of carbon atoms that are formed during the photosynthesis process (van der Merwe, 1982; Ambrose, 1993; Tykot, 2004; Atahan et al., 2011; Leatherdale, 2013). Most plant life and plant products of nutritional value fall into the C3 group. These include wheat, barley, rice, wetland grasses, legumes, vegetables, all root crops, nuts, most fruits, and honey. The C4 groups of nutritional value include millets (e.g. setaria millet, broomcorn millet), maize, sorghum, sugar cane, some amaranths, Chenopods, and tropical grasses (Ambrose, 1993; Tykot, 2004; Le Huray and Schutkowski, 2005). Setaria millet is also referred to as Hungarian millet, which is native to China and is one of the oldest cultivated crops (FAO, 1990). The CAM plants are less typically evaluated as there are limited members of nutritional value. Its members include succulents such as cacti, agaves, and pineapples (Ambrose, 1993; Tykot, 2004).
Figure 2.4 is a summarized diagram displaying the C\textsubscript{3} and C\textsubscript{4} pathways with the $\delta^{13}$C average values and the corresponding fractionation values that are passed on to skeletal tissue of animals that feed on the specific plant products (van der Merwe, 1982; Ambrose, 1993; Tykot, 2006). The $\delta^{13}$C values of enamel, bone apatite and collagen can be used to distinguish if the individual had a primarily C\textsubscript{3}, C\textsubscript{4}, or intermediate plant diet. Additionally, it can be determined if the individual consumes primarily a marine or terrestrial animal protein diet.

Isotopic fractionation, as explained by van der Merwe (1982), is a known chemical phenomenon which occurs when isotopes of an element undergo further chemical reactions and transform into another material. With the carbon isotopes in plants, the carbon becomes fractionated during photosynthesis when the plants metabolize atmospheric carbon dioxide. The leaf structure and the rate of carbon dioxide absorption correlate to the photosynthetic pathway of the plant (van der Merwe 1982; Ambrose, 1993). If the plant follows either a C\textsubscript{3} or C\textsubscript{4} photosynthetic pathway, an average carbon isotopic value will distinguish what type of plant it is. In Figure 2.2, the average $\delta^{13}$C for the C\textsubscript{3} plant is -26.5‰, but values have been seen as low as -35‰ to -20‰, and are highly dependent on environment and climate. Research has showed if the composition of the atmospheric carbon dioxide changes, the isotopic composition of the plant will have a corresponding shift in values. van der Merwe (1982) discussed the work of Vogel et al. (1978) in which their research discovered that the varying isotopic values from different leaves of the same tree were due to the elevation and the “canopy effect” which is correlated to photorespiration and sunlight availability. Similar plant species that grow side-by side can have varying isotopic values but will stay within specific isotope ranges, which is correlated to photorespiration and sunlight availability.
Figure 2.4 Diagram of the Pure C₃ and Pure C₄ pathways with the δ¹³C average values and the fractionation (offsets), which are passed on to skeletal tissue (adapted from Tykot, 2006 and van der Merwe, 1982).
The average $\delta^{13}C$ for C4 plants is -12.5‰, but can range from -16‰ to -9‰. However the ranges of C3 and C4 do not overlap, which can be utilized to estimate the dietary patterns of past and current populations (van der Merwe, 1982). Further isotopic fractionation has been documented in the consumers (herbivores and omnivores) of these plants. This well-established research has shown that the “isotopic signature” is passed on to the consumers, with an average of +5.1‰ fractionation (enrichment) factor for $\delta^{13}C$ in bone collagen and +12.0‰ in bone apatite (van de Merwe, 1982; Ambrose, 1993; Tykot, 2006; Tykot et al. 2009). The enrichment factor refers to an increase in the $\delta^{13}C$ isotopes in human or other animal tissues due to the consumption of nutritional sources that are carbon rich sources ascending the hierarchy of the food chain or trophic levels.

Nitrogen, like carbon, is also present in all living tissue. Nitrogen is found at its highest concentration in the amino acids. These amino acids are linked together to form proteins, which serve both metabolic and structural functions in tissues. By examining different nitrogen isotopes in a protein, it is possible to differentiate between animal protein sources (Ambrose, 1993; Larsen, 2002).

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios (C:N) are used in the estimation of protein content of collagen, the organic component of bone. An example for the ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ranges for plants and animals from a Gulf Coast population can be seen in Figure 2.5 (Tykot, 2006). Previous research has revealed that there is an average of +3.0 – 5.0‰ fractionation (enrichment) factor for $\delta^{15}N$ in bone collagen. This percentage increases as the human individual consumes other animal protein sources ascending the hierarchy of the food chain or trophic levels (van de Merwe, 1982; Ambrose, 1993; Tykot, 2006; Svyatko, 2012).
Herbivore mammals (feeders) such as Cervidae (deer), Bos (cattle) and Ovis (sheep) species will either exhibit the average of (-21.5‰ or -7.5‰) for $\delta^{13}C$ and up to 9‰ values for $\delta^{15}N$ isotope ratios depending on the plant species that is available for consumption because of their ruminant behavior. Carnivorous and omnivorous mammals that feed upon the herbivorous mammals will exhibit even higher $\delta^{13}C$ and $\delta^{15}N$ isotope ratios within their collagen. Marine and freshwater animal species and human populations consuming these ecosystems have higher documented $\delta^{13}C$ and $\delta^{15}N$ isotope ratios because aquatic sources are more extensive than those of terrestrial sources (Ambrose, 1993; Tykot, 2006; Svyatko, 2012). Generally the $\delta^{15}N$ isotope value will increase by 2-3‰ with each increasing trophic level, and research for dietary patterns of past populations have shown $\delta^{15}N$ isotope ratios at approximately 10‰ for a mixture of terrestrial and marine food sources (Tykot, 2006; Svyatko, 2012).
Oxygen ($\delta^{18}O$) isotope values are linked to food, water, and geographic sources. Oxygen isotopes are also directly related to precipitation and temperature of the geographic region, climate, and seasonality of crops (Saurer and Siegworld, 2007). Oxygen isotope data was collected for this current study, however discussion and results will be deferred until sufficient analysis has been done. Isotope analysis involves the amount (parts per thousand) of specific isotopes that were incorporated within the enamel or bone to estimate the possible food sources and regions the food resources were available (Ambrose, 1993; Tykot, 2004). Stable isotopic analysis of carbon and oxygen within tooth enamel and bone apatite, along with stable carbon and nitrogen isotopes from collagen can assist in distinguishing patterns of subsistence. The combination of apatite and collagen isotope analysis can be used to reconstruct the trophic level of animal protein and produce an estimate of a $C_3$ or $C_4$ plant source within the individual’s diet.

Heavy isotopes have also been used for evaluation of human skeletal remains. The analysis of strontium isotope ratios ($^{87}$Sr/$^{86}$Sr) and lead ($^{206,207,208}$Pb/$^{204}$Pb) in human skeletal material reveals information about migration throughout an individual’s life (Turner et al. 2009; Kamenov and Gulson, 2014). Strontium and lead isotopes vary among different types of geological bedrock, and this variation can be used to identify different geographic areas. These isotopes are transferred from the local soil by food, water, and soil and/or dust ingestion and become incorporated into an individual’s biochemical profile (Beard and Johnson, 2000; Price et al. 2004; Bentley et al., 2004; Kamenov, 2008; Voerkelius et al., 2010; Kamenov and Gulson, 2014). While the heavy isotopes have proven to be a powerful tool in bone and enamel analysis, any study using the two must consider the natural processes that effect these elements. The natural chemistry of these isotopes, and how they interact with other elements, informs any assay results.
Both Rb and Sr are soft metals and close in atomic weight and atomic number. There are three stable Sr isotopes ($^{84,86,88}\text{Sr}$) and one radiogenic ($^{87}\text{Sr}$) isotope. $^{87}\text{Sr}$ is the daughter product of the $^{87}\text{Rb}$ isotope decay. Therefore, depending on the age and initial Rb/Sr ratios different rocks will have different $^{87}\text{Sr}/^{86}\text{Sr}$ isotopic ratios at present. In the research of Voerkelius et al. (2010), they explained limestone, marble, and basaltic lavas have very low Rb/Sr ratios, but shale, granite rock, and sandstone have higher Rb/Sr ratios. The highest Rb/Sr ratios are found in clay minerals. Soils that develop on shale tend to have high Sr isotope ratios due to high Rb/Sr. In contrast, basaltic rocks tend to have low Rb/Sr ratios and so low Sr isotope ratios. The older and rubidium/strontium-rich rocks from the Palaeozoic granites exhibit higher ratios while rubidium/strontium-poor rocks such as the Quaternary basalts have the lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, from 0.70200 to around 0.70600 (Voerkelius et al., 2010). Voerkelius et al. (2010) suggest that Hungary’s $^{87}\text{Sr}/^{86}\text{Sr}$ has a range of 0.70901–0.71100 based on its natural mineral waters. This last point is an important reference for the $^{87}\text{Sr}/^{86}\text{Sr}$ values that are seen with the Avar samples in the following results section. When rainfall or natural precipitation process occurs this precipitation collects into bedrock and then migrates into soil and water sources. Local plants uptake this strontium (Sr) overtime. Animals in turn ingest the local plant life and water sources, and people will ingest the local animals, plant life, and water sources for sustenance as well.

Voerkelius et al. (2010) have also found through past geological research and their current work that there has not been significant isotope fractionation that

“occurs when the groundwater obtains its isotopic signature from the minerals of the soil and rock strata through which it percolates. Precipitation processes only change the strontium content but do not alter the isotopic signature”

(Voerkelius et al., 2010:934).

So while some of the isotopes are adsorbed onto the bedrock and the total amount present decreases, the ratios of the isotopes remain constant. As discussed earlier, the age of the bedrock
has a direct relationship with the Rb/Sr isotopic signature that carries into the local water, soil, and plant sources with no significant fractionation. The isotopic values will be reflected in animals and humans skeletal remains because strontium (Sr) isotopes are incorporated into their diets and embeds the chemical geological signature into teeth and bones.

Strontium is an alkaline-earth metal that is chemically similar to calcium, and can readily substitute for calcium in the body over time. As a result, strontium accumulates in the body tissues (enamel and bone) in vivo (Beard and Johnson, 2000; Larsen, 2002; Price et al. 2004; Bentley et al., 2004; Giblin, 2009). Both strontium and lead vary in their relative atomic masses, which allow these isotopes to cycle through foodwebs without measureable fractionation (Bentley et al., 2004; Turner et al. 2012). It is possible to examine the strontium isotope levels of the enamel and the bone, then compare and contrast to identify migration patterns. Strontium and lead isotopic values in enamel and bone indirectly reflect those found in the local bedrock, unlike the stable isotopic values used to reconstruct dietary patterns. Tooth enamel crystalline structure is less porous than bone and is more resistant to biochemical degradation with respect to $^{87}\text{Sr}/^{86}\text{Sr}$ ratios, and after the enamel crown is formed there is not an exchange of Sr isotopes (Beard and Johnson, 2000; Bentley et al. 2004, 2006). The strontium and lead isotopic compositions will differ depending on the local geological and environmental factors (Beard and Johnson, 2000; Kamenov and Gulson, 2014).

The long-distance importation of food and water may affect the individual’s strontium isotope ratios and may not be entirely controlled by the local environment. However, this issue has been more of a concern in modern forensic cases than in prehistoric cases. Past populations relied more on local water and food sources, which limited the variability in isotope exposure and uptake. Similarly, the lead isotopic compositions of individuals can be linked back to local
environmental sources of lead from the soil and anthropogenic sources such as domestic and industrial products (Kamenov, 2008). The Romans used lead with metal alloys to manufacture cooking equipment, which would contaminate food and wine and, in turn, was expressed in high levels of lead in their skeletal remains (Montgomery et al., 2010). This information is helpful as it can be used to differentiate Roman from Avar remains. The Roman elites of the Roman Period were exposed to higher lead levels due to the cookware and wine making process, and this is an example of distinct Pb isotope levels that aid in the examination of social differentiation (Montgomery et al., 2010).

Lead is more directly absorbed through soil and/or dust ingestion or inhalation (Kamenov and Gulson, 2014). Due to this primary mechanism of absorption, its isotopes are not likely to be affected by importation of foods from other regions. Therefore, the combination of \(^{87}\text{Sr}/^{86}\text{Sr}\) and \(^{206, 207, 208}\text{Pb}/^{204}\text{Pb}\) isotope compositions of skeletal remains allows for a tighter constraint to estimate the origin and geographic mobility of individuals (Turner et al., 2009). Lead is an element that has also historically been used for anthropogenic purposes. In heavy isotope analysis, the isotope ratios of an individual’s tooth enamel and bone have been compared and contrasted to one another. Isotope analysis data are plotted against comparative geographic data to clarify meaningful patterns and to demonstrate changing subsistence and migration patterns (Turner, 2009; Giblin, 2009).

The current multi-isotope research of the Avar skeletal remains compliments other findings regarding subsistence patterns, which yield insight into the behaviors of ancient populations. The incorporation of both stable and heavy chemical isotope analysis is a fairly novel practice within the field of anthropology because past studies have either focused on stable
isotope or on the heavy isotope analysis, while both types of examination can complement each other.

**Past and Present Isotope Research**

Bioarchaeological research uses a holistic approach to investigate past populations by the incorporation of multiple lines of evidence to produce a better understanding of past cultures. By looking at prior investigations which utilize isotopic analysis it is possible to take current studies and place them into a larger framework. This accumulation of data and techniques helps to increase the accuracy of any study that utilizes isotopes. Additionally, by looking at studies that have focused primarily on European or Asian regions, it is possible to gain context for the results yielded in this study. However, there are other studies throughout the Americas that are influential because of their contrasting isotope values or that they have also investigated the relationship between social status and stable isotope values (Larsen, 1987; Ambrose, 1993; Tykot, 2006; Nymstrom, 2009).

Turner et al. (2012) describes understanding the diet of past communities as a “key intersection between political economy, ecology, and physiological well-being” of the people (Turner et al., 2012:1). Turner and colleagues investigated mummified remains from southern Mongolia through osteological and isotope analysis. These human remains exhibited a high degree of trauma and mortuary burial practices that were observed to be atypical for Mongolian pastoral burials. Turner’s research focused on the dietary and migration patterns as well. The results indicated that an economic and cultural disconnect existed in medieval Mongolia. Examining the dietary patterns of the people, it would be possible to develop insights into the
relationship between local populations and larger economic and political structures (Turner et al., 2012).

Giblin (2009) utilized strontium isotope analysis to investigate how human populations migrated and adapted and settled into their environment within the Great Hungarian Plain region during the Neolithic and Copper Age. Evidence for migration and the shift from larger permanent settlements to smaller impermanent sites spread over a larger geographic area has been primarily seen through indirect sources such as ceramic pottery. It is suggested that the “increase in mobility and reliance on cattle was due to the emerging agro-pastoral economy”, but this idea has not been tested as of yet through biogeochemical analysis (Giblin, 2009:492). The study consisted of human enamel and faunal samples from seven different sites along the Hungarian Plains. Interestingly, the strontium values exhibited greater variation in the Copper Age and later periods verses the Neolithic Period, indicating there were changes in how the populations were interacting with each other. Giblin’s (2009) research has also assisted in the establishment of biogeochemical data in Hungary and Central Europe for further anthropological research. This thesis research aims to contribute to the isotope mapping of the environment and dietary variables that will help us to better understand human behavior.

Le Hury and Schutkowski (2005) questioned if it was possible to infer hereditary inequality or the presence of social ranking of past cultures other than by examining the contrasts in grave goods, past constructions or associated artifacts. Their research includes the analysis of carbon and nitrogen stable isotopes in bone collagen, to identify the dietary patterns and differences between the different social ranks during the La Tène Period (approximately 450 BC) in Bohemia (Czech Republic). They discovered that the correlation of men buried with items of weaponry and warrior status did have higher values of $\delta^{15}\text{N}$ in their bone collagen. Their aim was
to examine the diet at both the individual and population level and cast light on the social division in the La Tène Bohemia. The authors also questioned the view that society during that period was more egalitarian or that the population had unrestricted access to dietary resources than the preceding Hallstatt period. Although stable isotope analysis has been utilized for a number of decades in archaeology, this study was one of the first conducted for this region. The authors were highlighting the potential research possibilities of this method for other researchers in their region.

Diet and social status are interlinked; the presence, quantity, and quality of the foodstuffs available in one’s diet can be related to the sex, age, or social rank of an individual (Goodman, 1993; Knudson, 2008; Larsen, 2006; Cheung et al., 2012; Knipper et al., 2013). Le Huray and Schutkowski’s (2005) paper states that, “in so-called ‘egalitarian’ societies, all individuals do not have equal status and a range of social differences can persist” and affect differential access to dietary resources for nutrition (Le Huray and Schutkowski, 2005:136). Their research revealed that the men who had more iron weaponry (i.e. sword, shield, and spear) had higher values of $\delta^{15}N$. This suggested that grave goods were based on social status among the male group. These male individuals were identified as “warrior” burials, but during the La Tène and Hallstatt Period in the Czech Republic an egalitarian society existed. Le Huray and Schutkowski (2005) suggested there were other factors that lead to the access to meat and dairy that are beyond accessibility, and dietary differences are a reflection of social stratification.

Ambrose and colleagues (2003) have also found similar findings within the Cahokia Mound 72 dating to the Lohmann and early Stirling Phases of the Mississippian Period (AD 1050-1150). The male individuals of high status, buried with artifacts such as projectile points from local and exotic cherts, copper, and mica, had higher levels of $\delta^{15}N$ and $\delta^{13}C$. However, the
Values seen in the low status individuals were much higher, suggesting there was less dependence on maize by healthy high-status individuals. Ambrose and colleagues further proposed that differences in health and status and maybe correlated to sex, quality of diet and geographic origin. This is in contrast to other parts of the Americas (e.g. Mesoamerica and South America), where the elites have more positive C values than the non-elite, which suggests special maize products like chicha beer were staples in the elite diet (Freiwald, 2009).

The research of Hu et al. (2008) included stable isotope analysis which examined the past dietary patterns of humans during the early Neolithic (sites located in North and Central China). This work is helpful in the examination of the past dietary patterns of the Avar population because of the history and documentation written on the Avar. The Avar population was known to have geographically originated from Central Asia, but the exact location is unknown.

Carbonized rice grains that underwent radiocarbon dating from the Yeuzhuang site dates back to the Houli Culture (6060-5750 cal BC) and is evidence millet agriculture likely originated in Northern China in the early Neolithic period (ca. 8000 BP), but less research has been focused on the importance of millet or how millet may have migrated into Europe (Hu et al., 2008). The stable isotope values from a number of these sites will be compared to the Avar data, because archaeological records have documented millet as a primary agricultural source for the Avar population. Hu et al. (2008) have also included collagen isotope values for wild and domestic faunal remains discovered in these archaeological sites, which serve as a good baseline for $\delta^{13}C$ and $\delta^{15}N$ values. The modern foxtail millet seeds in China exhibit a range of -12.0‰ to -11.6‰ for $\delta^{13}C$, but due to fossil-fuel effect prehistoric millet approximately exhibits a less negative value of 1.5‰ (Hu et al., 2008; Pechenkina et al., 2005). Hu et al. (2008) noted the $\delta^{15}N$ values of modern foxtail millet seeds range 2.4‰ to 3.9‰, while wild or domestic animals that feed on
these C₄ plants will range 4.2‰ to 8.0‰. The faunal remains found at these sites included fish, bovine, and pigs. The stable isotope results from the Xiaojingshan site was used as comparison data against the Avar population located in the proceeding discussion chapter.

Tafuri et al. (2009) had completed a study in Northern and Southern Italy for stable carbon and nitrogen isotope analysis for human and faunal remains that dated to the Early and Middle Bronze Age. Their objective was to investigate the dietary differences between Northern verses the Southern Italy sites and if differences existed between Early and Middle Bronze Age time periods. Tafuri et al. (2009) discovered wheat and barley was a stronger contributor for cereal cultivation around Southern Italy during the Bronze Age, which is a C₃ plant. However, in Northern Italy, broomcorn millet and/or foxtail millet (Panicum miliaceum and/or Setaria italica) a C₄ plant was the more dominant cereal in the population’s diet. Their results support the idea millet first occurred in Northern Italy from across the Alps from Central Europe. New botanical data from recent excavations in Italy are available, but the stable isotope analyses of Tafuri et al. (2009) for these past populations compliment the research of plant consumption and dietary patterns.

The four sites (two in Northern Italy and two sites from Southern Italy) were inland occupations so marine sources were not anticipated. The results revealed the mean value for δ¹⁵N was 9.3‰ ± .9, and generally δ¹⁵N values over 12‰ is an indicator of marine or riverine/lacustrine sources in one’s diet (Richards and Hedges, 1999). The southern site, Toppo Daguzzo had a mean value -19.6‰ ± .2 for δ¹³C, while the mean value for δ¹³C was -15.2‰ ± .8 for the northern site, Olmo di Nagara. The δ¹³C value for the northern site was more enriched than the southern site; exhibiting millet contributed more to the human and animal diets. Interestingly, Tafuri et al. (2009) discovered the stable isotope values for these sites did not have
a statistically significant difference between sexes or in the amount of grave goods interred with the burials.

The stable isotope analysis study conducted by Bourbou et al. (2011) also looked at numerous historic archaeological sites in Greece, but these sites were occupied during the same time period, the Greek Byzantine Period (6th-15th centuries AD) as the incoming Avar migration. Bourbou and colleagues objective was to reconstruct and identify the dietary patterns among eight different sites (coastal versus inland villages/towns) throughout Greece. Surprisingly, the $\delta^{13}C$ values did not significantly fluctuate over many centuries, and the primary plant staple crops were wheat and barley, the $C_3$ plant source. Although, millet was evident, the $C_3$ plant sources were still the dominant agricultural crop. Interestingly, they found the more recent populations had higher $\delta^{15}N$ values than the previous time periods (before 6th century AD), and they suspect this was due to better fishing techniques and cultural values surrounding food (Bourbou et al., 2011).

Murray and Schoeninger (1988) utilized stable isotope analysis to examine the collagen content of a population from the Hallstatt Period (Early Iron Age, 800-400 BC) to learn the diet, status, and complex social structure of that prehistoric population in Slovenia, a country that is located on the western border of Hungary. Archaeological and ethnographic evidence suggested that social differentiation existed through grave goods interred with burials during late prehistoric Europe. Adding to this traditional approach, the authors used bone chemistry to help further document differences in diet between social hierarchies. They discovered that there was not a statistical significance between diet and material culture or grave wealth in the burials as they had anticipated, but there was a definite trend toward higher nitrogen ratios in the males suggesting that males had more meat products in their diets. There was not a statistical
significance between male burials of warrior and non-warriors, but there were definite higher ratios of nitrogen between Tumulus (burial mound) X verses Tumulus IV and V. Murray and Schoeninger proposed that the higher nitrogen levels (associated with meat consumption) may have been based more on family or clan membership rather than status recognition.

The stable isotope ratios for individuals from Magdalenska Gora, Slovenia had a higher carbon isotope ratio than expected. Prehistoric Europe was primarily a homogenous C3 plant regime, which includes the traditional cereal crops of wheat and barley. The δ¹³C apatite/enamel mean ranges for young to middle-aged males were -14.8‰ to -14.3‰ and for females were -14.2‰ which, these isotope ranges fall within the C₄ plant range. The authors concluded this population most likely cultivated millet in the spring, but may have been able to produce enough millet as a staple crop for the year (Murray and Schoeninger, 1988).

The research of Craig et al. (2009) investigated dietary patterns of two Imperial Roman coastal sites in Velia, (Campania) Southern Italy that dated to the 1st and 2nd centuries AD. Their results are an interesting comparison to the Avar group isotope data because the time period predates the invasion of the Avar, and the Roman Empire extended throughout the Carpathian Basin during this time period. Their research included δ¹³C values and δ¹⁵N for collagen values from adults (>15 yrs old) from a large Imperial Roman necropolis in the ancient port of Velia (Campania, Southern Italy) with a sample size of 117 individuals. Two populations were compared, one from the necropolis of Velia and the other from the necropolis of Potus at Isola Sacra located on the coast near Rome. Craig et al. (2009) discovered that the dietary pattern consisted of a high consumption of cereals, small contributions of meat and only a minor input of marine fish even though both populations were coastal communities. The diets were not consistent, a few individuals, mostly males but not solely, had greater access to marine resources,
including high trophic level fish. Generally, the $\delta^{15}$N increase by 3-5‰ with increasing trophic levels (Schoeninger and DeNiro, 1984). This is helpful in the estimation of plant-rich diets, animal-rich diets, and trophic level marine and freshwater fish diets. Interestingly, the dietary variation did not associate with age of death, burial type, or number of grave goods interred with burial. Men did have slightly higher values for both $\delta^{13}$C with a mean of -19.4‰, sd = 0.2 and $\delta^{15}$N of 8.9‰, sd = 1.4, while women had values of $\delta^{13}$C with a mean of -19.5‰, sd = 0.2 and $\delta^{13}$C of 8.3‰, sd = 1.4.

Historically, the people of Velia were known for their industry around a marine and seaport economy. This included the construction, repair and service of ships. This group fished and had a fish-preservation industry, so the majority of the population that was included in the analysis did not exhibit as high $\delta^{15}$N as was anticipated. Other terrestrial animals that were included in the stable isotope analysis and were possible animal proteins for human consumption included: red deer (Cervus), cattle (Bos), sheep (Ovis) pigs (Sus) and horse (Equus), tuna (Thunnus) and some unidentified fish. The basic staples of the Roman diet appear to be cereals and olive oil, the main sources of dietary carbohydrates in Italy during this time. However, wine and dry legumes were also important. Pork and beef were also part of the animal proteins consumed, but meat and dairy produce was more a supplement than a staple food. There were two subgroups that clustered within the Velia sample, and one group that had slightly higher $\delta^{15}$N values. Craig and colleagues’ (2009) interpretation for the group with the higher $\delta^{15}$N values was that there was likely minor fish, garum (fish sauce), and meat intake between the two groups. The population at Isola Sacra was on average 0.6‰ for $\delta^{13}$C values and for $\delta^{15}$N were approximately 2.2‰ higher than Velia results. However, the stable isotope results from the faunal remains from both sites show the herbivore animals at the Velia site compared to Isola
Sacra are generally lower as well. Therefore, the human diets from either site may have been similar, and it is just the isotopic differences in their foodstuffs that exhibit the observed isotopic shift (Craig et al., 2009).

Another study of interest used as a comparison with the Avar results was conducted by Cheung et al. (2012). This work was conducted on the Roman Britain population from Gloucestershire, England from the 1st to 5th century AD. Cheung and colleagues examined dietary patterns through the use of collagen stable isotope analysis from three populations from Gloucestershire in South West England, to identify differences between urban and rural populations (thirty-two samples from urban and forty-six samples combined from rural groups).

Both populations showed that they mainly subsisted on a terrestrial-based diet. However, there were differences between the urban and rural sites as well as regional variation within Britain. The urban population showed slightly higher $\delta^{15}$N ratios, which may indicate more marine and/or freshwater resources than the people from the rural communities. Data suggest that the Roman Britain had “regional differences and local traditions where access to food was determined by a number of factors including status, access to urban markets and the availability of imports,” because they found more variation within the urban site than within the rural sites. (Cheung and Schroeder, 2012: 71). Cheung states the higher elevated $\delta^{15}$N values were correlated with the higher status burials, demonstrating these individuals likely had more access to animal proteins but another study at Berinsfield in the UK, the pattern was the opposite where the poorer burials had the higher $\delta^{15}$N values (Privat et al., 2002)

During the pre-Roman Iron Age, in northern Britain, animal husbandry was the leading force in the economy. Cattle and sheep were the primary livestock because they provided dairy products, wool, and cattle could be used for heavy labor. Pigs and wild game birds were
consumed but in smaller numbers. Millet and other fruits (e.g. grapes, cherries) are seen for the first time in Britain, and with a notable increase in beef consumption (King, 1999; van der Veen et al., 2008).

Fuller et al. (2012) had conducted stable isotope studies in Turkey during the Imperial and Byzantine time periods. The ancient city of Sagalassos, Turkey was of Roman governance and extended into the Byzantine to Medieval Periods. During the early Hungarian Migration Period, Turkish and Iranian groups were known to have occupied the Carpathian Basin. Europe had a primarily C3 diet, and Fuller’s study detailed isotopic site comparisons of animal remains, which helped in the interpretation of the human diets in Turkey. The animals included pig, dog, sheep/goat, and cattle, the isotopic results exhibited temporal changes. The δ¹³C increased with dogs and cattle, reflecting more of a C₄ plant diet during the Imperial and Byzantine Periods, but the pigs and goat isotope values exhibited little change over time. The Early to Middle Byzantine Periods overlaps with the occupation of the Avar in Hungary, and from historic records there were Turkish groups who occupied the Carpathian Basin during the Migration Period. The comparison of Fuller’s research and isotope values with the possible Avar diets and the stable isotope values that it yielded, were helpful in placing this current research into a broader context.

There are a number of stable isotope studies in Greece from a variety of time periods that also do not support millet consumption as a primary agricultural crop in prehistoric Europe (Triantaphyllou et al., 2008; Petrousta and Manolis, 2010; Vika, 2011; Bourbou et al., 2011). Triantaphyllou and colleagues (2008) conducted stable isotope (δ¹³C and δ¹⁵N) analysis for a number of archaeological sites throughout Greece that dated to the Middle Bronze Age (or Middle Helladic, ca. 2100-1700 BC). Their isotopic data supported the inhabitants (including faunal remains) relied on a C₃ terrestrial type diet, and marine resources were not an major
component of their diet as would be expected from past populations living in coastal communities. However, Triantaphyllou and colleagues (2008) stated certain marine resources such as sardines and anchovies exhibit a low trophic $\delta^{15}$N level, and are traditional consumed in the Mediterranean diet.

Petroutsa and Maolis (2010) investigated four populations from mainland Greece that dated back to the Late Bronze Age (1600-1100 BC). Their isotope analysis ($\delta^{13}$C and $\delta^{15}$N) also revealed these past populations exhibited a homogeneous diet that mainly consisted of a C$_3$ terrestrial plant diet and very little marine protein dietary intake regardless of their closeness to the Aegean Sea. The authors noted there were written records of archaeobotanical evidence and stable isotope analysis of C$_4$ plants in Greece, but their results revealed the main plant staple was the C$_3$ staple crop and animal protein consisted mainly of sheep, goats and cattle. In the research of Vika (2011), millet is noted to have existed at several sites throughout ancient Greece but stable isotope analysis still leads to a C$_3$ plant diet. Vika’s (2011) research was based in ancient Thebes, Greece, with burial that dated back to the Early Bronze Age to the Hellenistic times (3000-300 BC). A main objective of Vika’s research was to detect dietary variation over time, between sexes or wealth of the individuals from this population. Interestingly, the $\delta^{13}$C values ranged from -19.1‰ to -20.2‰ over numerous time periods, but the $\delta^{15}$N values showed more variation during the Classic Period (500 BC). The $\delta^{15}$N values were much higher than the previous prehistoric Greece or the later Hellenistic period, an indicator of more marine dietary sources within the individual’s diet. They found no statistically significant differences between males or females or with either the number of grave goods buried with individuals (Vika, 2011).

Price et al. (2004) investigated strontium isotope ratios within skeletal remains from the Bell Beaker Period from southern Germany, Austria, the Czech Republic, and Hungary for
human migration patterns. They compared the tooth enamel to corresponding bone of the individuals to investigate if the individuals had migrated and geographical residence during their lifetimes. Price et al. (2004) addressed the difficult issue of quantitative evidence in human movement and residential changes because the evidence is circumstantial at times. Price et al. (2004) had expressed concern that “archaeologists have relied on indirect means, such as diagnostic signals of identity,” to study the mechanism of mobility through artifacts and material goods and that these can be considered “proxy information” at best; because these material goods may have been traded or stolen or other unknown mechanisms of transfer (Price et al., 2004:10). Isotopic research can help to clarify the origin of material goods when data gathered by traditional means is ambiguous.

Price and co-authors (2004) suggest that strontium isotope analyses should be used to investigate the arrival and migration of modern humans (paleoanthropology), the spread of agriculture, or the beginning of metallurgy. Ongoing discussions have continued in different fields of anthropology on the nature and effects of populations’ migration in prehistory. Theories of prehistoric migration range from searching for new resources for survival, marriage, conquest, and colonization have also led to the appearance of innovative features and technology in the archaeological records (Price et al., 2004). The migration of people allows for cross fertilization of ideas and sharing of technology.

The Bell Beaker period is positioned during the transition between Neolithic and Bronze Age, from 2500 to 2000 BC. The Bell Beaker Period is identified with distinctive grave goods that include; ceramic drinking vessels, jet and amber ornaments, some of the first gold and bronze objects, archery equipment, and in some cases, equestrian gear. The term Bell Beaker refers to the type of uniformed pottery, a distinctive shaped ceramic vessel (thought to be a
drinking cup) found as a grave good along with the other grave goods previously mentioned. Bell Beaker grave goods have been found in intermittently throughout Europe; scattered throughout Central Europe, from Denmark to Sicily, and from Slovakia to as far as Ireland. The theories proposed that the irregular distribution of these artifacts were due to migration or that colonization was responsible for the movement of the Bell Beaker Period. Others have suggested that it was exchange and trade that moved these distinctive cultural artifacts among the ‘indigenous elites’. Another argument suggests that the shortage of these artifacts is due to the effects of population migration and a diffusion of cultural change (Price et al., 2004:10).

Price and colleagues (2004) discovered 51 out of 81 of the individuals in their sample moved in their lifetime, which indicates these individuals were non-locals and mobility during the Bell Beaker Period was frequent. Through the strontium isotope evidence, they were able to demonstrate the considerable mobility during the Bell Beaker Period and determine the occurrence of migration throughout prehistoric Europe and examine the variability among the studied sites. The researchers have made some suggestions on the geographic origins for some of the individuals but at the time of the publication, they had not yet confirmed place of origin (Price et al., 2004). The heavy isotope values that were collected in Hungary during the Bell Beaker Period was utilized as a local strontium isotope signature for Hungary and as a comparison sample for the current Avar study.

Bentley et al. (2004) used histograms to display enamel versus bone $^{87/86}$Sr values per individual. Additionally, they also compared the values between groups. The researchers had individuals that would cluster in their values and others that were outliers; those individuals, in turn, were considered to be the non-locals. The samples they collected were from Flomborn, Schwetzingen and Dillingen (Germany) and are case studies from Neolithic Europe; seven
individuals had similar Sr bone values displaying a local residency for Flomborn. The enamel values were very different from the bone values, which had showed they had lived in the current region within the last 7-10 years before their death. This method was also applied to identify if the Avar individuals were locals or non-locals to the Carpathian Basin region.
Chapter Three

Material and Methods

Materials

This section details the location of where the samples were collected, the number of samples for each specific isotope analysis, the distribution of sex and social status groups, and how the social status groups are defined. The protocols for stable and heavy isotope analyses are explained and detailed. Finally, this section identifies the statistical tests that were utilized to analyze the data.

The Sajópetri cemetery collection is currently housed at the Herman Otto Museum in Miskolc, Hungary. In December 2011, bone and enamel samples were collected from twenty-seven individuals (sample n=54) under the direction of Dr. Ivett Kovari, the Curator (Head of Anthropology), at the Directorate of BAZ County Museums, Department of Archaeology. Research had not been conducted for this region of Hungary, or for this Avar cemetery population, and so it is the first of its kind. The sample includes adult males (n=13, 48.1 percent) and adult females (n=14, 51.9 percent); it was further grouped according to type and number of grave goods to identify social status. The three groups were categorized as high (n=8, 29.7 percent), middle (n=10, 37.0 percent), and lower status (n=9, 33.3 percent). Stable isotope analysis of carbon, nitrogen and oxygen were conducted for enamel and bone of the 27 individuals for dietary reconstruction. In addition, 23 enamel samples and 12 bone samples were analyzed for strontium isotope values and 19 enamel samples were analyzed for lead isotope values to investigate migration patterns of the Avar.
Assessment of Social Status

Artifacts and documentation that will be used to assess the social status of individuals includes the following: maps of individual graves exhibiting positioning of remains, evidence of post holes surrounding burial, burial depth, inventory of mortuary goods (artifacts involved in the mortuary practice, such as weapons, pottery, faunal remains and jewelry), and grave goods interred with each individual (Kiss, 1977; Young, 1978; Pearson, 2000; Makoldi, 2011). The preliminary categorization of grave goods is critical to achieve a better understanding of the social hierarchy of the past population. The types and amount of grave goods interred with the individual burials were the criteria used to categorize the social groups:

- An example of a high status burial for a male (i.e. Grave/Sir 200) would include the skeletal remains of a decorated horse accessorized with iron belt and saddle mounts buried alongside the individual. The male individual is also decorated with ornamental iron belt mounts and weapons, which is shown in Figure 3.1 (Makoldi, 2011; Siman, 1998). Other high status grave goods include pottery and post holes on the corners of the burial.

- The intermediate status includes individuals buried with a few grave goods, such as belt accessories, jewelry, or smaller faunal remains.

- Individuals grouped as the lower status group had only one or no grave goods interred with the individual.

Table 3.1 displays the burial number, sex, and assigned status with a summary of corresponding grave goods. Based on the amount and types of grave goods, along with burial depths; these factors aided in the assignment of social status. Previous research and historic documentation have recorded the variation among the Avar burials, and the observed levels of hierarchy are
based on types and amounts of grave goods and mortuary behavior (Kovrig, 1975; Vida, 2003; Makoldi, 2011). The aforementioned archaeological evidence is the basis for identification of social status. The previous literature was used to categorize the Avar population from the Sajópetri cemetery into high, middle, and low social status groups, and this is the reason that I inferred the categories of the different social status groups.

After the status of individuals had been assigned through these types of archaeological evidence, the hypotheses can then be addressed based on the isotopic analysis and osteological data within each status category. Below (Figure 3.1) is an example of a burial diagram from the Sajópetri cemetery, and more examples are located in Appendix A.

![Burial Diagram](image)

Figure 3.1. Grave 200 and Grave 201 exhibits a high status male with numerous belt accessories and accompanied decorated horse burial.
Table 3.1. Summary table of grave goods identified to infer social status for the Avar.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Status</th>
<th>Grave Goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ52</td>
<td>M</td>
<td>2</td>
<td>Iron buckle, one round and square, faunal remains, blade/knife</td>
</tr>
<tr>
<td>SJ70</td>
<td>F</td>
<td>2</td>
<td>Earring, belt buckle, bronze tweezers, animal bone</td>
</tr>
<tr>
<td>SJ86</td>
<td>M</td>
<td>1</td>
<td>Knuckle ring, large scale knife, large iron nail, 4 post holes (-110 cm), horse burial</td>
</tr>
<tr>
<td>SJ91</td>
<td>M</td>
<td>3</td>
<td>Iron buckle</td>
</tr>
<tr>
<td>SJ117</td>
<td>M</td>
<td>3</td>
<td>No grave goods</td>
</tr>
<tr>
<td>SJ146</td>
<td>F</td>
<td>3</td>
<td>No grave goods</td>
</tr>
<tr>
<td>SJ147</td>
<td>F</td>
<td>3</td>
<td>Iron buckle</td>
</tr>
<tr>
<td>SJ148</td>
<td>F</td>
<td>2</td>
<td>Pottery sherds, animal bones</td>
</tr>
<tr>
<td>SJ156</td>
<td>M</td>
<td>1</td>
<td>Numerous belt accessories, blade/knife, horse burial</td>
</tr>
<tr>
<td>SJ167</td>
<td>F</td>
<td>1</td>
<td>Post holes, blade/knife, earrings, ironing bucket (kék csüngődisze)</td>
</tr>
<tr>
<td>SJ174</td>
<td>M</td>
<td>3</td>
<td>No grave goods</td>
</tr>
<tr>
<td>SJ175</td>
<td>F</td>
<td>2</td>
<td>Earrings, beads, iron buckle</td>
</tr>
<tr>
<td>SJ246</td>
<td>F</td>
<td>3</td>
<td>No grave goods</td>
</tr>
<tr>
<td>SJ250</td>
<td>M</td>
<td>2</td>
<td>Belt clips</td>
</tr>
<tr>
<td>SJ251</td>
<td>F</td>
<td>3</td>
<td>Earring</td>
</tr>
<tr>
<td>SJ252</td>
<td>M</td>
<td>1</td>
<td>Belt clip, blade/knife, animal bones, post holes, horse burial #253</td>
</tr>
<tr>
<td>SJ258</td>
<td>F</td>
<td>2</td>
<td>Earrings, beads, button reel, pottery</td>
</tr>
<tr>
<td>SJ259</td>
<td>F</td>
<td>2</td>
<td>Earring, beads, féműööedék (no translation) hoops, animal bones</td>
</tr>
<tr>
<td>SJ291</td>
<td>F</td>
<td>1</td>
<td>Left ribs missing-burial looting: 4 post holes (-110 to -105cm), beads, 4 decorative bronze pieces, animal bones, bracelet link</td>
</tr>
<tr>
<td>SJ304</td>
<td>M</td>
<td>2</td>
<td>Iron piece by right hip area, blade/knife, earring</td>
</tr>
<tr>
<td>SJ315</td>
<td>F</td>
<td>2</td>
<td>Button reel, bronze fragment, pottery</td>
</tr>
<tr>
<td>SJ331</td>
<td>F</td>
<td>1</td>
<td>Thorax missing/ burial looting: rozettes-dress decoration, earring, beads, button reel, brass buttons, animal bones</td>
</tr>
<tr>
<td>SJ337</td>
<td>F</td>
<td>2</td>
<td>Iron pieces, near a horse burial</td>
</tr>
<tr>
<td>SJ343</td>
<td>M</td>
<td>3</td>
<td>No grave goods</td>
</tr>
<tr>
<td>SJ365</td>
<td>M</td>
<td>1</td>
<td>Buried beneath 364 (burial looting), adjacent horse burial, bronze gold safety pin, blade/knife, pitcher/pottery</td>
</tr>
<tr>
<td>SJ379</td>
<td>M</td>
<td>1</td>
<td>(-150 cm w/ horse to his left) bronze belt end, bronze decorative squares for belt, swivel belt clip, particulate material, iron pieces, blade/knife, grommet piece for belt, (horse accessories: mouth bit, stirrups, iron buckle (-140cm) burial depth</td>
</tr>
<tr>
<td>SJ592</td>
<td>M</td>
<td>3</td>
<td>Iron piece</td>
</tr>
</tbody>
</table>
Osteological Analysis

Skeletal analysis was performed on each skeleton to obtain an estimation of the sex, ancestry, and age-at-death (Buikstra and Ubelaker 1994). The skeletal remains are stored at the Directorate of BAZ County museum and an individual is boxed with corresponding reference numbers. Osteometric data was collected on intact bones (when present), one anterior tooth (central and lateral incisors, canine or premolar), and either a rib or cranial fragment, for each of 27 individuals. Sex estimation was performed using a standard protocol outlined by Buikstra and Ubelaker (1994). Morphological features of the cranium, mandible and pelvis are observed and skeletal traits are rated on an ordinal scale to determine sex (Buikstra and Ubelaker, 1994; White, 2000). Due to the large age ranges provided by current aging methods, multiple lines of evidence were employed to narrow estimates of age-at-death as much as possible. Adults were aged with the use of scoring systems, such as: the degenerative morphological changes of the pubic symphysis, sternal rib ends, cranial suture closure, and tooth eruption and attrition (Buikstra and Ubelaker, 1994). This study focused exclusively on only adult individuals because of the established literature on the assessment of social statuses and associated grave goods interred within the burials.

Isotope Analysis

Protocols for Carbon, Oxygen, and Nitrogen Isotope Analysis

The samples for isotope analysis consisted of a small fragment of rib or crania (approximately 2-3 grams) and one anterior tooth (primarily incisor or canine). The selected teeth for enamel samples were from primarily adult anterior teeth, which include central incisors, lateral incisors or canines. These were chosen in particular due to their earlier crown development in childhood (Hillson, 1996). There were two individuals in which the first
premolar was collected due to missing anterior teeth. Bone samples collected included either a rib fragment or a cranial fragment.

The stable isotopes investigated in enamel are $\delta^{13}C$ and $\delta^{18}O$ (indicative of diet in early childhood), and in the apatite of bone are also $\delta^{13}C$ and $\delta^{18}O$ (indicative of diet for the last 7-10 years of life). To estimate protein content for the individual, the $\delta^{13}C$ and $\delta^{15}N$ isotope values in the collagen of bone were examined. The enamel and bone samples were also collected for the strontium and lead isotope analysis. Enamel and bone samples were used for the strontium and lead isotope analysis, although the enamel has a crystalline structure that is less prone to contamination and diagenetic effects during burial conditions (Ambrose, 1993; Montgomery et al., 2010).

Preparation and purification of enamel and bone samples for dietary analysis were completed at the USF Archaeological Sciences Lab under the supervision of Dr. Robert Tykot. The bone fragment and teeth were ultrasonically cleaned in deionized water to remove dirt and adherent materials. A sample of approximately one-gram in powder form (or small fragments) of bone and enamel is necessary, and an acid solution bath is used to demineralize and remove contaminants from the sample. When collecting an enamel sample, the surface of the selected tooth is drilled. This drilling must be done with care to ensure only enamel is collected and not the dentin of the crown. The following pretreatment protocols utilized were from previous well-established methods completed by researchers in the area of stable isotope analysis for the investigation of dietary patterns for past populations (Ambrose and Norr, 1993; Tykot, 2002).
Enamel Pretreatment

In the processing and purification of enamel samples for mass spectrometry, the protocol was as follows:

1. Each powdered sample was weighed to approximately 10 mg and placed into a 1.5 ml conical vial and labeled with the appropriate burial number and USF number.
2. Then 1 ml of 2.0% bleach solution (sodium hypochlorite) was added to the enamel sample to remove the bacterial proteins and humic acids.
3. After 24 hours, the conical vials were centrifuged and excess bleach solution with contaminants were removed. The samples were washed with deionized water four times and then placed overnight into a drying oven at 60° C to dry the sample of excess deionized water.
4. Next, 1 ml of 1M acetic acid/sodium acetate buffer solution was added, and the sample had to sit for the next 24 hours. The samples then were centrifuged and the excess 1M acetic acid/sodium acetate buffer solution was pipetted out.
5. Afterward, the samples were washed 4 times with deionized water and placed in the drying oven (60° C) overnight (Tykot, 2006).
6. The following day the samples were weighed and ready for mass spectrometry analysis, and were analyzed at the University of Florida using a Finnigan-MAT 252 isotope ratio mass spectrometer coupled with a Kiel III carbonate preparation device (personal communication, Jason Curtis, 2012).

Oxygen and carbon isotopes were measured on bulk enamel by reacting treated samples in orthophosphoric acid at 70° C using a Finnigan-MAT Kiel III carbonate preparation device. Evolved CO₂ gas was measured online with a Finnigan-MAT 252 mass spectrometer at the
Geological Sciences Laboratory, University of Florida, Gainesville. All isotope results were reported in standard delta notation relative to Vienna Pee Dee Belemnite (VPDB) (personal communication, Jason Curtis, 2012).

**Apatite Pretreatment**

For the bone apatite samples, drilling of the surface of the bone for approximately 10 mg of bone powder was all that was required.

1. The sample was then collected into a 1.5 ml conical vial. The vials were labeled with the burial and a USF number, and 1 ml of a 2.0% bleach solution was added to each vial, which then needed to sit for the next 72 hours. The sodium hypochlorite (bleach) was used to dissolve any organic components (bacterial proteins, collagen, and humic acids), and a weak acid solution was employed to remove any non-biogenic carbonates.

2. After 72 hours, the samples were washed four times with deionized water and then placed in the drying oven at 60° C overnight.

3. After the samples are dried, the samples were weighed and pretreated with 1 ml of 1M acetic acid/sodium acetate buffer solution for the next 24 hours.

4. After the allotted time, the 1M acetic acid/sodium acetate buffer solution was removed and discarded, and the sample was washed with deionized water four more times.

5. The samples were placed in the drying oven overnight and then weighed the following day. This was the last step before mass spectrometry analysis (Tykot, 2006).
**Collagen Pretreatment**

The protocol for the processing and purification to analyze the collagen content of bone was conducted at the USF Archaeological Sciences Lab under the supervision of Prof. Robert Tykot. The bone samples were cleaned with deionized water within an ultrasonic water bath instrument to remove soil or adherent materials.

1. The samples were dried overnight and cut into smaller bone fragments, resulting in a sample weighing approximately 1 g for the purification and analysis process. Each sample was placed into a 100 ml glass vial, and 50 ml of 0.1M NaOH were added to each sample to remove humic acids and contaminates for the next 24 hours.

2. The NaOH solution was removed and samples were washed with deionized water three times. The samples were cut into smaller fragments for further analysis, and 50 ml of a solution of 2% HCl were added to the samples within their corresponding vials.

3. Every 24 hours the 2% HCl solution was replaced with fresh acid until the acid solution within the glass vial containing the sample was no longer a yellowish tint and there were no longer any bubbles on the surface of the liquid (personal communication, Robert Tykot, 2012).

4. These samples took approximately 72 hours to process in the 2% HCl solution to completely demineralize. The samples were then washed three times with deionized water and then soaked in 50 ml of 0.1M NaOH for another 24 hours to remove humic acids again.
5. After 24 hours, the samples were then rinsed with deionized water another three times and soaked in a defatting solution (2:1:0.8 mixture of methanol, chloroform and deionized water) for another 24 hours to remove fat (lipid) content.

6. The following day, the samples were removed from the defatting solution, thoroughly rinsed with methanol and placed into the drying oven (60° C) overnight.

7. Each of the dried samples was weighed to determine collagen yield. A smaller sample weighing approximately 1 mg was retrieved from the dried sample, which was carefully placed and wrapped into a tin capsule for the mass spectrometry analysis. A minimum of two collagen samples was submitted for each individual to ensure reliability of the mass spectrometry values (Honch et al., 2006).

The initial and final weight of the sample provides a percentage yield of the product. Yields less than 1% are potentially problematic, with unequal degradation of the amino acids that make up collagen. The collagen yield refers to the minimum weight yields of carbon and nitrogen. Yields of 2.9-3.6 are understood to produce reliable $\delta^{13}C$ and $\delta^{15}N$ values for modern bone.

In the collagen analysis, reference gases and solid standard samples (NBS-19) are analyzed at the beginning of each run and then every six or seven samples thereafter to ensure the reliability of all the C:N results (Tykot, 2004). Honch and colleagues (2006) suggested that the minimum weight yields of 0.5 mg for carbon and 0.2 mg of nitrogen, per combusted sample (2-3 mg total weight) are generally utilized to ensure sample reliability within the analytical limits of the mass spectrometers. A minimum of two samples was processed through mass spectrometry for $\delta^{13}C$ and the $\delta^{15}N$ per individual, as per standard protocol for collagen analysis. In some cases, if there was analytical machinery malfunction or the sample did not meet the
minimum analytical threshold of carbon and nitrogen values, another two samples would be run through the mass spectrometry again to ensure sample integrity (Honch et al., 2006).

The mass spectrometry instrument used in the collagen (carbon and nitrogen isotope) analysis was the Thermo Electron Delta V Advantage isotope ratio mass spectrometer coupled with a ConFlo II interface linked to a Carlo Erba NA 1500 CNS Elemental Analyzer. The tin capsules that contain 1 mg samples were loaded and placed in a 50-position automated Zero Blank sample carousel on a Carlo Erba NA1500 CNS elemental analyzer. The sample in the tin capsule passes through a quartz column at 1020° C and undergoes a high combustion reaction. The sample gas then moves through a series of elemental copper reduction column at high temperatures and a magnesium perchlorate trap to remove water and separate N2 from CO2. This sample gas flows into the ConFlo II preparation system and into the chamber of the Thermo Electron Delta V Advantage isotope ratio mass spectrometer running in a continuous flow mode, which measures the sample gas relative to laboratory reference N2 and CO2 gases. All carbon isotopic results are expressed in standard delta notation relative to VPDB. All nitrogen isotopic results are expressed in standard delta notation relative to AIR (personal communication, Jason Curtis, 2012).

Protocol for Strontium and Lead Isotope Analysis

The sample processing for tooth enamel and bone for strontium (Sr) and lead (Pb) isotope analysis was completed at the Department of Geological Sciences, University of Florida, in a class 1000 clean lab that was equipped with class-10 laminar flow hoods. The following protocol was performed at the Geological Sciences Laboratory under the supervision of Dr. George D. Kamenov, at the University of Florida, Gainesville.
1. The bone and enamel were cleaned with deionized water and an approximately 1 gram powder sample was collected from the bone and enamel for isotope analysis (initially performed at USF).

2. The bone and corresponding enamel samples were dissolved in pre-cleaned Teflon vials on a hotplate for 24 hours in 8 N HNO₃ (optima).

3. The vials were then opened and the solution evaporated to dryness in a laminar flow hood.

4. Strontium and lead were sequentially separated by ion chromatography from single aliquots.

5. The stems of 100 µl columns were packed with Dowex 1X-8 (100-200 mesh), the resin was then rinsed with 2 ml of 6N HCl (optima).

6. Each enamel sample was dissolved in 400 µl of 1N Seastar HBr and loaded onto the column resin, and then washed three times with 1 ml 1N Seastar HBr.

7. The collecting vial was then replaced with another pre-cleaned Teflon vial to collect the lead fraction in a final wash of 1 ml 20% HNO₃ (optima grade) (Kamenov et al. 2009).

8. The lead solution was evaporated to dryness on a hot plate located within the laminar flow hood.

9. Throughout the lead elution step, the three 1 ml HBr washes were collected for successive strontium separation, as strontium is not absorbed on the Dowex resin.

10. The dried residues from the washes were dissolved in 3.5N HNO₃ and loaded on to cation exchange columns (columns with a stem for resin bed) packed with strontium-selective crown ether resin (Sr-spec (#SR-B100-S), Eichrom Technologies, Inc.) to
separate Sr from other ions following recognized procedures (Pin and Bassin, 1992; Kamenov et al. 2009).

11. Each 100 µl column stem was packed with Sr-spec resin, washed with 2 ml of 4× H₂O (deionized H₂O) and equilibrated with 2 ml 3.5N HNO₃ (optima).

12. Then 200 µl were collected from the dissolved samples and loaded into the resin columns and washed four times with 100 µl of 3.5N HNO₃ (optima).

13. A final wash of 1 ml of 3.5N HNO₃ was completed, and strontium was collected in 1.5 ml of 4× H₂O which was then evaporated on a hot plate within the laminar flow hood.

The strontium and lead isotopic ratios were measured by utilizing the “Nu-Plasma” multiple-collector inductively coupled plasma mass spectrometer (MC-ICP-MS), using the time-resolved analysis method of Kamenov et al. (2008). For Sr isotope analysis, on-peak zero was determined before each sample introduction in order to correct for isobaric interference caused by impurities of Kr in the Ar carrier gas. ⁸⁷Sr/⁸⁶Sr was corrected for mass-bias using exponential law and ⁸⁶Sr/⁸⁸Sr = 0.1194. ⁸⁷Sr was corrected for presence of Rb by monitoring the intensity of ⁸⁵Rb and subtracting the intensity of ⁸⁷Rb from the intensity of ⁸⁷Sr, using ⁸⁷Rb/⁸⁵Rb = 0.386 and mass-bias correction factor determined from ⁸⁶Sr/⁸⁸Sr. The average value of the TRA-measured ⁸⁷Sr/⁸⁶Sr of NBS 987 is 0.71024 (2σ = 0.00003), which is indistinguishable from long-term TIMS NBS 987 results (0.71024; 2σ = 0.00002). Pb isotopic analyses were conducted using the Tl normalization technique on fresh mixtures to prevent oxidation of thallium to Tl³⁺ (Kamenov et al. 2004). The reported data in this work are relative to the following long-term NBS 981 Pb isotope analyses: ²⁰⁶Pb/²⁰⁴Pb=16.937 (2σ = 0.004), ²⁰⁷Pb/²⁰⁴Pb=15.490 (2σ = 0.003), and ²⁰⁸Pb/²⁰⁴Pb=36.695 (2σ = 0.009).
Statistical Tests

The output data for the carbon, oxygen, and nitrogen isotope analysis were compiled in Microsoft Excel spreadsheets. The spreadsheets display the numeric values for percentile yields in parts per thousand for each of the specific elements, and were plotted to compare the variability between individuals and the social groups. The output data for strontium and lead isotope analysis were compiled in Excel spreadsheets which exhibit the numeric ratios of each of the isotopic forms, and were plotted to compare the variability between individuals and among the group.

Both non-parametric (Mann-Whitney U Test and Kruskal-Wallis Test) and parametric T-tests and ANOVA (Scheffe Post Hoc) tests were utilized to identify if there were any statistical significance between the dietary stable isotope values between the social classes and between males and females. The non-parametric tests were used as a cautionary statistical method because of the small sample size, and to identify if there would be contrasting results between a non-parametric and a parametric test. However, results from the both types of statistical analysis were analogous.

The results for Scheffe Post Hoc and ANOVA tests identified if there was a statistically significant difference in the mean isotope values for all the dietary stable isotopes; and the data were found to be normally distributed. The use of bivariate plots demonstrates the variability between males and females, and the variability among the three social groups.
Chapter Four

Results

The following results are from the stable and heavy isotope analyses as generated by mass spectrometry. Table 4.1 displays the stable isotope results for each individual in the Avar sample: \( \delta^{13}C_{\text{col}} \) and \( \delta^{15}N_{\text{col}} \) represents values from bone for collagen content, \( \delta^{13}C_{\text{en}} \) and \( \delta^{18}O_{\text{en}} \) represents values from enamel and \( \delta^{13}C_{\text{ap}} \) and \( \delta^{18}O_{\text{ap}} \) represents the values for bone apatite. Table 4.1 displays the stable isotope results for each individual (n=27) including their sex and assigned social status category. Among the 27 decedents, there was not enough enamel to perform stable isotope analysis for each individual; however there were bone samples available from each individual for stable isotope analysis. While there was not enough enamel present in all individuals for stable isotope analysis this examination was accomplished via bone when necessary. The stable isotope analysis results are presented in Tables 4.2-4.5 and Figures 4.1-4.5, and the heavy isotope analysis results are displayed in Tables 4.6-4.8 and Figures 4.6-4.11. Table 4.2 lists the stable isotope value range, mean, and standard deviation for the entire sampled Avar cemetery population. Information in Table 4.3 also includes the carbon to nitrogen (C:N) ratio and percent yield, which is necessary to determine if the collagen preservation is satisfactory for analysis. The isotope values were run through both non-parametric (Mann-Whitney U Test and Kruskal-Wallis Test) and parametric \( t \)-tests as well as ANOVA to identify any statistically significant differences between the dietary stable isotope values and the social classes. This was used to analyze differences between males and females as well. \( t \)-tests were performed for the
heavy isotope analysis to determine if there were statistically significant difference between
social classes and sexes. The results from both types of statistical analysis were analogous.

**Stable Isotope Results for Carbon, Oxygen, and Nitrogen**

The socio-economic groups were assigned categories based on the amount of grave goods
interred within the burial and burial depth, with Status 1 assigned to the high status or equestrian
burials. Status 2 constitutes a moderate amount of grave goods within the burial, no post holes
present, and not an equestrian burial; while the lower status group (Status 3) had only one or no
grave goods within the burial. The C:N ratio and percent collagen yield are also listed as an
indication of the reliability of the $\delta^{13}C$ and the $\delta^{15}N$ sample amounts (Ambrose and Norr, 1992;
Tykot, 2004). The results for the carbon ($\delta^{13}C$), oxygen ($\delta^{18}O$), and nitrogen ($\delta^{15}N$) isotope
values for both males and females (N=27) are contained in Table 4.1.

Among the 27 individuals, the $\delta^{13}C_{\text{col}}$ data ranges from -19.0‰ to -16.7‰, with an
average of -17.5‰ and a standard deviation of ± 0.6. The $\delta^{15}N_{\text{col}}$ data results for the sample
population ranges from 9.6‰ to 11.4‰ with an average of 10.7‰ and a standard deviation of
±0.5. The $\delta^{13}C_{\text{en}}$ results for the sample population ranges from -11.8‰ to -7.2‰ with an average
of -9.7‰ and a standard deviation of ± 1.0. The $\delta^{18}O_{\text{en}}$ results for the sample population ranges
from -6.8‰ to -5.0‰ with an average of -5.6‰ and a standard deviation of ± 0.6‰. The $\delta^{13}C_{\text{ap}}$
results for the sample population ranges from -11.9‰ to -10.2‰ with an average -11.1‰ and a
standard deviation of ± 0.5. The $\delta^{18}O_{\text{ap}}$ results from the sample ranges from -5.8‰ to -2.8‰ with
an average of -4.9‰ and a standard deviation of ± 0.6. Table 4.2 exhibits the summary of isotope
ranges, means, and standard deviations for each of the stable isotopes for the sample Avar
population.
Table 4.1. Stable isotope results for each individual in the Avar sample: $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ represents values from bone for collagen content, $\delta^{13}C_{en}$ and $\delta^{18}O_{en}$ represents values from enamel and $\delta^{13}C_{ap}$ and $\delta^{18}O_{ap}$ represents the values for bone apatite.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Status</th>
<th>C/N ratio</th>
<th>% Yield</th>
<th>$\delta^{13}C_{col}$</th>
<th>$\delta^{15}N_{col}$</th>
<th>$\delta^{13}C_{en}$</th>
<th>$\delta^{18}O_{en}$</th>
<th>$\delta^{13}C_{ap}$</th>
<th>$\delta^{18}O_{ap}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ52</td>
<td>M</td>
<td>2</td>
<td>3.2</td>
<td>8.0</td>
<td>-17.1</td>
<td>10.9</td>
<td>-7.2</td>
<td>-6.0</td>
<td>-10.9</td>
<td>-5.4</td>
</tr>
<tr>
<td>SJ70</td>
<td>F</td>
<td>2</td>
<td>3.2</td>
<td>8.4</td>
<td>-16.6</td>
<td>10.3</td>
<td>-10.3</td>
<td>-6.0</td>
<td>-11.4</td>
<td>-5.3</td>
</tr>
<tr>
<td>SJ86</td>
<td>M</td>
<td>1</td>
<td>3.3</td>
<td>6.3</td>
<td>-17.4</td>
<td>10.6</td>
<td>-11.8</td>
<td>-6.0</td>
<td>-11.2</td>
<td>-5.8</td>
</tr>
<tr>
<td>SJ91</td>
<td>M</td>
<td>3</td>
<td>3.3</td>
<td>8.6</td>
<td>-17.3</td>
<td>11.7</td>
<td>-9.3</td>
<td>-6.8</td>
<td>-10.2</td>
<td>-5.5</td>
</tr>
<tr>
<td>SJ117</td>
<td>M</td>
<td>3</td>
<td>3.2</td>
<td>14.0</td>
<td>-16.7</td>
<td>11.41</td>
<td>-9.5</td>
<td>-5.7</td>
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<td>-5.2</td>
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<tr>
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<td>3</td>
<td>3.2</td>
<td>10.4</td>
<td>-16.6</td>
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<td>-9.3</td>
<td>-6.0</td>
<td>-10.7</td>
<td>-4.9</td>
</tr>
<tr>
<td>SJ147</td>
<td>F</td>
<td>3</td>
<td>3.2</td>
<td>9.1</td>
<td>-17.4</td>
<td>10.2</td>
<td>-8.6</td>
<td>-6.4</td>
<td>-10.7</td>
<td>-4.6</td>
</tr>
<tr>
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<td>F</td>
<td>2</td>
<td>3.3</td>
<td>14.7</td>
<td>-17.7</td>
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<td>3.3</td>
<td>14.3</td>
<td>-17.2</td>
<td>11.3</td>
<td>(***)</td>
<td>(***)</td>
<td>-11.3</td>
<td>-4.4</td>
</tr>
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<td>8.2</td>
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<td>-11.5</td>
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<tr>
<td>SJ174</td>
<td>M</td>
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<td>9.2</td>
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<td>-5.8</td>
<td>-10.7</td>
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<tr>
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<td>3.3</td>
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<td>-17.9</td>
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<td>-4.8</td>
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<tr>
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<td>F</td>
<td>3</td>
<td>3.2</td>
<td>9.5</td>
<td>-17.8</td>
<td>10.8</td>
<td>-9.3</td>
<td>-5.1</td>
<td>-11.3</td>
<td>-4.9</td>
</tr>
<tr>
<td>SJ250</td>
<td>M</td>
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<td>3.2</td>
<td>9.3</td>
<td>-17.8</td>
<td>10.4</td>
<td>-9.3</td>
<td>-4.8</td>
<td>-11.4</td>
<td>-5.6</td>
</tr>
<tr>
<td>SJ251</td>
<td>F</td>
<td>3</td>
<td>3.2</td>
<td>9.7</td>
<td>-18.1</td>
<td>10.9</td>
<td>-8.3</td>
<td>-5.5</td>
<td>-11.9</td>
<td>-4.5</td>
</tr>
<tr>
<td>SJ252</td>
<td>M</td>
<td>1</td>
<td>3.3</td>
<td>9.2</td>
<td>-16.8</td>
<td>11.0</td>
<td>-10.4</td>
<td>-5.1</td>
<td>-11.4</td>
<td>-5.2</td>
</tr>
<tr>
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<td>F</td>
<td>2</td>
<td>3.2</td>
<td>14.4</td>
<td>-17.6</td>
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<td>-5.0</td>
<td>-11.5</td>
<td>-5.4</td>
</tr>
<tr>
<td>SJ259</td>
<td>F</td>
<td>2</td>
<td>3.3</td>
<td>15.2</td>
<td>-18.1</td>
<td>10.6</td>
<td>-10.9</td>
<td>-4.2</td>
<td>-11.7</td>
<td>-5.0</td>
</tr>
<tr>
<td>SJ291</td>
<td>F</td>
<td>1</td>
<td>3.3</td>
<td>12.5</td>
<td>-18.0</td>
<td>10.1</td>
<td>-10.7</td>
<td>-5.1</td>
<td>-11.5</td>
<td>-3.9</td>
</tr>
<tr>
<td>SJ304</td>
<td>M</td>
<td>2</td>
<td>3.2</td>
<td>15.7</td>
<td>-17.7</td>
<td>10.3</td>
<td>-9.7</td>
<td>-5.6</td>
<td>-11.5</td>
<td>-4.6</td>
</tr>
<tr>
<td>SJ315</td>
<td>F</td>
<td>2</td>
<td>3.3</td>
<td>3.9</td>
<td>-18.4</td>
<td>9.7</td>
<td>-9.0</td>
<td>-5.4</td>
<td>-10.1</td>
<td>-5.9</td>
</tr>
<tr>
<td>SJ331</td>
<td>F</td>
<td>1</td>
<td>3.3</td>
<td>13.8</td>
<td>-18.2</td>
<td>10.4</td>
<td>-9.9</td>
<td>-6.0</td>
<td>-11.2</td>
<td>-5.3</td>
</tr>
<tr>
<td>SJ337</td>
<td>F</td>
<td>2</td>
<td>3.3</td>
<td>9.0</td>
<td>-17.3</td>
<td>11.3</td>
<td>-10.2</td>
<td>-5.4</td>
<td>-11.1</td>
<td>-5.0</td>
</tr>
<tr>
<td>SJ343</td>
<td>M</td>
<td>3</td>
<td>3.5</td>
<td>10.3</td>
<td>-16.6</td>
<td>10.8</td>
<td>-9</td>
<td>-5.4</td>
<td>-10.3</td>
<td>-5.1</td>
</tr>
<tr>
<td>SJ365</td>
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<td>3.5</td>
<td>3.1</td>
<td>-17.4</td>
<td>10.3</td>
<td>(***)</td>
<td>(***)</td>
<td>-10.6</td>
<td>-2.8</td>
</tr>
<tr>
<td>SJ379</td>
<td>M</td>
<td>1</td>
<td>3.6</td>
<td>5.1</td>
<td>-19.0</td>
<td>11.4</td>
<td>-8.8</td>
<td>-6</td>
<td>-11.7</td>
<td>-4.4</td>
</tr>
<tr>
<td>SJ592</td>
<td>M</td>
<td>3</td>
<td>3.3</td>
<td>3.6</td>
<td>-18.3</td>
<td>10.9</td>
<td>-10.5</td>
<td>-5.6</td>
<td>-11.2</td>
<td>-4.5</td>
</tr>
</tbody>
</table>

(***) Not an adequate amount of sample to perform analysis.

All delta values are reported in ‰ Vienna Pee Dee Belemnite (VPDB) or ‰ AIR for nitrogen isotopes.
The results for the carbon isotope values of the enamel and apatite indicate that the Avar population had a relative dependency on a C4 plant diet. The $\delta^{13}C$ average values for a C3 plant diet are approximately $-26.5 \pm 2.0$, while the average values of a C4 plant diet are approximately $-12.5 \pm 1.2$ (Tykot, 2006; Atahan et al., 2011; Leatherdale, 2013). Figure 4.1 displays this population plots closest to the C4 plant diet. The $\delta^{13}C$ and $\delta^{15}N$ collagen values indicate an omnivorous diet of protein, which includes cattle, ovicaprid (sheep or goat family), and pigs as the most probable animal meat sources, with very little or no seafood observed in their diets (Molnar 2000; Bartosiewicz, 2003; Hoekman-Sites and Giblin, 2012; Tykot, 2004). Table 4.2 displays the stable isotope results for each of the individuals sampled in the Sajopétri cemetery, along with their sex and assigned social status group. Valid collagen results yield a carbon-nitrogen (C:N) ratio of 2.9-3.6, however, the higher end of the ratio may indicate a degraded protein sample (Ambrose, 1990). The C:N ratio is automatically calculated by the mass spectrometer. The percent yield for the collagen results should range from 1% to 20% to have a reliable reading calculated by the mass spectrometer (Ambrose, 1990). The presence of solid pseudomorphs after pretreatment of the bone is also another good indicator of a quality collagen yield (as per conversation, Tykot, 2013).

Table 4.2. The stable isotope results for the sampled population (n=27), displaying the value ranges and the means with the corresponding standard deviation.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Value Range</th>
<th>Mean and SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta^{13}C_{\text{col}}$ (collagen)</td>
<td>$-19.0%$ to $-16.7%$</td>
<td>$-17.5%$, sd = .6</td>
</tr>
<tr>
<td>$\delta^{15}N_{\text{col}}$ (collagen)</td>
<td>9.6$%$ to 11.4$%$</td>
<td>10.7$%$, sd = .5</td>
</tr>
<tr>
<td>$\delta^{13}C_{\text{en}}$ (enamel)</td>
<td>$-11.8%$ to $-7.2%$</td>
<td>$-9.7%$, sd = 1.0</td>
</tr>
<tr>
<td>$\delta^{18}O_{\text{en}}$ (enamel)</td>
<td>$-6.8%$ to $-5.0%$</td>
<td>$-5.6%$, sd = .6</td>
</tr>
<tr>
<td>$\delta^{13}C_{\text{ap}}$ (apatite)</td>
<td>$-11.9%$ to $-10.2%$</td>
<td>$-11.1%$, sd = .5</td>
</tr>
<tr>
<td>$\delta^{18}O_{\text{ap}}$ (apatite)</td>
<td>$-5.8%$ to $-2.8%$</td>
<td>$-4.9%$, sd = .6</td>
</tr>
</tbody>
</table>
Table 4.3 displays the stable isotopes mean values with the corresponding standard deviation for men and women. Although the results do not exhibit statistically significant differences between males and females for the stable isotope values, the men do exhibit a trend of a slightly higher value on average (less negative value) for both $\delta^{13}$C and $\delta^{18}$O enamel values.

Table 4.3. A summary table displaying the stable isotope value means and corresponding standard deviation for both males and females

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Sex</th>
<th>n</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta^{13}$C$_{\text{col}}$ (collagen)</td>
<td>M</td>
<td>n=13</td>
<td>-17.4‰</td>
<td>.7</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>-17.7‰</td>
<td>.5</td>
</tr>
<tr>
<td>$\delta^{15}$N$_{\text{col}}$ (collagen)</td>
<td>M</td>
<td>n=13</td>
<td>10.9‰</td>
<td>.5</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>10.5‰</td>
<td>.5</td>
</tr>
<tr>
<td>$\delta^{13}$C$_{\text{en}}$ (enamel)</td>
<td>M</td>
<td>n=11</td>
<td>-8.2‰</td>
<td>.8</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>-9.6‰</td>
<td>1.0</td>
</tr>
<tr>
<td>$\delta^{18}$O$_{\text{en}}$ (enamel)</td>
<td>M</td>
<td>n=11</td>
<td>-4.8‰</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>-5.5‰</td>
<td>.5</td>
</tr>
<tr>
<td>$\delta^{13}$C$_{\text{ap}}$ (apatite)</td>
<td>M</td>
<td>n=13</td>
<td>-11.0‰</td>
<td>.5</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>-11.2‰</td>
<td>.5</td>
</tr>
<tr>
<td>$\delta^{18}$O$_{\text{ap}}$ (apatite)</td>
<td>M</td>
<td>n=13</td>
<td>-4.9‰</td>
<td>.8</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>n=14</td>
<td>-4.9‰</td>
<td>.3</td>
</tr>
</tbody>
</table>

The data were found to be normally distributed and were tested with the Shapiro-Wilk test, and the results are displayed in Table 4.4. The $p$ values from the Shapiro-Wilk test do not exhibit statistically significant differences for the stable isotope values between the social status groups, and are found to be normally distributed. Both parametric and non-parametric statistical tests were used because there was a concern the sample size of 27 individuals may not produce normally distributed data set.
Table 4.4. A summary for the Shapiro-Wilk, a statistical test to identify the data are normally distributed.

<table>
<thead>
<tr>
<th>Test of Normality</th>
<th>Status</th>
<th>Statistic</th>
<th>df</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta^{13}C_{\text{col}}$ (collagen)</td>
<td>High</td>
<td>.977</td>
<td>4</td>
<td>.881</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.922</td>
<td>4</td>
<td>.548</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.999</td>
<td>3</td>
<td>.942</td>
</tr>
<tr>
<td>$\delta^{15}N_{\text{col}}$ (collagen)</td>
<td>High</td>
<td>.883</td>
<td>4</td>
<td>.351</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.924</td>
<td>4</td>
<td>.560</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.981</td>
<td>3</td>
<td>.739</td>
</tr>
<tr>
<td>$\delta^{13}C_{\text{en}}$ (enamel)</td>
<td>High</td>
<td>.840</td>
<td>4</td>
<td>.196</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.796</td>
<td>4</td>
<td>.096</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.750</td>
<td>3</td>
<td>.000</td>
</tr>
<tr>
<td>$\delta^{18}O_{\text{en}}$ (enamel)</td>
<td>High</td>
<td>.982</td>
<td>4</td>
<td>.911</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.993</td>
<td>4</td>
<td>.972</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.983</td>
<td>3</td>
<td>.747</td>
</tr>
<tr>
<td>$\delta^{13}C_{\text{ap}}$ (apatite)</td>
<td>High</td>
<td>.772</td>
<td>4</td>
<td>.060</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.971</td>
<td>4</td>
<td>.850</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.947</td>
<td>3</td>
<td>.554</td>
</tr>
<tr>
<td>$\delta^{18}O_{\text{ap}}$ (apatite)</td>
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<td>.820</td>
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<td>.142</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.899</td>
<td>4</td>
<td>.428</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.987</td>
<td>3</td>
<td>.780</td>
</tr>
<tr>
<td>$^{87}\text{Sr}^{86}\text{Sr}$ enamel</td>
<td>High</td>
<td>.952</td>
<td>4</td>
<td>.729</td>
</tr>
<tr>
<td></td>
<td>Intermediate</td>
<td>.932</td>
<td>4</td>
<td>.608</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>.992</td>
<td>3</td>
<td>.833</td>
</tr>
<tr>
<td>$^{87}\text{Sr}^{86}\text{Sr}$ bone</td>
<td>High</td>
<td>.784</td>
<td>4</td>
<td>.077</td>
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<tr>
<td></td>
<td>Intermediate</td>
<td>.877</td>
<td>4</td>
<td>.327</td>
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<tr>
<td></td>
<td>Low</td>
<td>932</td>
<td>3</td>
<td>.496</td>
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</table>

The results for Levene’s Test for equality of variances and the t-test for Equality of Means, shown in Table 4.5, and the results do not exhibit statistically significant differences for the stable isotope values between the social status groups, and are found to be normally distributed. The Levene’s Test is the parametric test to determine if statistically significant differences are occurring between the means (of the isotope values) of the sexes. This test is only done for two groups. Since it is a parametric test, it needs to meet certain assumptions to increase the likelihood that the significance and (t) and (F) values found are reliable and best determine the accuracy of the within and between group variances. The Levene’s Test is to determine homogeneity of the groups and this is one of the assumptions that should be met before parametric tests are done. The test can proceed if the other (normality,
Table 4.5. A summary of the results for the Levene’s Test for equality of variances and the t-test for Equality of Means.

<table>
<thead>
<tr>
<th></th>
<th>Levene’s Test for Equality of Variances</th>
<th>t-test for Equality of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>δ13Ccol</td>
<td>.165</td>
<td>.688</td>
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<tr>
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<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ15Ncol</td>
<td>.232</td>
<td>.634</td>
</tr>
<tr>
<td>Equal variances assumed</td>
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<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
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<td></td>
</tr>
<tr>
<td>δ13Cen</td>
<td>.051</td>
<td>.824</td>
</tr>
<tr>
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<td>Equal variances not assumed</td>
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</tr>
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<td>δ18Oen</td>
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<td>.587</td>
</tr>
<tr>
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<tr>
<td>Equal variances not assumed</td>
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<tr>
<td>δ13Cap</td>
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<td>.765</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ18Oap</td>
<td>.980</td>
<td>.332</td>
</tr>
<tr>
<td>Equal variances assumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equal variances not assumed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

randomness/independent nature of the samples, etc) are met. The F statistic looks to see that even if the means may differ, the standard deviations obtain are not too different from each other. The (F) value is the ratio of the within group variance/between group variance and often used for ANOVA. The F value shows the ratio of variation between the standard deviations of the values for the groups. In the independent sample “t-test Equality of Means”, the statistical values within the Sig (2-tailed) column, the numeric values are greater than $p = < 0.05$, thus statistically significant differences were not found in the isotope values between the sexes. Table 4.6, The Test of Homogeneity of Variance, is needed for the ANOVA, and the Levene’s statistic, along with the degrees of freedom for both numerator and denominator (df1), (df2), and p-values (Sig.)
are recorded within the table. The p-values in the (Sig) column do not exhibit statistically significant differences.

Table 4.6. A summary of the results for the Test of Homogeneity of Variance.

<table>
<thead>
<tr>
<th>Test of Homogeneity of Variance</th>
<th>Levene Statistic</th>
<th>Df 1</th>
<th>Df 2</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>δ13Ccol</td>
<td>.449</td>
<td>2</td>
<td>24</td>
<td>.644</td>
</tr>
<tr>
<td>δ15Ncol</td>
<td>.214</td>
<td>2</td>
<td>24</td>
<td>.809</td>
</tr>
<tr>
<td>δ13Cen</td>
<td>1.023</td>
<td>2</td>
<td>22</td>
<td>.376</td>
</tr>
<tr>
<td>δ18Oen</td>
<td>.292</td>
<td>2</td>
<td>22</td>
<td>.750</td>
</tr>
<tr>
<td>δ13Cap</td>
<td>1.237</td>
<td>2</td>
<td>24</td>
<td>.308</td>
</tr>
<tr>
<td>δ18Oap</td>
<td>2.997</td>
<td>2</td>
<td>24</td>
<td>.069</td>
</tr>
</tbody>
</table>

Table 4.7. A summary of results for the ANOVA comparing stable isotope values between groups.

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>δ13Ccol</td>
<td>Between Groups</td>
<td>.609</td>
<td>2</td>
<td>.305</td>
<td>.823</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>8.878</td>
<td>24</td>
<td>.370</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>9.487</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ15Ncol</td>
<td>Between Groups</td>
<td>.223</td>
<td>2</td>
<td>.112</td>
<td>.367</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>7.295</td>
<td>24</td>
<td>.304</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>7.518</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ13Cen</td>
<td>Between Groups</td>
<td>2.209</td>
<td>2</td>
<td>1.105</td>
<td>1.095</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>22.200</td>
<td>22</td>
<td>1.009</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>24.410</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ18Oen</td>
<td>Between Groups</td>
<td>1.336</td>
<td>2</td>
<td>.668</td>
<td>2.352</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>6.249</td>
<td>22</td>
<td>.284</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>7.586</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ13Cap</td>
<td>Between Groups</td>
<td>.970</td>
<td>2</td>
<td>.485</td>
<td>2.162</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>5.384</td>
<td>24</td>
<td>.224</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>6.354</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>δ18Oap</td>
<td>Between Groups</td>
<td>2.086</td>
<td>2</td>
<td>1.043</td>
<td>2.808</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>8.913</td>
<td>24</td>
<td>.371</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>10.999</td>
<td>26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In Table 4.7, the ANOVA, the statistical analysis of variance between three or more groups (the status groups), and it tests whether or not the groups exhibit statistically significant
differences in the mean values. In this case, the stable isotope values among the social status groups do not demonstrate statistically significant differences.

Both non-parametric Mann-Whitney U Test and Kruskal-Wallis Test, and parametric t-tests and ANOVA were utilized to identify if there were any statistical significance between the dietary stable isotope values among the social classes and between males and females. The non-parametric tests were used as a cautionary statistical method because of the small sample size, and to identify any conflicting results between the non-parametric or a parametric test. Results from both types of statistical analysis were analogous. In Table 4.8, the Mann-Whitney U and Wilcoxon W are test statistics to identify if there is a statistically significant difference with the mean isotope values between the male and female group. In the results observed in the asymptotic statistical significance (2-tailed), the p-values are greater than \( p < .05 \), therefore the stable isotope values between sexes are not statistically significant different.

<table>
<thead>
<tr>
<th>Test Statistics\textsuperscript{a}</th>
<th>( \delta^{13}C_{\text{col}} )</th>
<th>( \delta^{15}N_{\text{col}} )</th>
<th>( \delta^{13}C_{\text{en}} )</th>
<th>( \delta^{18}O_{\text{en}} )</th>
<th>( \delta^{13}C_{\text{ap}} )</th>
<th>( \delta^{18}O_{\text{ap}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann-Whitney U</td>
<td>62.0</td>
<td>54.0</td>
<td>72.5</td>
<td>59.0</td>
<td>70.5</td>
<td>85.0</td>
</tr>
<tr>
<td>Wilcoxon W</td>
<td>167.0</td>
<td>159.0</td>
<td>177.5</td>
<td>125.0</td>
<td>175.5</td>
<td>176.0</td>
</tr>
<tr>
<td>( Z )</td>
<td>-1.411</td>
<td>-1.802</td>
<td>-.247</td>
<td>-.995</td>
<td>-.999</td>
<td>-.292</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.158</td>
<td>.072</td>
<td>.805</td>
<td>.320</td>
<td>.318</td>
<td>.770</td>
</tr>
<tr>
<td>Exact Sig. [2*(1-tailed Sig.)]</td>
<td>.169\textsuperscript{b}</td>
<td>.076\textsuperscript{b}</td>
<td>.809\textsuperscript{b}</td>
<td>.344\textsuperscript{b}</td>
<td>.325\textsuperscript{b}</td>
<td>.793\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\textsuperscript{a}. Grouping Variable: SexNumeric
\textsuperscript{b}. Not corrected for ties.

Table 4.9 and Table 4.10 displays the results for the Kruskal-Wallis (non-parametric) statistic test equivalent to the ANOVA, and used to identify if there are any statistically significant differences with the stable isotope mean values among the status groups and between the sexes. The p-values are greater than \( p \leq .05 \), thus, the null hypothesis must be retained.
The null hypothesis states: \( H_0: \) The distribution of \( \delta^{13}C, \delta^{15}N, \delta^{18}O, \) and \(^{87}Sr^{86}Sr\) values are the same across categories of status and sex.

Table 4.9. A summary of the results for the Kruskal-Wallis (non-parametric) to identify statistical significance in the stable and heavy isotope values among the status groups

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Significance</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The distribution of ( \delta^{13}C_{co} ) is the same across categories of Status.</td>
<td>0.525</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{15}N_{co} ) is the same across categories of Status.</td>
<td>0.792</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{14}C_{en} ) is the same across categories of Status.</td>
<td>0.294</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{18}O_{en} ) is the same across categories of Status.</td>
<td>0.168</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{17}C_{ap} ) is the same across categories of Status.</td>
<td>0.145</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{18}O_{ap} ) is the same across categories of Status.</td>
<td>0.092</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{87}Sr^{86}Sr ) enamel is the same across categories of Status.</td>
<td>0.990</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{87}Sr^{86}Sr ) bone is the same across categories of Status.</td>
<td>0.870</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{206}Pb^{204}Pb ) is the same across categories of Status.</td>
<td>0.640</td>
<td>Retain the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is 0.05 \( (p = < 0.05) \).

Table 4.10. A summary of the results for the Kruskal-Wallis (non-parametric) to identify statistical significance in the stable and heavy isotope values among the sexes

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Significance</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>The distribution of ( \delta^{13}C_{co} ) is the same across categories of SexNumeric.</td>
<td>0.158</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{15}N_{co} ) is the same across categories of SexNumeric.</td>
<td>0.072</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{14}C_{en} ) is the same across categories of SexNumeric.</td>
<td>0.805</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{18}O_{en} ) is the same across categories of SexNumeric.</td>
<td>0.320</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{17}C_{ap} ) is the same across categories of SexNumeric.</td>
<td>0.318</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( \delta^{18}O_{ap} ) is the same across categories of SexNumeric.</td>
<td>0.770</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{87}Sr^{86}Sr ) enamel is the same across categories of Status.</td>
<td>0.990</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{87}Sr^{86}Sr ) bone is the same across categories of SexNumeric.</td>
<td>0.870</td>
<td>Retain the null hypothesis.</td>
</tr>
<tr>
<td>The distribution of ( ^{206}Pb^{204}Pb ) is the same across categories of SexNumeric.</td>
<td>0.640</td>
<td>Retain the null hypothesis.</td>
</tr>
</tbody>
</table>

Asymptotic significances are displayed. The significance level is 0.05 \( (p = < 0.05) \).
Figure 4.1 below exhibits a bivariate plot graph in which the $\delta^{13}\text{C}_{\text{col}}$ values and the $\delta^{15}\text{N}_{\text{col}}$ values for men and women are compared against each other. Figure 4.1 also exhibits a bivariate plot graph with the carbon and nitrogen isotope values, and displays the variability among the social groups. The mean value for the nitrogen isotope value for females is 10.5‰, whereas the mean nitrogen isotope value for males is 10.9‰, which suggest there was slightly higher consumption of animal protein for males. However, this value is not statistically significant different. Figure 4.2 below exhibits a bivariate plot graph in which the $\delta^{13}\text{C}_{\text{ap}}$ and $\delta^{18}\text{O}_{\text{ap}}$ values from the apatite content of bone for men and women and a corresponding bivariate plot graph with the carbon and oxygen isotope values that displays the variability among the social groups. The mean value for the carbon and oxygen isotope values for males and females is almost identical.

Figure 4.3 below exhibits a bivariate plot graph in which the $\delta^{13}\text{C}_{\text{en}}$ and $\delta^{18}\text{O}_{\text{en}}$ values for the enamel content for men and females, as well as the different social groups. Figure 4.4 displays the $\delta^{13}\text{C}_{\text{ap}}$ versus $\delta^{13}\text{C}_{\text{col}}$ for males and females. This graph demonstrates that there was not a statistically significant difference between males and females. Though, the males exhibit slightly higher average carbon isotope values than the females in both the apatite and collagen forms. Figure 4.5 displays the $\delta^{13}\text{C}_{\text{ap}}$ results versus $\delta^{13}\text{C}_{\text{col}}$ for the different social classes. This graph also shows variation in the $\delta^{13}\text{C}$ values but not a statistically significant difference. Both Figure(s) 4.4 and 4.5 have an enrichment factor of +5.1‰ added to their existing values to account for the fractionation (offsets) which are passed on to skeletal tissue. The fractionation offsets and absorption of carbon isotopes are related to the trophic levels of mammals (omnivores) eating other animals that are either on a diet of $C_3$ or $C_4$ plant diets. All of the stable
Figure 4.1. The stable isotope values for $\delta^{13}$C values and the $\delta^{15}$N values plotted to demonstrate the variability between the three social groups, males and females.
Figure 4.2. The stable isotope values for $\delta^{13}$C$_{ap}$ values and the $\delta^{18}$O$_{ap}$ values plotted to demonstrate the variability between the three social groups, males and females.
Figure 4.3. The stable isotope values for $\delta^{13}C_{en}$ and $\delta^{18}O_{en}$ values plotted to demonstrate the variability between the three social groups, males and females.
Figure 4.4. The stable carbon isotope values for apatite versus collagen content ($\delta^{13}C_{ap}$ versus $\delta^{13}C_{col}$) plotted to demonstrate the variability between males and females.

Figure 4.5. The stable carbon isotope values for apatite versus collagen content ($\delta^{13}C_{ap}$ versus $\delta^{13}C_{col}$) plotted to demonstrate the variability between the social classes.
δ^{13}C_{ap} and δ^{13}C_{col} values for the Avar population fall within the C_{4} plant pathway, confirming millet was a probable staple crop for this population.

**Heavy Isotope Results for (Sr) Strontium and (Pb) Lead**

The results for the \(^{87}\text{Sr}/^{86}\text{Sr}\) and lead \(^{206}\text{Pb}/^{204}\text{Pb}\) ratios for both males (n=9) and females (n=13), along with their corresponding social status (high status=4, middle status=10, low status=8), are contained in Table 4.11. The \(^{206}\text{Pb}/^{204}\text{Pb}\) isotope value has been pooled with the \(^{87}\text{Sr}/^{86}\text{Sr}\) value to offer a tighter constraint in the estimation of geographic origin and migration pattern for the individual. In Figure 4.6, the \(^{87}\text{Sr}/^{86}\text{Sr}\) values identified in the enamel are compared to the \(^{87}\text{Sr}/^{86}\text{Sr}\) values identified in the bone. Analyses by Giblin (2013) revealed that the suggested \(^{87}\text{Sr}/^{86}\text{Sr}\) values for the Carpathian Basin region fall in the range of 0.70900 to 0.71070, with a mean of 0.70967. The Avar sampled from this study show that \(^{87}\text{Sr}/^{86}\text{Sr}\) ratios between their enamel and bone are fairly similar, except for three individuals. These results will be discussed in greater detail in the following discussion chapter. The \(^{87}\text{Sr}/^{86}\text{Sr}\) mean value for the sampled Avar population was 0.710336 with a standard deviation of ±0.00027. The \(^{87}\text{Sr}/^{86}\text{Sr}\) values seen in the Avar is slightly higher than what is known for the Carpathian Basin. The Avar \(^{87}\text{Sr}/^{86}\text{Sr}\) values are plotted against other sampled individuals in the European and Asian regions as comparison and reviewed in the discussion chapter starting on page 102. Figures 4.7 and 4.8 are bivariate plot graphs displaying the variability between males and females, as well as the social classes respectively. Both plot graphs show that the individuals stay within close proximity and overlap for their \(^{87}\text{Sr}/^{86}\text{Sr}\) values.
Table 4.11. The heavy isotope results strontium (\(^{87}\text{Sr}/^{86}\text{Sr}\)) and lead (\(^{206}\text{Pb}/^{204}\text{Pb}\)) for the selected individuals (n=22) of the sample population from the Avar cemetery

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Status</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr}) (enamel)</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr}) (bone)</th>
<th>(^{206}\text{Pb}/^{204}\text{Pb}) (enamel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ86</td>
<td>M</td>
<td>1</td>
<td>0.710115</td>
<td>0.710292</td>
<td>18.74851</td>
</tr>
<tr>
<td>SJ252</td>
<td>M</td>
<td>1</td>
<td>0.710293</td>
<td>(***</td>
<td>18.71086</td>
</tr>
<tr>
<td>SJ167</td>
<td>F</td>
<td>1</td>
<td>0.710425</td>
<td>0.710454</td>
<td>18.81023</td>
</tr>
<tr>
<td>SJ331</td>
<td>F</td>
<td>1</td>
<td>0.710737</td>
<td>0.710247</td>
<td>(***</td>
</tr>
<tr>
<td>SJ250</td>
<td>M</td>
<td>2</td>
<td>0.710250</td>
<td>(***</td>
<td>18.87487</td>
</tr>
<tr>
<td>SJ304</td>
<td>M</td>
<td>2</td>
<td>0.710779</td>
<td>0.709978</td>
<td>18.85310</td>
</tr>
<tr>
<td>SJ52</td>
<td>M</td>
<td>2</td>
<td>0.710328</td>
<td>0.710448</td>
<td>18.73395</td>
</tr>
<tr>
<td>SJ148</td>
<td>F</td>
<td>2</td>
<td>0.710003</td>
<td>0.710469</td>
<td>18.65690</td>
</tr>
<tr>
<td>SJ175</td>
<td>F</td>
<td>2</td>
<td>0.710003</td>
<td>(***)</td>
<td>18.62940</td>
</tr>
<tr>
<td>SJ258</td>
<td>F</td>
<td>2</td>
<td>0.710291</td>
<td>(***)</td>
<td>***</td>
</tr>
<tr>
<td>SJ259</td>
<td>F</td>
<td>2</td>
<td>0.710326</td>
<td>(***)</td>
<td>18.76040</td>
</tr>
<tr>
<td>SJ315</td>
<td>F</td>
<td>2</td>
<td>0.710246</td>
<td>(***)</td>
<td>18.76040</td>
</tr>
<tr>
<td>SJ337</td>
<td>F</td>
<td>2</td>
<td>0.710328</td>
<td>0.710149</td>
<td>18.88260</td>
</tr>
<tr>
<td>SJ70</td>
<td>F</td>
<td>2</td>
<td>0.711084</td>
<td>(***)</td>
<td>18.75818</td>
</tr>
<tr>
<td>SJ91</td>
<td>M</td>
<td>3</td>
<td>0.710623</td>
<td>0.710602</td>
<td>18.68222</td>
</tr>
<tr>
<td>SJ117</td>
<td>M</td>
<td>3</td>
<td>0.710302</td>
<td>0.710222</td>
<td>(***</td>
</tr>
<tr>
<td>SJ174</td>
<td>M</td>
<td>3</td>
<td>0.710149</td>
<td>(***)</td>
<td>18.71535</td>
</tr>
<tr>
<td>SJ343</td>
<td>M</td>
<td>3</td>
<td>0.710230</td>
<td>0.710244</td>
<td>18.86070</td>
</tr>
<tr>
<td>SJ146</td>
<td>F</td>
<td>3</td>
<td>0.710331</td>
<td>0.710307</td>
<td>18.69030</td>
</tr>
<tr>
<td>SJ147</td>
<td>F</td>
<td>3</td>
<td>0.710430</td>
<td>(***)</td>
<td>18.70311</td>
</tr>
<tr>
<td>SJ246</td>
<td>F</td>
<td>3</td>
<td>0.710012</td>
<td>(***)</td>
<td>18.85672</td>
</tr>
<tr>
<td>SJ251</td>
<td>F</td>
<td>3</td>
<td>0.710116</td>
<td>0.710200</td>
<td>18.70706</td>
</tr>
</tbody>
</table>

(*** Not an adequate amount of sample to perform analysis

The highest variability observed in the \(^{87}\text{Sr}/^{86}\text{Sr}\) values were between individuals SJ148 (female), SJ304 (male) and SJ331 (female). These first two individuals had a moderate amount of grave goods, while SJ331 was a high status burial as indicated by the high amount of grave goods. The \(^{87}\text{Sr}/^{86}\text{Sr}\) values indicate that the entire sampled population was not local to the region, but three individuals may have originated from another region from the larger Avar group. The \(^{87}\text{Sr}/^{86}\text{Sr}\) mean value was 0.710336 with a standard deviation of ±0.000267.
A $t$-test was performed to identify if there was a significant difference in the mean isotope values between males and females. The $p$ value was $p = .472$, which demonstrates that these isotope values are not a statistically significant difference between males and females.

Table 4.12 displays the lead isotope values for the Avar samples. By showing the contrasting Pb values, current samples from the Sajopétri cemetery can have their point of origin further elucidated. Figures 4.10- 4.12 are bivariate plot graphs which exhibit the different Pb isotope ratios for the Avar decedents and are also plotted against other known samples in the Discussion chapter to identify the contrasting geographic regions established on the Pb isotope
Figure 4.7. The bivariate plot graph exhibits the variability of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between males and females.

Figure 4.8. The bivariate plot graph exhibits the variability of $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between the social classes.
Table 4.12. Heavy isotope results for strontium (\(^{87}\text{Sr}/^{86}\text{Sr}\)) values for both male and female individuals, which display changes in their values over time.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Status</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr}) (enamel)</th>
<th>(^{87}\text{Sr}/^{86}\text{Sr}) (bone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ52</td>
<td>M</td>
<td>2</td>
<td>0.710328</td>
<td>0.710448</td>
</tr>
<tr>
<td>SJ86</td>
<td>M</td>
<td>1</td>
<td>0.710115</td>
<td>0.710292</td>
</tr>
<tr>
<td>SJ91</td>
<td>M</td>
<td>3</td>
<td>0.710623</td>
<td>0.710602</td>
</tr>
<tr>
<td>SJ167</td>
<td>F</td>
<td>1</td>
<td>0.710425</td>
<td>0.710454</td>
</tr>
<tr>
<td>SJ337</td>
<td>F</td>
<td>2</td>
<td>0.710425</td>
<td>0.710454</td>
</tr>
<tr>
<td>SJ251</td>
<td>F</td>
<td>3</td>
<td>0.710116</td>
<td>0.710200</td>
</tr>
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<td>3</td>
<td>0.710302</td>
<td>0.710222</td>
</tr>
<tr>
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<td>F</td>
<td>3</td>
<td>0.710331</td>
<td>0.710307</td>
</tr>
<tr>
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<td>0.710003</td>
<td>0.710469</td>
</tr>
<tr>
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</tr>
<tr>
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<td>0.710247</td>
</tr>
<tr>
<td>SJ343</td>
<td>M</td>
<td>3</td>
<td>0.710230</td>
<td>0.710081</td>
</tr>
</tbody>
</table>

Table 4.13. Results of heavy isotope analysis for lead ratios from enamel: \(^{206}\text{Pb}/^{204}\text{Pb}, \(^{207}\text{Pb}/^{204}\text{Pb}, \) and \(^{208}\text{Pb}/^{204}\text{Pb}\) for the selected individuals (n=19) of the sample population from the Avar cemetery.

<table>
<thead>
<tr>
<th>Individual</th>
<th>Sex</th>
<th>Status</th>
<th>(^{206}\text{Pb}/^{204}\text{Pb})</th>
<th>(^{207}\text{Pb}/^{204}\text{Pb})</th>
<th>(^{208}\text{Pb}/^{204}\text{Pb})</th>
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<tbody>
<tr>
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<td>18.7340</td>
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</tr>
<tr>
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</tr>
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</tr>
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<tr>
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</tr>
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<tr>
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<td>F</td>
<td>2</td>
<td>18.6569</td>
<td>15.6515</td>
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<td>F</td>
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<td>SJ259</td>
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<td>3</td>
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<td>15.6640</td>
<td>38.7958</td>
</tr>
</tbody>
</table>
values. Figure 4.13 is a plot graph for the results of the heavy isotope values ($^{87/86}$Sr versus $^{206/204}$Pb) of the enamel samples for individuals of the Avar population. The enamel samples are primarily used because there has been established research showing enamel has far less diagenetic contamination from soil due to the crystalline structure of the enamel.

Figure 4.9. The heavy isotope values for $^{208/204}$Pb versus $^{207/204}$Pb for individuals of the Avar population.
Figure 4.10. The heavy isotope values for $^{207/204}$Pb versus $^{206/204}$Pb for individuals of the Avar population.

Figure 4.11. The heavy isotope values for $^{208/204}$Pb versus $^{206/204}$Pb for individuals of the Avar population.
Figure 4.12. A bivariate plot graph for the results of the heavy isotope values ($^{206}\text{Pb} \text{ versus } ^{87}\text{Sr}$) of the enamel samples for individuals of the Avar population.
Chapter Five
Discussion

The isotope results from this study imply several trends concerning the Avar diet and migration patterns. The results for the stable isotope analysis revealed that at least one important staple crop was a C₄ plant, most likely millet. This was consistent from early childhood to later adulthood. The heavy isotope analysis revealed that the Avar individuals were non-locals to the Carpathian Basin and most likely arrived to the region within the last 10 years of their life. Historically, most of Europe was known during this time period to harvest wheat and barley, which are C₃ plant crops (Ambrose, 1993; Le Hury and Schutkowski, 2005; Tykot 2006; Fuller et al. 2012; Knipper et al. 2013). It is also known that millet is a C₄ plant, and it was harvested in Asia, originating in northern China in the early Neolithic period (ca. 8000 BP). The research study of Hu et al. (2008) was utilized as comparison data (Figure 5.1.) to show the similarities in the δ¹³C values with the Avar population. Their research site was located in Xiaojingshan, northwest China and dated back to Neolithic Period. Their sample size is smaller than the Avar population, but the δ¹³C values are useful as a baseline for millet isotope values consumed by humans. There were archaeological sites in Europe before the migration of the Avar population with botanical evidence of millet and stable isotope values that indicated some populations had sources of C₄ plants within their diets, but millet was more likely a secondary cultivated cereal source (Taufri et al., 2009; Cheung et al., 2012; Motuzaite-Matuzeviciute et al., 2013).
The $\delta^{15}$N stable isotope results for the Avar population revealed that there was a fair amount of meat consumed by the sample population, but values were not high enough to indicate that aquatic resources (saltwater or freshwater fish) were part of their diets. These low values of $\delta^{15}$N indicate that the population did not have much, if any, saltwater seafood or riverine/lacustrine foods in their diets. The $\delta^{15}$N isotope levels of saltwater seafood or riverine/lacustrine foods generally range 11-15‰, and mammals who feed on marine seafood generally exhibit very high nitrogen values due to tropic level enrichment (Bonsall et al., 1997; Tsutaya et al. 2014; Tykot, 2004, 2006).

Figure 5.1 also includes the stable isotope results of Craig et al. (2009), where they examined the dietary patterns from two coastal sites in Italy during the Roman Period (1st and 2nd centuries AD). This research was an interesting contrast to the Avar population because of the coastal dietary patterns versus the inland terrestrial dietary patterns. The Roman Empire had extended their boundaries into the Carpathian Basin during the 2nd century AD, but Italy still primarily exhibited a C3 plant diet.

Craig et al. (2009) noted Isola Sacra was closer to Rome and had higher $\delta^{13}$N values than the other coastal site, Velia. Both sites were on the west coast of Italy, and Velia was known to for their industry around marine and seaport economy. Velia was known to have a strong marine and ship industry that repaired, constructed, and serviced ships. They had also fished and had a fish-preservation industry (Craig et al., 2009). Isola Sacra was more an urban center closer to Rome than Velia, which was considered more rural. The basic staples of the Roman diet appeared to be cereals and olive oil, while dry legumes and wine were very important foodstuffs. Pork and beef were part of the animal proteins consumed, but meat and dairy produce was more
a supplement than a staple food. There was minor fish and garum (fish sauce) intake as well.

Between the two groups from Velia, the population at Isola Sacra was on average 0.6‰ for $\delta^{13}C$

Figure 5.1. Bivariate plot graph with the $\delta^{13}C$ and $\delta^{15}N$ values (collagen analysis) from Asian and European regions for comparison against the Avar population (Hu et al., 2008; Craig et al., 2009; Ogrinc and Budja, 2005; Papathanasiou et al., 2013).

values and for $\delta^{15}N$ were on average 2.2‰ higher than the Velia results. But the stable isotope results from the faunal remains from both sites show the herbivore animals at the Velia site compared to Isola Sacra are generally lower as well. Therefore, the human diets from either site may have been similar, and it is just the isotopic differences in their foodstuffs that exhibit the observed isotopic shift (Craig et al., 2009).
The study of Papathanasiou et al. (2013) investigated a small cemetery population located at Agios Dimitrio Fthiotis, Central Greece that dated back to the Early Iron Age. The results revealed the $\delta^{13}C$ values ranged from -19.5 to -20.2‰, and the $\delta^{15}N$ values ranged from 6.8 to 9.2‰. These results (Figure 5.1) indicate the population likely had a $C_3$ plant diet and did not rely on a marine type diet. The individuals who had the higher $\delta^{15}N$ values were likely the nursing children.

The research of Ogrinc and Budja (2005) was utilized as another comparison data set (Figure 5.1). This data set was helpful as a comparison due to the proximity of Slovenia to Hungary. Ognirc and Budja (2005) researched a site near Namska, located in the southeastern foothills of Krsko, eastern Slovenia, which borders Hungary on its southwestern side. Their research site dates back to the Neolithic period, and the terrestrial faunal remains fall in the range of -22.9‰ to -19.6‰ in the temperate terrestrial $C_3$ ecosystem. These results are consistent with the $C_3$ plants and the $\delta^{15}N$ fall in the range of modern legumes and non-legumes. However, the children who were two years and younger exhibited the highest $\delta^{15}N$ values, which is a reflection of the elevated trophic level of nursing infants and the consumption of maternal milk (Richards et al., 2002; Fuller et al., 2003).

Figure 5.2 displays other regions of interest to compare the $C_3$ and $C_4$ plant dietary differences between the Avar population and other European regions. The Hungarian Plains results are Giblin’s (2011) dissertation research results. The Turkish Roman results are from the research of Losch et al. (2014), where they examined the dietary patterns of gladiators versus contemporary Romans from Ephesus, Turkey during 2nd and 3rd century AD. There is a slight overlap in $\delta^{13}C$ values, but the Avar population still exhibits a diet closer to $C_4$ plants and higher $\delta^{15}N$ values. The research of Losch et al. (2014) was utilized because historic and archaeological
research claims Turkish groups inhabited the Carpathian Basin before the advent of the Avar population. The Roman Period also predates the Avar invasion into the Carpathian Basin.

Another worthwhile comparison data set was the research of Cheung et al. (2012), in which they investigated the dietary patterns of urban and rural sites from Gloucestershire, England during the Roman period (1st to 5th century AD). Their goal was to reconstruct diet by examining bone collagen from three Roman-British sites (urban: Gloucester (32 samples), and rural Horcott Quarry and Cotswold community (46 samples combined, n=78). Both populations showed that they mainly subsisted on a terrestrial-based diet, but there were differences between the urban and rural sites displaying evidence for regional variation within Britain. Their data suggest there were “regional differences and local traditions where access to food was determined by a number of factors including status, access to urban markets and the availability of imports” between the Great Britain regions (Cheung and Schroeder, 2012: 71). During pre-Roman Iron Age, in northern Britain, animal husbandry was more dominant in the economy. Cattle and sheep were the major livestock because they provided dairy products, heavy labor, and wool. Pigs and wild game birds were consumed but in smaller quantities. During this period millet is seen for the first time in Britain, as well as fruit such as cherries and grapes, and important changes in livestock management. Cattle and sheep were still consumed but there was a noteworthy increase in beef consumption (King, 1999; van der Veen et al., 2008; Cheung et al., 2012)

In previous studies of stable isotopes from the transition of the late Iron Age to the Romano-British period, a upward trend in the use of marine foodstuffs had also been discovered (Richards et al., 1998; Redfern et al., 2010). As shown in Figure 5.2, there are few individuals that exhibit higher δ15N values than the Avar population, which may indicate more meat or
possible freshwater fish consumption. However, the δ^{13}C values for the Roman-British populations fall under the C3 plant ecosystem. Cheung et al. (2012) stated that the elevated δ^{15}N values were correlated with the higher status burials, demonstrating these individuals had likely more contact to animal proteins. However, another study at Berinsfield in the UK, showed a pattern that was quite the opposite. This study showed that the poorer burials had the higher δ^{15}N values (Privat et al., 2002). The research of Papathanasiou et al. (2013), dated back to the Early Iron Age, was located in central Greece. The δ^{15}N were lower than expected considering seafood and fish products were easy accessible, but the δ^{13}C values are much closer to a C_3 plant ecosystem. On a cautionary note, stable isotope analyses, cannot tell us the specifics on the quality of food resources that was consumed or if high status foods were consumed from time to time, but the stable isotope values can be a useful gauge of social segregation if the historic and cultural context is known (Craig et al., 2009).

There have been mixed statements relating to the Avar’s reliance on freshwater fish from the Danube, Tiza River or smaller tributaries. Some zooarchaeology literature expresses the importance of fish and seafood diets in the Avar diet, but some sources have stated otherwise (Molnar 2001; Bartosiewicz, 2003, 2005). Bartosiewicz (2005) suggested during the Early Neolithic Period in the Carpathian Basin, the Körös culture (in Hungary) had a heavy emphasis on herding sheep and goats, and in comparison to the Late Neolithic and Early Copper Period in which there was an increase in cattle and swine herding as the social organization became more complex over time.

The δ^{15}N stable isotope values for the Avar ranged from 9.6-11.4‰ with a mean of 10.7‰ ± .5, which is not a high enough value to indicate saltwater or freshwater fish was a staple food item within their diet. However, the δ^{15}N values do fall within the ranges that indicate the
use of secondary products of domesticated livestock. In the research of Hoekman-Sites and Giblin (2012), their results for $\delta^{13}$N values ranged from 9-12‰, a value indicating the use of secondary products of domesticated livestock. Hoekman-Sites and Giblin (2012) suggested secondary products of dairy and/or manure for plant crops. They also noted that the domesticated animals, cattle, sheep, and sheep/goat remains exhibited higher $\delta^{15}$N values compared to

Figure 5.2. Bivariate plot graph displaying stable isotope $\delta^{15}$N and $\delta^{13}$C values associated with bone collagen of previous studies throughout Europe as comparison data versus the Avar population (Losch et al., 2014; Cheung et al., 2012; Giblin, 2011; Paphanasiou et al., 2013)
previous studies from the Early and Middle Neolithic Periods, which helps support the idea that δ^{15}N-enriched crops were likely being used for animal food and for human consumption with the Avar population as well (Hoekman-Sites and Giblin, 2012; Bartosiewicz 2003).

The time period Hoekman-Sites and Giblin researched was from the late Neolithic to the early Copper Age (4000-4500 BC), and these areas of research were within the same geographic regions the Avar occupied during the Migration Period. There is a large discrepancy in time periods between the Copper Age and the Migration Period (568-895 AD), but the research is limited for stable isotope analysis for the Carpathian Basin during the intermediate time periods before the arrival of the Avar into Hungarian region. Other central European populations occupying the region utilized wheat and barley, both C\textsubscript{3} plants, as staple crops (Hoekman-Sites and Giblin, 2012; Motuzaite-Matuzeiciute et al., 2013; Papathanasiou et al., 2013). The central European populations occupying the region had a very different diet, and the stable isotope data helps support the hypothesis the Avar were non-locals to the area and their diet contained primarily a C\textsubscript{4} plant diet.

Possible future research surrounding the Avar stable isotope analysis could include the investigation of the introduction of millet into Central Europe. Antanaitis and Ogrinc (2000) researched sites in southern Lithuania and northern Italy and they had revealed significant C\textsubscript{4} values in the collagen from human skeletal remains from the Late Bronze Age (1300 BC). Evidence of millet cereal grains were found in pottery and ^{14}C dated to 1400 BC in Hungary, and again in Germany sites to approximately AD 500 (Motzuaita-Matuzeviciute et al., 2013). Motzuaita-Matuzeviciute and colleagues (2013) state the early crops in Europe had their origins in south-west Asia; broomcorn millet was identified as one of the early staple crops brought to Europe and first domesticated in China. Through the use of ^{14}C accelerator mass spectrometry
(AMS) radiocarbon dating, the millet grains tested were found to be significantly younger in the Carpathian region and southern Ukraine than previously expected. The presence of the millet cereal grains peaked around (AD 774-991) in Bulgaria, and in Bosnia-Herzegovina (AD 4-576) (Motzuaite-Matuzeviciute, 2013). This suggests the possibility that the Avar may have been one of the influential populations who brought millet into the Carpathian Basin region.

The Hoekman-Sites and Giblin (2012) collagen isotope research evaluated $\delta^{13}C$ values in the Carpathian basin for the Late Neolithic Period and the Copper Age. They determined that the $\delta^{13}C$ values were approximately -21‰ to -19‰ for humans, and that they still relied on a C₃ plant based and animal protein diet. They had suspected that there would be higher values of $\delta^{13}C$ and a transition towards a more C₄ plant based diet towards the Copper Age with the introduction of millet and consumption of freshwater fish in the area. The $\delta^{15}N$ values for humans did not increase overall from the Late Neolithic to the Copper Age, however they were higher than the Early Neolithic Period of their previous study. Comparisons to other central European Late Roman to Early Medieval cemeteries indicate the dietary composition of the Avar was different during this parallel time period (Hungarian Migration Period). Figure 5.1 displays the stable $\delta^{13}C$ and $\delta^{15}N$ isotopes from several studies through the Carpathian Basin region and adjacent European countries that date from as far back to the Neolithic Period up to the Iron Age/Migration Period. These $\delta^{13}C$ and $\delta^{15}N$ isotope values are plotted against the Avar as a comparison to show the distinction between a between the C₃ and C₄ plant diet (Hu et al., 2008; Craig et al., 2009; Orginc and Budja, 2005; Papathanasiou et al., 2013).

Figure 5.3 and Figure 5.4 display $\delta^{13}C$ and $\delta^{15}N$ isotope values for faunal remains (colored rectangles) from the Hungarian Plains, collected by Giblin (2011) for her dissertation research. Only the ranges for $\delta^{13}C$ and $\delta^{15}N$ isotope values in animal bone collagen are displayed
to aid in the construction of past dietary patterns for the Carpathian Basin region. Individuals from her research study are also displayed within the plot graph (Figure 5.3) as a comparison to the Avar population. The dietary pattern of the Avar was different from the earlier population that occupied the Hungarian Plains, where the Avar have a distinctive C₄ plant diet and the occupants of the region had exhibited a C₃ plant diet. A number of the individuals from Giblin’s research also exhibited higher δ¹⁵N values than the Avar population, which may indicate more freshwater fish than the Avar population. The results of Losch et al. (2014) were also used as a comparison against the Avar population because their area of study was from Ephesus, Turkey, during the Roman Period (2nd and 3rd century AD) prior to the invasion of the Avar. There were historic accounts of Turkish groups occupying the Carpathian Basin before the advent of the Avar population (Vida, 2003).

The first hypothesis of this research proposed that the stable isotopes would exhibit more variability (wider discrepancy) between social groups; the elites would exhibit higher levels and the commoners would exhibit lower levels of δ¹³C and δ¹⁵N isotope ratios in their overall diet. However, there was not a statistically significant difference among the assigned social classes. The first hypothesis was formulated based on the stark contrast of types and amount of grave goods interred with the burials. Archaeological documentation and historic accounts led to the idea that there were distinct social hierarchies that existed among the Avar, but the stable isotope results suggest the nutritional resources were available to the different social classes. This sample of the Avar population exhibited stable isotope values that would be more indicative of an unrestricted society for food resources rather than one of distinct social stratification. Males had slightly higher values of carbon and nitrogen isotopes compared to the
females in this sample population, however, there are a few possible explanations for this outcome.

One possibility to explain this difference between men and women is that due to the seasonality of crops and their availability during the formative childhood years, there would be a resulting higher value for the older individuals. Another suggestion is that the time of the year the individual was born may have offered that individual the opportunity to ingest more staple

![Figure 5.3. Displays the of $\delta^{13}$C and $\delta^{15}$N isotope ratios for the Avar compared to known values within the Hungarian Plains, Turkey and Greece to demonstrate the differences in C$_3$ and C$_4$ diet and protein intake (adapted from Giblin, 2011). The different ethnic and geographic regions’ diets tend to cluster together, highlighting regional differences of the populations’ dietary patterns (Giblin, 2011; Papathanasiou et al., 2013; Losch et al., 2014).](image-url)
crops during their formative years (as per conversation, Tykot, 2013). Additionally, it is possible that males had a higher status value because of gender roles among the community. Men of nobility were the conquerors and warriors, and likely offered better nutrition starting in their formative years and throughout their adulthood. Women were responsible as gatherers and agriculturalists, and domestic roles. There were lesser status roles within the community, and

Figure 5.4. Bivariate plot graph displaying stable isotope $\delta^{15}$N and $\delta^{13}$C values associated with bone collagen of faunal remains found at Hungarian archaeological sites collected by Giblin (2011) as comparison data versus the Avar population. The $\delta^{15}$N value for the Avar does not exceed over 12‰, so they likely did not have freshwater fish or riverine/lacustrine diet.
consequently required less nutritional resources (Pearson, 1999; Goodman, 1993; Knipper et al., 2013; Knudson, 2008; Larsen, 2006).

The stable isotope results demonstrated more variability between males and females than among the social status groups. Results obtained quantitatively demonstrated the degree to which diet can be linked to gender differences within the society. In future research, if the sample size was increased, there is a possibility the differences between sexes and social classes would be more evident. However, the results did not provide statistically significant differences among the socially stratified groups, and only exhibited a slightly higher value in terms of the stable isotope results between males and females. There is also a possibility that there was an error in the evaluation of social status; some of the burials could have been looted without the displacement of the skeletal remains. Therefore, the individual may have been of a higher status and incorrectly classified as a lower status.

Strontium (Sr) and Lead (Pb) Isotope Results and Discussion

The second hypothesis tested was whether the strontium and lead isotope ratios would help identify if this sample population of Avar was local or non-local. These results demonstrated that the Avar populations excavated from Sajópetri were non-locals to the region. Numerous individuals exhibited Sr isotope levels in their enamel and bone that were closely related, indicating their migration to Hungary was within the last decade of their life. A few individuals exhibited rather large differences within the Sr values between their enamel and bone, indicating they were also foreigners to the Avar group but most likely integrated or travelled with the Avar to the Hungarian region. The strontium isotope results for the individuals from the Sajópetri cemetery have been compared to strontium isotope data of human enamel,
collected by Giblin (2009, 2013) and Turner et al. (2012). Giblin (2009) conducted strontium isotope research with both faunal and human skeletal remains from the Carpathian Basin from the Late Neolithic to the Copper Age era. These Sr values were used as reference samples for the current Avar study.

The samples analyzed by Giblin (2009) were collected at various archeological sites throughout the Hungarian Plains and the samples collected by Turner et al. (2012) were from a site in Mongolia. The data from Mongolia was selected because of the geographic vicinity. It was once thought that the Avar originated from Mongolia. However, historic and archaeological records suggest that the Avar are more likely to have originated from somewhere in Central Asia (Vida, 2003). Figure 5.2 displays a plot graph with the values from within the Carpathian Basin based on the research of Giblin (2009) and Giblin et al. (2013), and Turner et al. (2012). Turner and co-authors samples were from Mongolia during the Ming Dynasty; their data are plotted as a comparison against the Avar Sr isotope ratios. The Avar ⁸⁷/⁸⁶Sr isotope ratios are slightly higher than the known ⁸⁷/⁸⁶Sr values within the Carpathian Basin.

The individuals from the Sajópetri cemetery exhibit a distinctive pattern and are contained within a specific range for their strontium values, although they overlap with the individuals from Mongolia and one individual from the Samartian Period.

Voerkelius and co-authors (2010) claim Hungary is made up of primarily Cenozoic sediments, and the range for ⁸⁷Sr/⁸⁶Sr results for natural mineral waters is (0.70901–0.71100). Giblin et al. (2013), also found that the local geochemical local signature for ⁸⁷/⁸⁶Sr ratios range from 0.70963 to 0.71057, and a mean of 0.70997 for both faunal and human remains. The ⁸⁷/⁸⁶Sr mean value for the sampled Avar population was 0.710336 ± 0.00027. The ⁸⁷/⁸⁶Sr values from the enamel of several animal species (cattle, pig, wild boar, sheep/goat, dog, clam and snail shell
(n=60) from archaeological sites within the Great Hungarian Plain were used to evaluate the local biologically available strontium in this region (Giblin, 2004, 2007, 2009, 2011).

According to Giblin (2013), the $^{87/86}$Sr ratios ranged from 0.70909 for cattle to 0.71026 for pig with a mean value of 0.70967 for the faunal remains. The archaeological sites sampled were approximately 205 km south of Sajópetri, and are of similar geographic lowlands to Sajópetri. Radiogenic strontium measurements taken from the Danube River and Tisza Rivers range from 0.70890 to 0.70963 (Palmer and Edmond, 1989; Price et al., 2004). The surrounding Carpathian mountain ranges have varying $^{87/86}$Sr ratios due to the formation of the volcanic rock at different geological time periods. Placing the sampled values in context with both time and geographic location is important. Values throughout this region of the Carpathian Basin are much lower than the results obtained from this study. The area surrounding the Carpathian Basin are composed of a series of parallel mountain ranges that had formed at different geologic time periods: the innermost mountain ranges in the Carpathians have a lower strontium isotope composition, the $^{87/86}$Sr value for the Apuseni Mountains average from bulk rock samples is low (0.7051), the Tokaj Mountains of the northern Carpathians; and the average $^{87/86}$Sr rock value was (0.7074) (Salters et al., 1988; Seghedi et al., 2004; Giblin, 2013).

In a previous study of Giblin (2009), strontium isotope values from human burials from Neolithic and Copper Age sites located in the Köröös region of Hungary, samples also exhibited higher strontium values (mean: 0.70968; n=38) consistent with animal and water values from the Plain; however, the Copper Age human samples exhibited more variability than the Neolithic samples (Giblin, 2009).

Previously reported groups in the Carpathian Basin were of Germanic, Iranian, Turkish, and Mongolian ancestry. The research of Schweissing and Grupe (2003) conducted $^{87/86}$Sr
isotope analysis in the Bavarian region (southeast region of Germany) and had documented Rb/Sr isotope ratios where the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is >0.71000 to the north-east region of the Danube River. This value is due to the granites and gneisses (metamorphic rock generally with light and dark banding due to different minerals). Areas within this granitic region contain smaller pockets of metagabbro characterized with lower $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of approximately 0.70600, whereas, the region south of the Danube has carbonate sediments and loess deposits with $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of 0.70800-0.70900 (Schweissing and Grupe, 2003). The Avar data were compared to these Bavarian data (Figure 5.3) to display the distinct differences in $^{87}\text{Sr}/^{86}\text{Sr}$ ratios due to geographic

Figure 5.5. The plot graph exhibits the variability of $^{87}/^{86}\text{Sr}$ ratios from the Avar Sajopétri cemetery decedents to other cemetery sites from earlier time periods within the Carpathian Basin and individuals from Mongolia (Ming Dynasty). Comparison data were from the research of Giblin (2009) and Giblin et al. (2013), and Turner et al. (2012).
regions. Additionally, Figure 5.4 displays a geological sketch map with the mean $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of the Carpathian-Pannonian region along with the faunal samples values from Giblin’s (2011) research and mean ratio value of the Avar population from Sajópetri (Dolton, 2006; Giblin, 2013; Harangi and Lenkey, 2007).

The histogram (Figure 4.6) was utilized to identify if any of the individuals had distinct values between their enamel verses bone $^{87}/^{86}\text{Sr}$ isotope ratios, and if there were any outliers from the sample population (Valentine et al., 2008). There were three individuals who had a significant difference in their Sr isotope ratios between their enamel and bone; SJ148, SJ304, and SJ 331 (refer to Figure 4.6). Burial SJ148 was an adult female with a moderate amount of grave goods (i.e. pottery pieces and animal bones) placing her among the middle status group. Burial

Figure 5.6. The $^{87}/^{86}\text{Sr}$ isotope ratios of the Avar compared to historic samples from Bavaria, Germany (Schweissing and Grupe, 2003).
SJ304 was an adult male with a moderate amount of grave goods (i.e. iron piece by right hip area, blade/knife, and an earring) placing him among the middle status group. Burial SJ 331 was a high status adult female with numerous grave goods of jewelry and animal bones, but her skeletal remains were missing from the thorax region, an indication of burial looting. Her 87Sr/86Sr ratio displayed the greatest difference between enamel and bone values. The enamel 87Sr/86Sr ratios for SJ304 and SJ331 were very close (0.710779 and 0.710737 respectively). Yet, these 87Sr/86Sr ratios for the enamel are also higher than the remainder of the sample population. The 87Sr/86Sr isotope ratio for enamel of SJ148 was very low compared to SJ304 and SJ331,
while her $^{87}\text{Sr}/^{86}\text{Sr}$ bone ratio was higher than SJ304 and SJ331. Attention is paid to these three individuals because they may represent individuals who joined the Avar in their early childhood, and then integrated with the Avar in their adulthood and subsequently migrated with them into the Carpathian Basin.

The Pb results were presented in Figures 4.10 - 4.12 in the previous chapter, and below are bivariate plot graphs (Figures 5.5 and 5.6) that display these values. The Avar’ enamel samples show elevated Pb isotope ratios, in particular $^{206}\text{Pb}/^{204}\text{Pb}$ when compared to European teeth (Fig. 5.5). Compilation of historical European teeth data show $^{206}\text{Pb}/^{204}\text{Pb}=18.44 \pm 0.1$ (Kamenov and Gulson, 2004). This phenomenon of relatively narrow range in Pb isotopes is referred as “cultural focusing” for the population and is due to higher Pb exposure as a result of anthropogenic activities (Montgomery et al. 2010; Kamenov and Gulson, 2014). Wide-spread usage of lead in pipes, cooking utensils and even direct consumption of Pb acetate during the Roman Empire period caused high human Pb exposure resulting in the cultural focusing of the European teeth at the time (Montgomery et al., 2010). Kamenov and Gulson (2014) hypothesized that historical European skeletal remains can be distinguished from human remains from other parts of the world due to the cultural focusing. In this particular case, the Avar population invaded the Carpathian Basin towards the end of the Roman Empire. The research area in Hungary was part of the Roman Empire and most likely the local population was also exposed to high levels of Roman Pb. As can be seen on Figures 5.5 and 5.6, the Avar show distinct Pb isotopic compositions when compared to European individuals. This provides direct evidence that the individuals buried at the cemetery were not exposed to Roman Pb during their childhood years (Pb in the enamel will reflect only early childhood). This indicates that the buried Avar were not born and raised in the Carpathian Basin. Therefore, the Pb isotope data further support
the earlier conclusion based on δ^{13}C isotopes, and to some extent Sr isotopes, that the Avar individuals were foreigners to the region.

Figure 5.8. A bivariate plot graph of the heavy isotope results (^{207/204}Pb versus ^{206/204}Pb) of the Avar groups compared to similar European regions at the end of the Roman Period (Budd et al., 2004; Montgomery et al., 2004).
Figure 5.9. A bivariate plot graph of the heavy isotope results ($^{208/204}\text{Pb}$ versus $^{206/204}\text{Pb}$) of the Avar groups compared to a few European regions at the end of the Roman Period.
Chapter Six

Conclusion

The Avar population of prehistoric Hungary had a reputation for being ruthless barbarians. It is commonly thought that this ruthlessness was essential in their rise to rule of the Carpathian Basin in the 6th and 7th centuries AD. While this view of their iron-fisted governing is commonly accepted, data from Sajópetri opens the door for a more nuanced view of their reign. The invasion and migration of the Avar populations into the Carpathian Basin likely aided in the downfall of the Roman Empire’s rule of the area. The Roman Empire had grown so large that they had difficulty patrolling their borders, as well as supplying and feeding their soldiers. The military theory proposed by Kennedy (1989) posits that large empires eventually collapse due to the cost of defending their borders (Eades, 2005).

The arrival of the Avar occurred at a point in time in Central Europe when the Roman Empire was straining under its own weight. According to Radovčić (2011), the Avar were instrumental in the collaboration of different ethnic groups banding together to gain independence from the Roman Empire. While it is thought that simple coercion from the Avar was what compelled the other groups to fight, evaluation of grave goods and dietary intake suggests that there may have been an element of cooperation. The archaeological records and grave goods of the Avar burials has led to an idea of distinct social classes that included nobility (i.e. equestrian burials, military decorated burials) and lower classes, whose grave goods were of moderate value or non-existent. The stable isotope results suggest that the Avar had more equal
access to nutritional resources than was previously noted. This unrestricted approach to resource distribution may have been a key component in getting the different groups to work cohesively.

Under the political economy perspective, Eades (2005) explained that different societies living among each other are seen as a network of partners “based on flows of information, prestige goods, power, basic foodstuffs and raw materials,” and can maintain that connection to one another (Eades, 2005: 33). When researching the Avar population, having the understanding of their history and involvement with the other ethnic groups is crucial; they could not be studied in isolation (Eades, 2005). In the linking of political processes and historical changes, the health and nutrition of a population can be better understood. To better recognize the relationship between social stratification and the differential access to resources and health, these questions cross over numerous disciplinary boundaries and a multidimensional approach is needed (Martin, 1998). Socioeconomic and cultural factors, kinship patterns or alliances that are built over time have a huge impact on the growth and development of the individual. This in turn has an impact on the health, success, and fitness of the community (Miekle et al., 2004; Larsen, 2006).

Anthropologists and archaeologists recognize that patterns in the mortuary practices of the deceased can offer insight with important information about the social relations of the living. Archaeologists have used this approach to make inferences about social organization and the social significance of burial practices (Pearson, 1999; Gamble et al., 2001). They have explored the interpretive value of grave goods in association with bioarchaeological data on genetic relationships, health condition, and occupational patterns to help further their knowledge about a culture. Isotopic analysis complements the traditional archaeological analysis of grave goods and mortuary practices and gives further insight into past cultures. In this instance, they further delineate the subsistence and migration patterns of the Avar population as well as how they were
affected by social stratification. The stable isotope results were unexpected considering the archaeological research and historic documentation. As mentioned, prior interpretation of the material evidence and mortuary behavior inferred the Avar had a type of hierarchy. While the dataset is preliminary, there is the real potential to reevaluate previously held beliefs about this population.

Diet and social status are interlinked; the presence, quantity, and quality of the food resources available in one’s diet can be related to the age, sex or social status of an individual (Goodman, 1993; Knipper et al., 2013; Knudson, 2008; Larsen, 2006; Cheung et al., 2012).

Different groups of people—be they defined by wealth, occupation, social status, age or gender tend to consume different kinds of foodstuffs either by choice or by necessity. Differences in diet within a population as revealed by stable isotope analysis can thus potentially provide useful insights into the social structure of past communities (Cheung et al., 2012:64).

While this may hold true, the stable isotope results for the Avar population from Sajópetri suggest that resources were divided in a more unrestricted manner than would be expected from grave goods alone. Millet was likely an important staple crop for the Avar population and other regions scattered throughout Europe, but the amount of specific foods in the individual diets is difficult to differentiate. While stable isotope values for faunal remains were available from previous times periods in the region of study, faunal remains were not available during the analysis of this study. In addition, it is important to note, that stable isotope analyses cannot tell us the specifics on the quality of food resources that was consumed or how often high status foods were consumed, but the stable isotope values can be a useful indicator of social differentiation if the historic and cultural context is known (Craig et al., 2009). The use a political economy perspective had also helped laid a foundation to better understand why groups
within a population may have differences concerning isotope values. It is important to have an understanding of historic, cultural, and political context to further help with interpretation of dietary or migration patterns.

The isotopes were not only useful in assessing social structure, but also the migration of the Avar into the Carpathian Basin. The Sr and Pb isotope results indicate the Avar were non-locals and were not from the Carpathian Basin region. There is a scarcity of heavy isotope research for comparison from Central Asia, and putting some of the results in a historical context with faunal or human remains was a challenge. This is an area that needs more multidisciplinary research with the collaborative efforts of archaeology, anthropology, and geological sciences. The research included scientific methods and technology that have not been available to the Borsod-Abaúj-Zemplén (BAZ) region. Prior studies involving bioarchaeology have investigated demographic structure, health disparities, or trauma with conventional tools. More recently the field of bioarchaeology has had the opportunity to conduct this research with advanced technology and other applied sciences and disciplines.

Isotope analysis is a novel technology for BAZ region and this research has not been conducted for the cemetery population of Sajópetri, Hungary. This research contributes to the isotope mapping of the environment and dietary variables that can shed light on past human behavior. With the advent of new construction and urbanization in the BAZ region, it is critical to educate and inform the community of the importance in preservation of their cultural heritage and material culture. By raising awareness by ongoing research it is hoped that efforts of preservation will be redoubled.

The results of the analysis and artifacts recovered will be available for further research for the Hungarian community and public outreach. Findings from this current study could assist
in the establishment of biogeochemical data in Hungary and Central Europe. This growing
database could be the point from which further anthropological research in either bioarchaeology
or forensic anthropology can be based. The use of stable and heavy isotope analysis is a fairly
new method in forensic anthropology to aid in georeferencing origins for unidentified decedents.

Although this current research has revealed the variance of isotope values in the studies
of diet, migration and social stratification for prehistoric Europe, additional research is necessary
to develop a better understanding of the entire cemetery population. This research builds upon
earlier works that aimed to understand processes underlying human behavior, and in particular
how skeletal remains provide evidence of events during the life of the individual and population.
The biogeochemical analysis builds upon earlier work that showcases how skeletal biology can
provide a valid record of past dietary and ancestral history.
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Appendix A

Appendix A displays a few of the burial diagrams with burial depths, grave goods interred with the burial, and the human and animal remains orientation. Drs. Ivett Kovari and Mikolos Makoldi from the Hermann Otto Museum supplied the translations of the grave goods. The north arrow is generally located above the skull in the following burial diagrams and the letter (E) corresponds to the direction north.
Figure A.1. Burial 379: Male High Status Burial
Burial 379 was assigned as a high status burial because it was an equestrian burial and the number of grave good interred with the burial. The items interred were the following: bronze belt end, bronze decorative squares for belt, swivel belt clip, particulate material, iron pieces, blade/knife, and grommet piece for belt. The male individual was buried at burial depth of -150 cm, and the accompanying horse was at a burial depth of -140 cm. The horse had accessories that included a mouth bit, stirrups, and iron buckle.
Figure A.2. Burial 331: Female High Status Burial
Burial 331 was assigned a high status burial because of the amount of grave goods interred with the burial. Most of the thorax missing was missing most likely due to burial looting. Grave goods present include rosettas-dress decoration, earring, beads, button reel, brass buttons, and animal bones.
Burial 315 was assigned a middle class status burial because of the moderate amount of grave goods interred with the burial. Grave goods present include a button reel, bronze fragment, and pottery.
Figure A.4. Burial 304: Male Middle Class Status
Burial 304 was assigned a middle class status due to the moderate amount of grave goods that include iron piece by right hip area, blade/knife, and an earring.
Figure A.5. Burial 291: Male High Class Status
Burial 291 was assigned a high class statue due to the post holes, and the moderate amount of grave good interred in the burial that included: beads, four decorative bronze pieces, bracelet metal link, and animal bones. The burial appeared to have been disturbed and possible evidence of grave robbing.
Figure A.6. Burial 91: Male Low Class Status
Burial 91 was assigned a low class status because only one iron buckle was present.
Burial 86 was assigned a high status burial because the post holes are indicative of the high-status burial along with the grave goods, but there has burial disturbance around the thorax and pelvis region (i.e. missing bones and bones out of place) and probable grave robbery.
Figure A.8. Burial 70: Female Middle Status Burial
Burial 70 was assigned as a middle status burial due to the moderate amount of grave goods that included: an earring, belt buckle, bronze tweezers, and animal bones.
Figure A.9. Burials 364 and 365:
Burial 365 is considered a high status burial with pottery interred with the burial, and a horse burial was at the foot (south) of Burial 365. Unfortunately, Burial 364 was disturbed and the skeletal thorax region was scattered and disarticulated, which is evidence of probable grave robbery.
Figure A.10. This figure has close-up photographs of the artifacts interred with Burial 531, which included bronze and iron belt ornaments, two knife blades, one iron arrowhead, fragments of iron, iron buckle, brass plate remains (1); bronze belt ends (2); bronze decorative rings from belt (3); arrowhead (4); posterior and anterior view of propeller-shaped hanger (pendant) (5); protective pierced hole mount, anterior and posterior views (6).