A biocultural perspective on the transition to agriculture in Ukraine

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A BIOCULTURAL PERSPECTIVE ON THE TRANSITION TO AGRICULTURE IN UKRAINE

by

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Department of Anthropology

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Abstract

The development of agriculture and its spread around the globe is one of the most consequential events in the history of our species. The transition to agriculture is associated with many cultural developments, such as craft specialization, urbanization, and the creation of social hierarchies. Many social theorists believe that these changes associated with the adoption of farming were beneficial to the human condition, however, not all agree. The goal of this research is to evaluate the impact of the adoption of agriculture on human health. To do this, bioarchaeological analysis is employed, comparing the skeletal and dental health of Mesolithic and Neolithic foragers from Ukraine with later Eneolithic farmers from the region. Specifically, the two groups are compared in terms of enamel hypoplasias, stature, and dental caries. The farming population was also examined for porotic hyperostosis, cribra orbitalia, periostitis, and periodontal disease. Statistical tests demonstrate that the early agriculturalists experienced a significantly higher rate of enamel hypoplasias and dental caries, as well as had significantly shorter long bone lengths. This indicates that the transition to agriculture in Ukraine was detrimental to human health, resulting in significantly more physiological stress and dental disease. The early farmers were also found to have moderate to high rates of porotic hyperostosis, cribra orbitalia, and periodontal disease, which is further evidence of their compromised health. The adoption of farming in prehistoric Ukraine likely resulted in poor health through heavy reliance on nutritionally-poor cereals, settlement in permanent population-dense villages, and close contact with domesticated animals.
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Chapter 1: Introduction

For the majority of the history of our species, all humans lived in small mobile bands that subsisted by foraging, fishing, and hunting (Klein, 2009). Then, around 10,000 years ago in the Near East, some populations began to cultivate plants and practice animal husbandry (Simmons, 2011). These behaviors eventually led to the creation of new plant and animal species through the process of domestication (Diamond, 1997; Flannery, 1969; Vigne et al., 2011; Willcox, 2005; Zeder, 2011). Eventually, human groups across the Near East became dependent upon the domesticated species and agricultural production, fundamentally transforming the way people interacted with their environment. Since then, agriculture has spread from the Near East and other centers of agricultural origins (China, Mexico, South America, North America) to become the world’s dominant subsistence system.

The adoption of agriculture is not only associated with changes in subsistence practices and economics, but also with alterations in diet, sedentism, demographic parameters, and social organization. As such, the transition to agriculture was one of the most consequential events in the history of our species and set us on the trajectory that has resulted in modern civilization. The most obvious consequence of the adoption of agriculture is its effect on diet and subsistence. Typically, hunter-gatherers are characterized by a diverse diet that is usually high in protein (Cohen, 1989; Cordian et al., 2000; Larsen, 1995). Cordian et al. (2000) were able to quantify the average amount of protein consumed by hunter-gatherers using ethnographic data from 229 societies. They found 73% of these cultures to have diets where animal protein comprised greater than
50% of the foods consumed (Cordian et al., 2000). This was likely also true for archaeological foragers. For example, most hunter-gatherers that occupied Europe during the Mesolithic relied upon marine and freshwater animal species, including fish, mammals, crustaceans, and mollusks (Milisauskas, 2011). These animals comprised the bulk of their diet (Richards and Hedges, 1999). Similarly, the archaic period Chinchorro hunter-gatherers of Peru and Chile’s Atacama Desert employed a subsistence system focused on marine resources, with fishing, sea mammal hunting, and mollusk collecting making up the majority of their diet (Aufderheide et al., 1993). To supplement their protein-rich diets, hunter-gatherers typically collected and utilized a wide array of wild plants, resulting in a highly diverse diet (Armelagos et al., 1991). By contrast, agriculturalists tend to focus on a few carbohydrate-rich staple crops, such as wheat, barley, rice, millet, maize, or potatoes (Larsen, 1995). Additionally, although early farmers from many regions kept domesticated animals, they consumed meat less frequently than the foragers that preceded them, as the animals were kept alive and used for their secondary products, such as wool, traction, and dairy (Chapman, 1982). Therefore, as compared to hunter-gatherers, early farmers had a much more narrowly focused diet, typically based on just a few carbohydrate-rich crops.

The adoption of agriculture is also associated with a more sedentary lifestyle. While foragers typically live in highly mobile bands, farmers tend to establish permanent settlements near their cultivated fields (Kelly, 1992). Although sedentism can be difficult to define archaeologically, agricultural societies are often associated with markers believed to reflect long-term permanent settlement (Kelly, 1992). As compared to mobile hunter-gatherers, sedentary early farmers tend to invest more energy into building
substantial permanent dwellings. Likewise, permanent settlements are also typically
marked by the construction of storage pits and silos (Kelly, 1992; Milisauskas, 2011; Simmons, 2011). This stands in contrast to mobile populations who, by necessity, do not store large quantities of goods over long durations. Food storage also resulted in permanent settlements being characterized by the presence of commensal species such as the house mouse, rat, and sparrow (Bar Yosef and Meadow, 1995). These species are attracted to stored food and trash, both of which occur in larger quantities at permanent settlements as compared to short-lived campsites (Bar Yosef and Meadow, 1995).

As compared to foraging, agriculture increases the productivity of land per unit area. This allowed farming groups to support large populations through agriculture’s ability to increase the carrying capacity of the land. One feature of the transition to agriculture is its association with population increases worldwide (Bocquet-Appel and Bar Yosef, 2008). Paleodemographic studies of cemetery samples linked to early agriculturalists have shown that, as compared to their foraging predecessors, farmers experienced a higher birthrate (Bocquet-Appel, 2002). These studies suggest that the average female in an early farming community gave birth to two more children than her foraging counterpart (Bocquet-Appel, 2002). This fits well with ethnographic data documenting higher fertility among farmers (6.6 births per female) as compared to foragers (5.6 births per female) (Gage and DeWitte, 2009). The increase in fertility and the resulting population explosion has been termed the Neolithic Demographic Transition. According to Bocquet-Appel and Naji (2006), the adoption of agriculture made the Neolithic Demographic Transition possible through the development of sedentism. Foraging societies typically maintain a mobile lifestyle where the population
follows a regular pattern of seasonal resource exploitation in different areas of their territory. In these mobile foraging populations, females carry their children continuously up to 3-4 years of age (Bocquet-Appel and Naji, 2006; Lee, 1972; 1979). The constant carrying allows children to suckle frequently, which inhibits their mother’s menstrual cycle (Bocquet-Appel and Naji, 2006; Rivera, 1996; Rosner and Schulman, 1990). This delay in menstruation caused by breast feeding is known as lactational amenorrhea, and is a major regulator of post-partum fertility (McNeilly, 2001). The decreased mobility associated with life in sedentary agricultural villages reduces the duration that females constantly carry their children to between 1-2 years of age (Bocquet-Appel and Naji, 2006). This earlier reduced contact stops frequent suckling sooner and shortens the length of lactational amenorrhea, allowing females to return to normal menstruation. Therefore the Neolithic Demographic Transition is a result of the increased sedentism that accompanied the transition to agriculture (Bocquet-Appel and Naji, 2006).

The population explosion associated with the adoption of agriculture had an impact on the social organization of human populations (Price, 1995). Mobile bands of hunter-gatherers are usually small, comprised of a few families and generally structured based on kin ties (Price, 1995). Furthermore, these bands are believed to have been egalitarian, where all individuals had equal access to resources (Price, 1995). Although differences in social status could have been achieved, they were not ascribed at birth. As populations grew following the transition to agriculture, villages, towns, and early cities saw an increase in the complexity of their social structure. Organizing the population for collective work projects led to a class of leaders and a hierarchically organized population. Furthermore, the generation of surplus food via agricultural production
allowed for new classes of people devoted to economic activities outside of food production. This included the development of professional scribes, soldiers, potters, blacksmiths, and merchants (Costin, 1991). These craft specialists contributed to the increasing social and economic complexity that followed the transition to agriculture.

When considered in combination, the adoption of agriculture and its associated dietary, demographic, social, and economic changes make it one of the most important developments in human history. Since the adoption of agriculture and its associated sedentary lifestyle set humanity on the trajectory that led to modern civilization, it has traditionally been viewed as an improvement over earlier foraging traditions. For example, Thomas Hobbes (1651) depicted the life of early hunter-gatherers as “solitary, poor, nasty, brutish, and short”, and improvements were made only after the transition to agriculture. In a similar vein, Childe (1951a, b) points out that the adoption of agriculture allowed for the development of the finer things in life, including the work of professional artists, writers, and musicians (as discussed in Harper and Armelagos, 2013). According to these thinkers, agriculture allowed humans to tame nature and improve the quality of human life through the development of civilization (Harper and Armelagos, 2013).

One of the most widespread beliefs is that by increasing the productivity of the land, the adoption of agriculture led to better health for human populations by creating an abundant source of food (Harper and Armelagos, 2013). Beginning in the second half of the twentieth century, a number of scholars began to challenge this idea. These researchers were heavily influenced by the theory of evolutionary medicine (Gage, 2005). According to this theory, organisms have evolved to thrive in a certain environment. Therefore, when an organism is placed in a novel environment it experiences less than
optimal health. Since humans evolved to live as foragers in small mobile bands, according to the theory of evolutionary medicine, they are poorly adapted for life as farmers in large sedentary settlements (Gage, 2005).

Using the paradigm of the theory of evolutionary medicine, biological anthropologists have made a series of predictions regarding the impact of the transition to agriculture on human health. These theorists began by using nonhuman primates to predict the types of diseases experienced by our hominin ancestors (Armelagos, 1990; Cockburn, 1971; Polgar, 1964). Since the great apes are our closest living relatives, and most of them live in small mobile bands, they serve as a particularly apt model. Both modern humans and the great apes are affected by lice, pinworms, yaws, and infections following traumatic injury (Armelagos, 1990; Polgar, 1964). Since we likely inherited these diseases from our hominin ancestors, they have been termed heirloom pathogens (Sprent, 1969a, b). Other diseases have been classified as heirloom pathogens using genomics. By sequencing the genomes of human pathogens and comparing them to closely related microbes, geneticists can estimate the time at which each disease began infecting humans using the average rate at which mutations are acquired. Some of these recently discovered heirloom pathogens include: the Epstein Barr virus (causes mononucleosis), GB Virus C, the herpes simplex viruses 1 and 2, human papilloma virus, Bordetella pertussis (causes whooping cough), Helicobacter pylori (causes gastric ulcer), Taenia segmeta (tape worm), and Taenia selium (tape worm) (Harper and Armelagos, 2013). These heirloom diseases likely represent the majority of the infectious pathogens that would have afflicted our hunting and gathering ancestors (Harper and Armelagos, 2013). In terms of diet, the theory of evolutionary medicine predicts that the typical
hunter-gatherer adaptation, focused on protein-rich foods and high variability, is the most nutritiously optimum diet for humans (Armelagos, 1990).

According to the theory of evolutionary medicine, the novel environment created via the adoption of agriculture would have resulted in an exponential increase in the infectious pathogens afflicting human populations (Armelagos, 1990; Cockburn, 1971; Harper and Armelagos, 2013; Polgar, 1964). These new, recently acquired diseases result from the increased contact with domesticated animals, environmental alterations, and increases in both sedentism and population density that accompanied the transition to agriculture. Animal domestication by early farmers put them in close contact with herds of livestock that included cows, pigs, sheep, goats, chickens, turkeys, llama, and alpacas (Diamond, 1997). These animals carried infectious pathogens adapted to each host. Through contact with the living animals and their waste, these pathogens hopped from the domesticated animals to humans. These cross-species infections are called zoonotic diseases. In most cases the pathogen would have been ill-suited to infect humans, and the spread of the zoonotic disease would have been limited. However, in a few cases the zoonotic pathogen may have been a good fit for human hosts, and became established in human populations (Harper and Armelagos, 2013; Wolfe et al., 2007). Many of the zoonotic diseases that became fixtures in human populations had the advantage of being adapted to large host populations, as most farm animals lived in herds both in the wild and following domestication (McNeill, 1976). Genomic research has allowed scientists to determine the source of many modern infectious diseases. Interestingly, domesticated animals appear to have transmitted over 100 diseases which have become established in humans (Harper and Armelagos, 2013; McNeill, 1976; Palmer et al., 1998; Weiss, 2001).
For example, small pox is derived from the bovine disease cow pox, measles arose from the bovine disease rinderpest, and both influenza and brucellosis were acquired from goats, sheep, pigs, and cattle (Diamond, 1997; Harper and Armelagos, 2013). These zoonotic diseases acquired from domesticated animals following the adoption of agriculture have been termed “souvenir pathogens” (Sprent, 1969a; b).

Besides putting us in close contact with domesticated animals, agricultural adaptations can expose human populations to new diseases through farming’s impact on the natural environment. Deforestation and the clearing of land through slash-and-burn agriculture significantly affect the ecosystems surrounding human settlements (Goodman and Martin, 2002). One consequence of land clearing is the creation of favorable breeding grounds for insects such as the mosquito, *Anopheles gambiae*, the vector of *Plasmodium falciparum*, the protozoa that causes malaria (Livingstone, 1958). Genomic evidence supports the notion that only after the development of agriculture did malaria become widespread and adapted to humans (Harper and Armelagos, 2013). Likewise, the development of the protective sickle cell allele appears to have only occurred following the adoption of agriculture in Africa (Harper and Armelagos, 2013).

Additional environmental changes resulted from the impact of the transition to agriculture on sedentism. As human populations established permanent settlements, they would have encountered serious sanitation problems. Long lasting settlements would have seen the accumulation of waste including sewage and food refuse, which served as reservoirs for bacterial pathogens such as *Salmonella, Escherichia coli, and Staphylococcus* (Cockburn, 1971; Walker, 1986). Contamination of the local environment with these bacteria could have led to widespread diarrheal disease, which
would have had an extremely deleterious effect on subadults who are highly susceptible to gastrointestinal infection during the weaning period (Walker, 1986).

As discussed above, the transition to agriculture is associated with a population explosion which has been termed the Neolithic Demographic Transition. According to the theory of evolutionary medicine, the increase in population size and density would have served as a new source of disease, as it represents a significant change over the conditions of humanity’s evolutionary background. Compared to small bands of foragers, densely settled agricultural villages would have allowed for the establishment and maintenance of the so-called “contagious crowd diseases” (Armelagos, 1990). These rapidly spreading infections require populations to meet a certain size threshold for them to be maintained, and this was only met following the Neolithic Demographic Transition (Armelagos, 1990). The contagious crowd diseases include the common cold, influenza, and measles, all of which originally spread to humans from domesticated animals (Harper and Armelagos, 2013).

In addition to introducing new pathogens, the theory of evolutionary medicine predicts that the adoption of agriculture likely led to nutritional problems through a reduction in dietary breadth. While hunter-gatherers typically consumed a highly diverse diet rich in protein, agriculturalists tend to focus on a few carbohydrate-rich staple crops. While these cultigens are calorie-dense, many of these plants, such as maize, wheat, and rice are relatively poor sources of protein, vitamins, and minerals (Larsen, 1997; 1995). According to the theory of evolutionary medicine, the agricultural dietary adaptation would lead to malnutrition and a deterioration in overall health. Furthermore, poor
nutrition predisposes individuals to infection, exacerbating any increase in exposure to infectious agents (Goodman et al., 1984).

To summarize, the theory of evolutionary medicine predicts that the transition to agriculture would have resulted in worse health for early farmers as compared to the foragers that preceded them. Bioarchaeology, the study of ancient human skeletons, is uniquely suited to test this prediction. By comparing foragers and farmers in terms of their skeletal health, bioarchaeology can empirically evaluate the impact of agriculture on the biology of prehistoric human populations.

My goal in this dissertation is to test the hypothesis that the transition to agriculture was detrimental to human health. I will accomplish this by comparing skeletal data from prehistoric agriculturalists and hunter-gatherers that occupied the territory of the modern nation of Ukraine. Specifically, I will be assessing the skeletal health of the agricultural Tripolye population excavated from the site of Verteba Cave. The Tripolye are a particularly interesting farming culture to examine as they were the first fully agropastoral group in the region, built Europe’s largest settlements (termed megasites or protocities), had the most densely settled territory on the continent, and were involved with the domestication of the horse (Korvin-Piotrovskiy, 2012). To test the hypothesis that the adoption of agriculture had a negative impact on human health, I will compare my skeletal data on the Tripolye to published data on earlier hunter-gatherers from Ukraine (Jacobs, 1993; Lillie, 1996). Unfortunately, these hunter-gatherer skeletal samples are unavailable for direct study (Potekhina, personal communication).
This dissertation is organized into six chapters. Following the introduction, Chapter two provides a background on bioarchaeological inquiry, particularly as it relates to the study of the transition to agriculture. The chapter discusses the comparative approach taken by most bioarchaeological studies, as well as the general stress perspective, where skeletal and dental lesions representing nonspecific physiological perturbations are used to assess the overall health of ancient populations. The skeletal markers most commonly used for this purpose include enamel hypoplasias, porotic hyperostosis, cribra orbitalia, periostitis, and stature. A large section of Chapter two is devoted to describing these skeletal markers and their relationship to overall health. Finally, Chapter two reviews previous bioarchaeological studies that have examined the impact of the transition to agriculture on human health. This section is organized by continent and is followed by a short discussion summarizing the current state of knowledge on the topic. As will be shown, the results of past studies do not entirely support the predictions made by the theory of evolutionary medicine, suggesting the impact of the adoption of agriculture is more complex than previously believed. Chapter two also points out a significant weakness in the literature: a complete lack of studies from Eastern Europe. By studying the transition to agriculture in Ukraine, my dissertation has the added benefit of addressing this weakness.

Chapter three provides the archaeological background on the transition to agriculture in Ukraine. It covers the Mesolithic, Neolithic, and Eneolithic periods and discusses what is known about the subsistence, economics, settlements, social organization, and burial practices of the Tripolye and their foraging predecessors. Since significantly more archaeological work has been conducted on Tripolye sites, the chapter
places specific emphasis on reviewing these studies. Chapter three concludes with a
discussion of Verteba Cave, one of the few burial sites attributed to the Tripolye and the
source of the skeletons examined in my study.

Chapter four describes the skeletal samples and methods used to assess the health
of the Tripolye farmers. Excavations at Verteba Cave have occurred periodically since
the late 19th century, and my study includes all skeletal material recovered from these
excavations. The methods used to assess health were chosen primarily on the basis of
accuracy and their ability to produce highly replicable results. Specifically, methods are
described for the evaluation of enamel hypoplasias, cribra orbitalia, porotic hyperostosis,
periostitis, stature, dental caries, antemortem tooth loss, and periodontal disease. This
data is then statistically compared to published data (Jacobs, 1993; Lillie, 1996) on
Mesolithic and Neolithic hunter-gatherers using $\chi^2$-tests, Fisher’s exact tests, and two-
sample t-tests. These statistics are used to test the hypothesis that the transition to
agriculture was detrimental to human health in prehistoric Ukraine.

Chapter five presents the results of my analysis of the Verteba Cave skeletal
material and the statistical comparisons with the hunter-gatherers. The Tripolye were
found to have significantly higher rates of enamel hypoplasias, dental caries, and porotic
hyperostosis/cribra orbitalia, and were significantly shorter than the earlier hunter-
gatherers based on a comparison of long bone lengths. No statistical comparison of
periostitis was possible, however, as the Tripolye had only one affected skeletal element
out of more than 2,000 examined.
Based on the results of the statistical tests, I accept my hypothesis that the transition to agriculture was detrimental to human health. Chapter six describes the specific aspects of the Tripolye agriculture adaptation that likely contributed to the observed decline in health. These include the establishment of large sedentary settlements, a diet highly reliant on nutritionally poor cereals, and the unique construction of Tripolye houses, which put animal stables in close proximity to human living space. Chapter six also discusses how the results of this study fit with those obtained from other regions in Europe and what this means for reconstructing the impact of agriculture on human health.

Overall, this research supports the theory of evolutionary medicine and the notion that the adoption of agriculture was detrimental to human biological well-being. This study presents new evidence with which to evaluate the Tripolye cultural adaptation and furthers the anthropological understanding of one of the most important periods in the history of our species.
Chapter 2: Bioarchaeological Studies of the Transition to Agriculture

Introduction

A substantial body of bioarchaeological literature on the health consequences of the transition to agriculture has been produced in the past thirty years. These studies have contributed a biocultural perspective to our understanding of this important period of prehistory. This chapter functions as a review of this literature. The first section examines the general stress perspective taken by the majority of bioarchaeological studies investigating health in the past. It is followed by a discussion of the skeletal and dental markers of stress commonly employed in bioarchaeological research. Next, research on the health consequences of the transition to agriculture is reviewed by continent. The chapter ends with a discussion summarizing the current state of knowledge on the topic and areas requiring further study.

The General Stress Perspective

The ability to examine human skeletal remains uniquely enables bioarchaeologists to answer questions about the health of past populations. One of the primary ways in which bioarchaeologists assess health is through the identification of stress, or physiological disruption, in the human skeleton. As a result, a large portion of paleopathological research has focused on the specific etiologies of various skeletal lesions (Goodman and Martin, 2002). While it is important to establish the potential causes of skeletal lesions, as Goodman and Martin (2002) point out, excessive focus on determining etiologies may be unproductive, as the skeleton tends to respond to stress in a variety of non-specific manners. Rather, they suggest that research focused on stress in
general holds greater potential for answering anthropological questions. For instance, by focusing on the level of general physiological stress in past populations, researchers can assess the relative success of different cultural adaptations and how health has changed through time.

Goodman et al. (1984) used the general stress perspective to develop a conceptual framework for studying health in past populations. This model has been widely applied in bioarchaeological studies and provides a useful mechanism for examining the adaptive process with a focus on health (Goodman and Martin, 2002). According to Goodman et al. (1984), all adaptations begin with a set of environmental constraints, which include limiting resources, such as food and water, and stressors including environmentally specific challenges, such as local parasitic species and climatic extremes. Human culture attempts to mitigate these environmental constraints as part of the adaptive process. For example, in areas where food is a limiting resource, populations may turn to cultivation to increase the environment’s productivity. Populations may also change their settlement practices in response to environmental stressors. For example, populations in Vietnam built their homes on stilts, keeping them just above the maximum flying height of malaria-carrying mosquitoes (Goodman and Martin, 2002). By adapting in these ways, culture serves as a buffer against stress resulting from environmental constraints. Culture, however, can create its own stressors. For instance, the clearing of land prior to cultivation can create new habitats for disease vectors such as mosquitoes, which may increase their habitat range and population size, and hence, their ability to spread disease to human populations. As Goodman and Martin (2002) point out, compromised adaptations are generally the rule, as better adaptations in one realm often result in
increased stressors from another. For these reasons, the consideration of stress in past populations must take into account environmental constraints, as well as the protective and detrimental impacts of cultural systems.

Another factor to consider in the general stress model is the level of host resistance (Goodman et al., 1984). This refers to the ability of the immune system of each individual to defend against environmental and cultural stressors. The level of host resistance is determined by the individual’s genetic and physiological makeup (Goodman and Martin, 2002). Unfortunately, aspects of individual host resistance are difficult, if not impossible, to quantify for past populations.

The main point of this model is that stress levels in a population can be conceptualized as the interaction of environmental and cultural stressors with the buffering capacity of the cultural system and individual host resistance (Goodman and Martin, 2002). In general, most stressors will trigger a physiological response. However, in the case of extremely severe and acute stressors, the response will not be of sufficient duration to result in a skeletal change, as skeletal remodeling takes significant time. More chronic stressors typically result in telltale changes to bones and teeth. These changes can be examined bioarchaeologically to quantify the general level of stress in a population and assess the success of cultural adaptation from a general health perspective. The next section reviews the common skeletal lesions and indicators of physiological stress examined in bioarchaeological studies of prehistoric health.

**Skeletal Stress Markers**

*Enamel hypoplasias*
Research over the last century has demonstrated that physiological perturbations during the period of tooth development result in the formation of enamel defects (Goodman and Rose, 1990). These defects manifest as areas deficient in enamel, and therefore have been termed enamel hypoplasias. They can appear as linear horizontal furrows, as single pits, as pits arranged linearly, or as large planes of missing enamel (Hillson, 1996). Enamel hypoplasias are especially useful indicators of health to archaeologists, as teeth are highly resistant to postmortem degradation and are one of the most frequently recovered items from archaeological sites.

The formation of tooth enamel begins with the deciduous incisors during the second trimester of fetal development, and progresses with the sequential development of the deciduous canines, premolars, and molars, and permanent incisors, canines, premolars, and molars (Goodman and Rose, 1990). This process lasts until about twelve years of age (Larsen, 1997; Smith, 1991; Tencate, 1991). At the level of the individual tooth, enamel producing cells called ameloblasts begin secreting enamel matrix at the occlusal end of the tooth and progress cervically to the cemento-enamel junction (Goodman and Rose, 1990). Enamel is produced by the ameloblasts in an imbricational manner, resulting in the regular distribution of peaks and troughs. Each peak and trough comprises a perikymata, which reflects one wave of ameloblast activity (Guatelli-Steinberg et al., 2004). Perikymata are formed at regular intervals of between seven to eleven days (Risnes, 1998). During this secretory phase of enamel formation, stress in the form of malnutrition and/or infection can disrupt the activity of ameloblasts and results in thin perikymata spaced at abnormally wide intervals (Hasset, 2012). Collections of abnormally formed perikymata are recognized macroscopically as enamel hypoplasias.
Our understanding of the etiology of enamel hypoplasias has been shaped by epidemiological and clinical studies of modern humans and nonhuman primates, as well as through experiments with animals. Following the development of detailed tooth crown formation schedules by Massler et al. (1941), a number of early clinical studies were able to link periods of disease from patients’ medical histories with enamel hypoplasias on their dentitions (Sarnat and Schour, 1941; 1942; Sheldon et al., 1945). Building on this earlier work, Kreshover (1960) was able to link the development of hypoplastic defects with specific diseases such tuberculosis and fevers. Goodman and coworkers (1987; 1989) linked the occurrence of enamel hypoplasias with poor nutritional status in their study of impoverished villages in highland Mexico. In their study, a subset of a cohort of village youths were given nutritional supplements beginning at birth, while the rest of the cohort was not supplemented. Observation and documentation of enamel hypoplasia prevalence for the supplemented and non-supplemented groups took place following the development and eruption of the permanent dentition. Goodman et al. (1989) found that the unsupplemented group had twice the prevalence of hypoplastic defects as the supplemented group. Although the exact nutrient deficiencies involved in the formation of the defect are unknown, this study clearly establishes a relationship between the occurrence of enamel hypoplasias and poor nutrition.

In a study similar to that of Goodman et al. (1989), Sawyer and Nwoku (1985) compared well-nourished children of high socioeconomic status to malnourished children of low socioeconomic status in Nigeria. They found that 15% of malnourished children exhibited hypoplastic defects, compared to 0% of the well-nourished children. Likewise, a study of rural Chinese populations found that individuals whose teeth developed during
the famine of 1959-1961 had significantly more enamel hypoplasias than individuals whose teeth developed either before or after the famine (Zhou, 1975).

Studies of linear enamel hypoplasias in populations of nonhuman primates have also helped to achieve a more complete understanding of their etiology. Guatelli-Steinberg and Benderlioglu (2006) performed a retrospective study examining the dentitions of rhesus macaques dating to the middle of the twentieth century from Cayo Santiago. Specifically, they compared the frequency of enamel hypoplasias on dentitions dating from periods prior to, and following the establishment of a dietary supplementation program for the monkeys on the island. Records show that the unsupplemented rhesus macaque populations suffered from higher levels of disease and malnutrition than did the later supplemented groups. Similar to the studies of living humans, Guatelli-Steinberg and Benderlioglu found a significantly higher frequency of enamel hypoplasias in the group that inhabited the island prior to the establishment of the dietary supplementation program.

Experimental models using animals have also contributed to the present understanding of the etiology of enamel hypoplasias. In one study, Suckling et al. (1983; 1986) infected a group of young sheep with parasites and compared their rate of enamel hypoplasias to that of a healthy control group. They found parasitic infection to be associated with a significant increase in hypoplastic defects.

Goodman and Rose (1990) created what they termed the threshold model for conceptualizing enamel hypoplasia development. This model focuses on the different factors that lead to the formation of a hypoplastic lesion. According to the model,
environmental and cultural stressors interact with an individual’s level of host resistance to determine the type, duration, and intensity of physiological stress (Goodman and Rose, 1990: 71). If the stress occurs during the period of dental development, the potential exists for ameloblastic activity to be disrupted by the physiological perturbation. If the interaction of all these factors leads to sufficient stress for ameloblastic activity to be altered, the result is an enamel hypoplasia.

In addition to systemic physiological stress, enamel hypoplasias can also result from congenital abnormalities and localized trauma. Enamel hypoplasias resulting from congenital abnormalities are considered rare, and Winter and Brook (1975) estimate that they impact fewer than 1% of individuals in modern populations. These were likely even rarer in ancient populations, in which individuals would have been unlikely to survive such congenital conditions past birth without modern medical intervention. Enamel defects resulting from localized trauma are also considered rare (Goodman and Rose, 1991). Their prevalence can be accurately estimated in well preserved skeletal samples. Unlike defects caused by systemic stress, which form on all teeth developing at the time of the physiological perturbation, hypoplastic lesions caused by trauma occur only on isolated teeth or a few adjacent teeth actually exposed to impact. Goodman et al. (1980) utilized this difference to estimate the rate of enamel hypoplasias caused by trauma in the prehistoric skeletal sample from Dickson Mounds, Illinois. They found that less than 1% of individuals had traumatically induced hypoplasias.

The combination of clinical, epidemiological, and experimental studies indicate that the majority of enamel hypoplasias are caused by infectious disease and malnutrition. Therefore, they are best regarded as nonspecific indicators of systemic physiological
stress (Larsen, 1997). As such an indicator, enamel hypoplasias are especially useful for monitoring the general health of a population.

**Porotic hyperostosis and cribra orbitalia**

Porotic hyperostosis and cribra orbitalia are two commonly documented skeletal lesions often discussed together because they are thought to both be skeletal manifestations of the same underlying cause. The current consensus within bioarchaeology is that both porotic hyperostosis and cribra orbitalia are skeletal responses to anemia (Eshed et al., 2012; Larsen, 1997; Oxenham and Cavill, 2010; Walker et al., 2009). Porotic hyperostosis is identified macroscopically as porosity symmetrically distributed across the bones of the cranial vault, especially the parietals and occipitals. Cribra orbitalia is a similar porotic sieve-like lesion occurring in the roofs of the orbits. In both lesions, the porosity is thought to result from the expansion of the spongy diploe at the expense of the outer cortical bone (Stuart-Macadam, 1985; 1987; 1989). The diploe of the cranial bones contains hematopoietic bone marrow which proliferates in response to anemic conditions (Stuart-Macadam, 1985). As the diploe expands, it exerts pressure on the outer cortical bone, triggering its resorption and exposing the underlying spongy bone, causing the porous appearance of the lesions (Stuart-Macadam, 1985). In severe cases, the diploe can continue to expand, significantly thickening the bones of the cranial vault.

Both porotic hyperostosis and cribra orbitalia are typically seen as active lesions (showing no signs of healing) in subadults, whereas the lesions typically show signs of healing (pores filled in with new bone) in adults (Stuart-Macadam, 1985; 1992; 1995).
This pattern results from an age-related change in the location of red blood cell production. During childhood and adolescence, the marrow located in the cranial bones is responsible for red blood cell production, while during adulthood hematopoietic activity shifts to the axial skeleton, with red marrow located in the vertebrae, ribs, and sternum (Stuart-Macadam, 1992). The shifting location of red blood cell production during the human lifecycle means that any archaeologically documented cases of cribra orbitalia and porotic hyperostosis represent anemic conditions that occurred prior to adulthood (Stuart-Macadam, 1985).

The specific etiology of porotic hyperostosis and cribra orbitalia has been frequently discussed in bioarchaeological literature. Angel (1966) originally interpreted the lesions as representing hereditary forms of anemia such as Thalassemia. These forms are relatively rare, however, and do not correspond to the high frequencies at which porotic hyperostosis and cribra orbitalia occur, in some cases affecting over 50% of individuals in a given population (i.e. Paphathanasiou, 2005). Genetic anemias are also normally fatal during childhood, yet both porotic hyperostosis and cribra orbitalia are frequently documented on the skeletal remains of adults. Furthermore, both lesions have been observed in New World populations, which lack hereditary anemia. Subsequent clinical studies have demonstrated that although hereditary anemias do result in porotic lesions on the cranial vault and orbital roofs, they are typically more severe and expand to include the facial skeleton and long bones (Larsen, 1997). Therefore, cribra orbitalia and porotic hyperostosis are typically considered to result from acquired forms of anemia.

Many researchers suggest that porotic hyperostosis and cribra orbitalia are associated with iron-deficiency anemia (El-Najjar et al., 1976; Lallo et al., 1977; Larsen,
1984; Walker, 1986; Wright and Chew, 1998). This theory is supported by clinical findings which link blood-serum evidence for iron deficiency with radiographic evidence for hypertrophy of the spongy bone of the orbits and cranial vault (Agarwal et al., 1970; Moseley, 1974).

Diet and infection are both potential causes of iron-deficiency anemia. Meat contains iron in the heme form, which is most easily absorbed by the human digestive system, whereas plants contain iron in the non-heme form, which is absorbed inefficiently (Baynes and Bothwell, 1990). Plants also contain phytates, which are chemicals that combine with dietary iron to prevent its absorption by the digestive system. Cultures that rely heavily on plant foods are therefore at a higher risk for iron-deficiency anemia, as is seen in modern vegans (Waldman et al., 2004).

Pathological factors including diarrheal diseases and parasitic infections can also cause iron-deficiency anemia. Diarrheal diseases significantly reduce nutrient absorption by the digestive tract, while parasites act to remove blood and nutrients from circulation (Walker, 1986). Water supplies contaminated with bacteria or parasites such as the diarrhea-causing Giardia lamblia or the parasitic round worm can cause blood and nutrient loss significant enough to result in iron-deficiency anemia (Lambert and Walker, 1991; Walker, 1986).

A recent study by Walker et al. (2009) challenged the hypothesized link between iron-deficiency anemia and porotic cranial lesions. The study used clinical evidence to demonstrate that iron-deficiency anemia actually inhibits marrow hypertrophy, and therefore would not cause either cribra orbitalia or porotic hyperostosis (Brugnur, 2002;
Walker et al., 2009). Additional clinical literature suggests that erythropoiesis only occurs when physiological iron stores are at adequate levels, and that when iron levels are low, red blood cell production is reduced, not expanded as has traditionally been believed (Furuyama et al., 2007). Trace element analyses on prehistoric burials from Poland indicated that iron levels in skulls with and without cribra orbitalia were statistically equivalent, further calling into question whether iron deficiency is correlated with such lesions (Glen-Haduch et al., 1997).

Walker et al. (2009) alternatively suggest vitamin B12-deficiency as a possible cause of porotic hyperostosis and cribra orbitalia. A deficiency in vitamin B12 results in megaloblastic anemia, which causes the abnormal division of red blood cells during erythropoiesis. To compensate for the abnormal cells, increased erythropoiesis is stimulated and marrow hypertrophy results. Vitamin B12 is only found in animal products, so much like iron, B12 deficiency may be caused by high reliance on plant foods, infections, diarrheal disease, and parasites (Olivares et al., 2002). Oxenham and Cavill (2010) have questioned Walker et al.’s interpretation of the clinical literature and defended the iron-deficiency anemia hypothesis, although they agree that megaloblastic anemia could have been the cause of porotic hyperostosis and cribra orbitalia in prehistoric populations.

Regardless of whether porotic hyperostosis and cribra orbitalia result from deficiencies of iron or vitamin B12, these conditions have serious consequences for health and behavior. Goodman and Martin (2002) discussed the functional implications of iron-deficiency anemia for prehistoric populations, which includes impaired mental and physiological faculties. Mild iron-deficiency anemia during childhood is associated
with cognitive impairments, including a loss of memory capacity, lower I.Q., and reduced attention spans (Howell, 1971; Pollitt, 1987; Salzer et al., 1973). For individuals of all ages, iron-deficiency is associated with a decreased work capacity and ability to carry out strenuous physical activity (Scrimshaw, 1991). Furthermore, iron-deficiency anemia is related to an impairment of the immune system and thus an increased susceptibility to infection (Pullman, 1987). Vitamin B12-deficiency results in similar problems, but also causes reduced alertness, nervous system demyelination, irritability, and various psychiatric disorders (Walker et al., 2009).

Another study examining the potential causes of porotic hyperostosis and cribra orbitalia used seven clinically established radiographic markers of anemia to examine archaeological skulls both with and without the lesions (Stuart-Macadam, 1987). Although Stuart-Macadam (1987) found a strong association between the skeletal lesions and radiographic markers of anemia, a number of skulls without macroscopically visible porotic hyperostosis and cribra orbitalia showed radiographic evidence of anemia. Additionally, there were also individuals observed to have the skeletal lesions without radiographic evidence of anemia (Stuart-Macadam, 1987). This suggests that while many macroscopically recognized cases of cribra orbitalia and porotic hyperostosis may be the result of anemia, they may also have other causes. Non-anemic disease processes, such as scurvy, may also result in skeletal lesions recognized as porotic hyperostosis and cribra orbitalia. Scurvy is caused by vitamin C deficiency, which leads individuals to develop structurally flawed blood vessels that are easily ruptured when subjected to outside mechanical forces (Ortner and Ericksen, 1997; Ortner et al., 2001). For this reason, scurvy often results in chronic bleeding in areas where blood vessels are located near the
surface of the skin or near muscles. Blood vessels located near the roofs of the orbits and along the cranial vault in scorbutic individuals are frequently ruptured by the contraction of ocular and masticatory muscles (Ortner et al., 2001). Chronic bleeding in these areas triggers an inflammatory response which results in the formation of additional defective blood vessels (Ortner and Ericksen, 1997). If bleeding occurs near the bone surface, the inflammatory response also results in the creation of increased vascular pathways into the bone, giving the bone surface a porous appearance often recognized as cribra orbitalia and porotic hyperostosis (Ortner et al., 2001).

Similar to scurvy, periostitis can also cause increased vascularization of the bone, creating porous lesions recognized as porotic hyperostosis and cribra orbitalia (Wapler et al., 2004; Weston, 2008). Periostitis occurs as a result of inflammation caused by bacterial infection, minor trauma, or as a consequence of normal bone growth, and will be discussed further in the next section (Cook, 2007).

A study by Wapler et al. (2004) used microscopic and histological methods to investigate the prevalence of different causes of cribra orbitalia using crania from Nubia. Bone samples were collected from each affected orbital roof and prepared into several thin-ground slices which were then viewed using microscopy at between x10.5 and x360 magnification. Cases of anemia-induced cribra orbitalia were recognized when marrow spaces in the diploe were wider than normal, reflecting marrow hypertrophy. Severe cases of anemia were recognized when the external lamina of the bone was opened. These widened marrow spaces and open lamina are easily recognizable microscopically, but invisible macroscopically. Wapler et al. (2004) also examined their sample of Nubian crania for cribra orbitalia caused by inflammatory reactions, such as those which occur in
periostitis and scurvy, as well as for alterations caused by post-depositional taphonomic damage. Lesions resulting from inflammatory responses were easily recognized microscopically by an abnormally large number of osteoclast cells, the bone resorption activity of which is necessary to create the pores which allow for increased vascularization. Lesions resulting from postmortem taphonomic damage were identified when collagen fiber was degraded but no other features of osteological reaction are present. The results of Wapler et al.’s analysis indicate that 20% of the macroscopically identified cases of cribra orbitalia in the Nubian sample were due to post-depositional degradation, and about 26% of cases were caused by inflammation, while less than 50% of cases showed evidence of anemia. These results were surprising, as traditional bioarchaeological interpretation has attributed all cases of cribra orbitalia to anemia.

Although the specific etiology of porotic hyperostosis and cribra orbitalia remains unresolved, they do serve as useful indicators of general physiological stress. Regardless of whether they are the result of infections, parasitic activity, dietary insufficiencies of iron, vitamin B12, or vitamin C, the lesions typically reflect the occurrence of suboptimal health, which can be useful in studies of prehistoric adaptation using the general stress perspective.

*Periostitis*

The periosteum is a membrane of connective tissue that surrounds all bone surfaces, except for areas of articulation (Weston, 2008). It is involved in the formation of new cortical bone through osteoblasts located on its underlying surface (Eyre-Brook, 1984). In addition to normal bone formation, the periosteum is also involved in abnormal
bone formation resulting from trauma and infection (Larsen, 1997). Abnormal bone formation, termed periostitis, is one of the most commonly observed pathologies in collections of archaeological skeletons. Periostitis is characterized macroscopically by discrete patches of woven bone superimposed on the normal cortical surface. The appearance of these lesions varies depending on whether they are active or healed. Active lesions are raised areas of porotic bone, whereas healed lesions can be highly remodeled and occur as abnormally raised areas along the bone’s normal contour (Ortner and Putschar, 1985).

Periostitis is caused by an inflammatory response resulting either from subperiosteal bleeding or infection of the periosteum. The inflammatory response temporarily reduces blood flow to periosteal osteoblasts (Weston, 2008). As the inflammation is reduced, blood flow returns to normal, stimulating osteoblastic activity which results in the formation of a periosteal lesion (Weston, 2008).

Inflammatory responses resulting in periostitis can be caused by infection, trauma, or nutritional deficiencies (Larsen, 1997). Bioarchaeologists typically consider periostitis the result of infection (Cohen and Armelagos, 1984; Cohen and Crane-Kramer, 2007; DeWitte and Bekvalac, 2011; Goodman and Marin, 2002). Although periostitis can be caused by infection, trauma, including anything that stretches, raises, or touches the periosteum, can also cause new periosteal bone formation (Richardson, 2001). Ortner and Putschar (1981) suggest that periostitis caused by trauma is often small and localized to single bones, whereas lesions resulting from systemic infection (most typically by bacteria belonging to \textit{Staphylococcus} and \textit{Streptococcus}) tend to be found in multiple
bones from the same individual and are generally larger. As noted above, nutritional deficiencies such as scurvy are also potential causes of periostitis (Ortner et al., 2001).

Despite all of the research on periostitis, certain aspects of its etiology and prevalence remain unknown. For example, no one has been able to explain why periostitis most commonly affects the tibia (Larsen, 1997). Attempts to relate periostitis to specific disease states have also been unsuccessful. For example, Weston (2008) tried to link quantitative and qualitative aspects of periostitis with specific forms of infection in skeletons archived at medical museums. Her analysis was unable to demonstrate links between periostitis and individual diseases.

The uncertainty surrounding the etiology of periostitis has led Cook (2007) to suggest that the condition be interpreted cautiously and treated as a marker of general stress. When integrated into a multiple-marker study of health, periostitis can contribute to our understanding of biological wellbeing in the past, especially from a general stress perspective.

Stature

Terminal adult stature is a product of genetics and the quality of the environment during growth and development (Tanner, 1981). Environmental quality includes factors such as nutritional adequacy, levels of infection, social status, and psychological wellbeing (Bogin, 1999; Eveleth and Tanner, 1976). Therefore, stature is regularly used in studies of health in living populations, and its correlation with nutritional status and physiological wellbeing is well established (Bogin, 1999; Eveleth and Tanner, 1976). Smaller stature is typically associated with reduced biological wellbeing; therefore,
stature is often used as a proxy for overall health in a given population (Tanner, 1994). For example, Bogin (1991) found that Guatemalan children of higher socioeconomic status were significantly taller than lower status children of the same age. This discrepancy in height is considered a result of the greater access of high status children to adequate nutrition and sanitation.

As Goodman and Martin (2002) point out, stature is a good marker of nutritional status, which is the balance between the needs of the organism and the nutrients actually consumed (McKaren, 1976). In addition to dietary composition, nutritional status is also affected by disease and infection, which can result in malnutrition by increasing the needs of the organism and reducing digestive efficiency (Goodman and Martin, 2002).

In addition to cultural factors like nutrition, stature is also affected by environmental stressors. One such stressor that has received considerable attention is high altitude. Human populations that live far above sea level are exposed to relatively low levels of oxygen. This can lead to a condition known as hypoxia, where the oxygen available during respiration is less than necessary to meet the metabolic demands of the organism. High altitude induced hypoxia can lead to reduced stature. For example, Greska (1988) compared well-nourished groups of European descent that lived at different altitude levels. High altitude populations were found to have statures reduced, on average, 4.3cm as compared to groups closer to sea level. This demonstrates the ability of stature to sensitively monitor deviations from optimal health.

Studies of health in living populations use measures of both average subadult and adult stature, whereas bioarchaeological studies focus on relative adult stature. This focus
on adult stature is a product of the difficulty of matching subadult long bone lengths to
exact age-at-death, which prevents accurate age-specific comparisons. Examining adult
stature provides information on the nutritional sufficiency of subadulthood, as it is the
product of the entire period of growth and development. Reduced adult stature, therefore,
represents the impact of poor nutritional status over this entire period. Reduced stature is
associated with a variety of functional impairments and increased risk of early mortality
(DeWitte and Hughes-Morey, 2012). Children with reduced stature have impaired
immune systems, a diminished capacity for physical activity and delayed cognitive
development (Allen, 1984; Chavez and Hutivez, 1982).

The combination of many nutritional factors, including proteins, vitamins,
minerals, and total calories are vital for growth. However, it is not typically possible to
determine the specific nutritional insufficiency resulting in reduced growth, and
therefore, relative stature is a non-specific indicator of stress. This makes it an especially
useful tool for investigating ancient health using the general stress perspective.

Dental caries

Unlike the previously discussed markers of nonspecific physiological stress
including enamel hypoplasias, cribra orbitalia/porotic hyperostosis, periostitis, and
stature, dental caries represents a specific disease process associated with carbohydrate
consumption. This disease process is characterized by the focal demineralization of the
dental hard tissues by organic acids produced as a byproduct of bacterial fermentation of
dietary carbohydrates (Larsen, 1997; Larsen et al., 1991; Temple and Larsen, 2007). This
demineralization varies in severity from slight pinpricks to large necrotic cavities where
the majority of the tooth is destroyed (Hillson, 2001). In addition to fermenting dietary carbohydrates, oral bacteria also metabolize dietary proteins, which results in alkaline byproducts. This more basic environment can work to prevent the demineralization associated with dental caries. Therefore, carious lesions form when a greater proportion of carbohydrates are consumed relative to proteins.

In bioarchaeological studies, the prevalence of dental caries is often used as a representative measure of overall oral health (Fields et al., 2009). Because dental caries result from the fermentation of dietary carbohydrates, bioarchaeologists also use their presence to reconstruct diet (Turner, 1979). However, the etiology of dental caries involves more than the relative consumption of carbohydrates and proteins. Factors including dietary composition, dietary texture, sex, salivary flow rate, the composition of saliva, the composition of oral flora, and the rate of dental attrition also affect the prevalence of caries (Lukacs and Largaespada, 2006). Many of the non-dietary factors, like salivary flow rate, are difficult to study in archaeological populations, and therefore the majority of research has focused on the relationship between diet and dental caries. For example, Watson et al. (2010) compared the rate of carious lesions between Formative Period (1500BC-AD500) populations from various regions in northern Chile and found that inland valley populations (19.65% of teeth) had a significantly higher frequency of caries compared to coastal groups (3.75% of teeth). Watson et al. regarded this difference as evidence that valley populations had a higher reliance on carbohydrate-rich plant foods than coastal populations, who likely consumed more protein-rich marine products.
Large-scale cross cultural studies have found the correlation between carbohydrate-rich diets and dental caries rates to be relatively consistent. This led Turner (1979) to investigate the relationship between subsistence system and rate of carious lesions. Turner reasoned that if reliance on carbohydrate-rich plants increases as societies transition from hunting and gathering to full-scale agriculture, dental caries rates should also increase. Turner hypothesized, therefore, that different subsistence systems should be characterized by different dental caries rates. Using a global sample of dentitions from prehistoric and living populations, Turner calculated average dental caries rates (and ranges) for hunter-gatherers, populations with mixed subsistence strategies, and agriculturalists. Specifically, he found the rates (and ranges) to be 1.72% (0-5.3%), 4.37% (.4-10.3%), and 8.56% (2.3-29%), for hunter-gatherer, mixed, and agricultural economies, respectively. The rates do indeed show an increase in caries rates as societies incorporate agricultural foods into their diets. Therefore, Turner concluded that the high reliance of agricultural societies on carbohydrate-rich cultigens results in elevated dental caries rates as compared to hunter-gatherers.

In addition to diet, a considerable amount of research has focused on the relationship between biological sex and dental caries susceptibility. Over the last century, paleopathological, epidemiological, and clinical dental studies have documented a relatively consistent pattern in which females are more frequently affected by dental caries than are males (Fields et al., 2009; Lambert and Walker, 1991; Larsen et al., 1991; Lukacs, 1992; 1994; Milner, 1984; Temple and Larsen, 2007; Watson et al., 2010). Traditionally, the higher prevalence of dental caries in females has been explained as the result of behavioral differences associated with the sexual division of labor (Larsen,
According to this behavioral explanation, females are cross-culturally associated with the gathering of wild plants, the cultivation of domesticated plants, and food preparation, resulting in constant access to cariogenic plant foods. By contrast, males are more frequently involved in hunting and tending to animal herds, giving them greater access to protein-rich foods and limiting their consumption of cariogenic plants.

One ethnographic study by Walker and Hewlett (1990) found evidence supporting this theory. By recording the dietary differences of pygmy foragers’ and Bantu farmers’ behavior, according to sex, Walker and Hewlett quantitatively demonstrated that females consumed more carbohydrates and had higher rates of dental caries than the males in each group. Comparatively, pygmy and Bantu men consumed more animal protein than did the females of their group. Interestingly, females in both the pygmy and Bantu populations were observed snacking on carbohydrate-rich foods throughout the day, due to their higher access to these foods during their sex-specific tasks. By frequently snacking on carbohydrate-rich foods, these females maintained a more acidic oral environment for longer periods throughout the day. Males, however, were observed to go for longer periods with no food consumption, a practice which lowers the risk for dental caries.

Although behavior undoubtedly plays a role in cariogenesis, sex-based biological differences predispose women to higher caries rates (Lukacs and Largaespada, 2006). Specifically, certain aspects of female reproductive biology lower the ability of saliva to protect against caries by reducing the rate of salivary flow, its buffering capacity, and antimicrobial action (Lukacs and Largaespada, 2006). Human saliva contains antimicrobial particles which limit the proliferation of oral bacteria (Lukacs and
Additionally, saliva is basic and can buffer acids produced by the bacterial metabolism of ingested carbohydrates (Lukacs and Largaespada, 2006). However, elevated blood estrogen levels reduce the buffering capacity of saliva by making it more acidic (Lukacs and Largaespada, 2006). Furthermore, high estrogen levels are also associated with the reduced production of antimicrobial salivary particles (Lukacs and Largaespada, 2006). Clinical studies have also documented a relationship between increased blood estrogen levels and decreased salivary flow rate in women (Leimola-Virtanin et al., 1997; Sewen et al., 2000). This occurs through the suppression of saliva production by the action of estrogen-receptor proteins on salivary glands (Leimola-Virtanin et al., 2000).

Reduced salivary flow impacts the formation of dental caries in three ways. First, as the quantity of saliva is reduced, the ability of the saliva to buffer against changes in acidity in the oral cavity is diminished. Second, lower levels of saliva lead to a reduced concentration of antimicrobial particles circulating within the mouth, allowing the bacteria that cause carious lesions (primarily *Streptococcus mutans*) to proliferate. Third, because the flow of saliva through the mouth acts to remove both bacteria and dietary carbohydrates, when salivary flow is reduced, less bacteria and sugar will be eliminated from the oral cavity, increasing the likelihood of caries formation (Lukacs and Largaespada, 2006).

Estrogen levels peak during pregnancy, at which point their negative effects on salivary flow and composition are the greatest (Lukacs, 2008). Even if diet remains a constant, women who are more frequently pregnant are at a greater risk of developing caries than those who are not (Lukacs, 2008).
Overall, analysis of dental caries prevalence is a valuable part of the bioarchaeologist’s toolkit. By assessing the prevalence of carious lesions, researchers can characterize the oral health of prehistoric populations and reconstruct past dietary practices. Additionally, the study of the dental caries in archaeological populations can allow for inferences to be made concerning the sexual division of labor and levels of fertility.

*Periodontal disease*

Periodontal disease is caused by the infection of the gingival tissues by oral bacteria (Li et al., 2000). The inflammation resulting from infection affects the gingival soft tissue and can spread to the alveolar bone, leading to its resorption. However, the exact mechanism by which inflammation of the gums leads to alveolar bone destruction is unknown (Hildebolt and Molnar, 1991). In archaeological collections of dentitions, periodontal disease is recognized as the destruction of the alveolar bone surrounding individual tooth sockets (Clarke and Hirsch, 1991). Like dental caries, periodontal disease has been used by bioarchaeologists as a proxy for dental health. Epidemiological studies show that periodontal disease is also significantly associated with other health problems such as respiratory infections, gastrointestinal infections, cancer, and diabetes (DeWitte and Bekvalac, 2011; Philstrom et al., 2005). These pathologies may result from the same bacteria that cause periodontal disease. Bioarchaeological studies have demonstrated that periodontal disease is associated with an increased risk of periostitis and mortality (DeWitte and Bekvalac, 2010; 2011). These clinical and bioarchaeological studies demonstrate that periodontal disease had significant health consequences for past populations.
Summary

The human skeleton and dentition respond in a variety of nonspecific ways to physiological stress. Enamel hypoplasias, porotic hyperostosis, cribra orbitalia, stature, and periostitis all provide valuable information on the level of systemic physiological stress in past populations. When considered in relation to each other and integrated using the general stress perspective, skeletal responses to physiological stress provide bioarchaeologists with the means for quantifying the health of past populations (Buikstra and Cook, 1980). Similarly, the study of carious lesions and periodontal disease allow bioarchaeologists to assess the dental health of prehistoric populations and investigate its relationship to subsistence practices. The next section of this chapter provides examples of how bioarchaeologists have utilized the general stress perspective and markers of dental health to study the impact of the transition to agriculture on human health in prehistory.

The transition to agriculture and its effects on health

The transition to agriculture occurred in various ways and at different times across the globe. Archaeologists have documented these transitions using paleobotanical and zooarchaeological techniques. To assess the impact of these transitions on the health of human populations, bioarchaeologists have used skeletal markers of stress to compare hunter-gatherers and early agriculturalists. In general, these studies suggest that following the transition to agriculture, there was an increase in physiological stress (Cohen and Armelagos, 1984; Larsen, 1995; 2006). However, there are exceptions to this pattern (i.e. Hodges, 1987). This section is subdivided into five distinct discussions of the
bioarchaeological studies that have examined the impact of the transition to agriculture in
North America, South America, Asia, Africa, and Europe.

*North America*

The health consequences of the transition to agriculture have been more extensively documented for prehistoric North America than for any other region of the world (Figure 2.1). Specifically, a large number of studies have examined the impact of agriculture on health in the Southeastern, Midwestern, and Southwestern United States. One reason for the focus on these regions is the plentiful skeletal samples created as the result of excavations associated with the Works Progress Administration during the 1930s.

The transition to agriculture here was unique in that it involved heavy reliance on a single crop (maize) and did not include animal husbandry in most regions (with the exception of the turkey in Mexico and the Southwestern United States). Maize is unique among the major domesticated staple crops in being an extremely poor source of protein. In terms of its amino acid content, maize is deficient in lysine, isoleucine, and tryptophan (Larsen, 1997). Additionally, maize contains low quantities of iron in the hard to digest non-heme form. It is, however, a carbohydrate-rich plant that supplies ample energy. The composition of maize, its iron and protein deficiencies, and carbohydrate-rich nature, have been implicated as the cause of many of the declines in health observed in bioarchaeological studies of the transition to agriculture.
Dickson Mounds, Illinois is one of the most important sites used to document the health consequences of the transition to agriculture in North America. This site includes large numbers of well-documented burials dating to three different cultural phases, including the Late Woodland, the Mississippian Acculturated Late Woodland, and the Middle Mississippian, which are characterized by hunting and gathering, mixed, and
agricultural economies, respectively (Goodman et al., 1984). During the Late Woodland period the Dickson Mounds population exploited wild plants and animals. During the Mississippian Acculturated Late Woodland, however, the population was increasingly influenced by agriculturalists at Cahokia. As a result, maize, bean, and squash cultivation spread to Dickson Mounds and began to contribute substantially to their diet. In the Middle Mississippian period, reliance on domesticated plants, primarily maize, increased, and agricultural practices were intensified. As the importance of agriculture increased, the importance of hunting decreased, perhaps as a result of overhunting (Goodman et al., 1984). Regardless of the cause, a reduction in hunting resulted in less animal protein available for consumption.

Changes in settlement practices and demographic parameters accompanied the changes in diet following the adoption of agriculture at Dickson Mounds. Settlement size and population density increased (Goodman et al., 1984). Initially, during the Late Woodland period, Dickson Mounds was only occupied on a seasonal basis by small mobile bands. As these bands became more reliant on agriculture, the population grew more sedentary and increased in size (Goodman et al., 1984). Over time, these changes had profound effects on the health of the population.

A study by Goodman et al. (1980) examined dental samples from each of the three periods of occupation at Dickson Mounds for evidence of enamel hypoplasias, used as markers of systemic physiological stress. The average number of hypoplastic defects per individual was calculated in order to quantify the systemic stress for each population. Goodman et al. (1980) documented a step-wise increase from the Late Woodland to Mississippian Acculturated Late Woodland to Middle Mississippian with averages of 0.9,
1.18, and 1.16 hypoplasias, respectively. The proportion of individuals with at least one enamel hypoplasia also increased over time, from 45% in the Late Woodland, to 60% in the Mississippian Acculturated Late Woodland, to 80% in the Middle Mississippian (Goodman et al., 1984). Statistical analysis determined that the Middle Mississippian population experienced, on average, a significantly higher number of enamel hypoplasias per individual as compared to the Late Woodland and Mississippian Acculturated Late Woodland periods. Goodman et al. (1980) hypothesized that this increase resulted from dietary insufficiency due to increased reliance on maize and reduced protein consumption. Furthermore, stress would have increased as a result of increased population density, which would have allowed for the maintenance of contagious crowd diseases and sanitation problems resulting from overcrowding (Goodman et al., 1980).

Additional studies of the Dickson Mounds skeletal material show that physiological stress increased following the transition to agriculture. Goodman et al. (1984) and Lallo et al. (1977) found that porotic hyperostosis increased significantly with agricultural dependence. The authors interpreted the lesions as the result of iron-deficiency anemia due to the iron-deficient nature of maize and the iron-depleting role of increased infections caused by higher population densities. Goodman et al. (1984) also calculated the average adult stature by sex. Although a decrease in average stature was found, the differences were not statistically significant.

Studies of the Dickson Mounds skeletal material also observed an increase in the prevalence of periostitis over time. A comparison of the foraging/horticultural samples (Late Woodland/Mississippian Acculturated Late Woodland) with the intensive agriculturalists (Middle Mississippian) indicated a significant increase in periostitis
associated with the transition to agriculture (Goodman et al., 1984; Lallo et al., 1978). While periostitis only affected 30.8% of foragers/horticulturalists, it affected over twice that, 67.4%, of later agriculturalists. Along with an increase in prevalence, the severity of the periosteal reactions also increased following the transition to agriculture, with each lesion, on average, covering relatively larger areas of the affected bone’s cortical surface (Goodman et al., 1984; Lallo et al., 1978). These increases, like those observed with enamel hypoplasias and porotic hyperostosis/cribra orbitalia, were interpreted as the result of increased reliance on maize, reduced animal protein consumption, sanitation problems associated with high population density, and the spread of infectious diseases among large populations.

Researchers at other sites in North America have found patterns of increased stress similar to those at Dickson Mounds. Studies examining the prevalence of enamel hypoplasias in the Ohio River Valley, southern Illinois, the lower Mississippi River Valley, and Mexico’s Yucatan Peninsula, each found the rates of hypoplastic lesions to be higher among agriculturalists than their hunting and gathering predecessors (Cassidy, 1984; Cook, 1984; Marquez-Morfin and Storey, 2007; Perzigian et al., 1984; Rose et al., 1984). Like enamel hypoplasias, a significant increase in porotic hyperostosis and cribra orbitalia were also observed in studies of prehistoric populations from the Ohio River Valley, southern Illinois, the lower Mississippi River Valley, Mexico’s Yucatan Peninsula, and North Carolina (Cassidy, 1984; Cook, 1984; Hutchinson et al., 2007; Marquez-Morfin and Storey, 2007; Rose et al., 1984). Studies in prehistoric Illinois, the Ohio River Valley, coastal Georgia, upland Georgia, Florida, Southwestern Puebloan groups, the lower Mississippi River Valley, Mexico’s Yucatan Peninsula, Ontario, New
York, and Virginia have also observed rates of periostitis to increase with the adoption of agriculture (Cassidy, 1984; Cook, 1984; Hodges, 1984; Hoyne and Bass, 1962; Hutchinson, 2004; Katzenberg, 1992; Larsen, 1984; Larsen et al., 2007; Marquez-Morfin and Storey, 2007; Martin et al., 1991; Milner, 1982; 1983; Pfeiffer and Farrington, 1994; Rose et al., 1991; Williamson, 1998).

Compared to the other skeletal markers of physiological stress, relatively few of the studies of prehistoric North America have examined changes in adult stature. Of the few that have, most found it did not change over time (Cook, 2007; 1984; Danforth et al., 2007; Goodman et al., 1984; Larsen et al., 2007). Two exceptions are studies that found slight decreases in stature associated with the adoption of agriculture in males of the southern Great Lakes region (Sciulli and Oberly 2002) and in both sexes in a coastal population in Georgia (Larsen, 1984; Larsen et al., 2002). The phenomenon of catch-up growth, which enables individuals to achieve their genetic potential for height despite physiological perturbations during the period of growth and development, may serve to explain why studies of stature fail to reflect the decreases in health seen in other skeletal markers of physiological stress (Ackland and Preece, 1987). It is also possible that the other skeletal stress markers, such as enamel hypoplasias, represent periods of stress too brief to significantly alter adult height (Temple, 2010). More research is needed on stature changes associated with the transition to agriculture in North America.

In addition to examining general physiological stress, studies examining the transition to agriculture in North America have also focused on the consequences of heavy reliance on maize for prehistoric oral health. Much of the work on this topic has been carried out by Larsen (1984; Larsen et al., 1991; Larsen et al., 2007). When
comparing foragers with early maize agriculturalists in coastal Georgia, Larsen et al. (1991) found that the prevalence of individuals displaying one or more carious lesions increased by over 600%. Larsen (1997) documents a similar increase in dental caries rates accompanying the adoption of agriculture in sites across the Eastern Woodlands of North America. While foragers had carious lesions on less than 7% of teeth, later farmers had lesions on over 15% of teeth. Larsen (1997) theorizes that these declines in oral health are related to the adoption of maize as a dietary staple. Maize has a very high sucrose content, and as a simple sugar, sucrose is easily fermented by oral bacteria (primarily *Streptococcus mutans*), resulting in high levels of acid production (Larsen 1997). In addition to Larsen’s work, other studies in Illinois, the Ohio River Valley, the Lower Mississippi River Valley, North Carolina, Tennessee, Alabama, Florida, and Mexico have observed an increase in dental caries prevalence following the transition to agriculture, indicating oral health declined substantially (Danforth et al., 2007; Goodman et al., 1984; Hutchinson et al., 2007; Marquez-Morfin and Storey, 2007; Rose et al., 1984).

Although an increase in dental caries is found in nearly every study investigating the transition to agriculture in North America, this pattern is not universal. Watson (2008) found that caries rates slightly decreased from foragers (14.0% of teeth) to farmers (13.5% of teeth) in the Sonoran Desert of the American Southwest. According to Watson, this stasis in oral health is a result of diet. Unlike many foragers who consume a high-protein, low-carbohydrate diet, these foragers consumed sticky carbohydrate-rich plants, including cactus, mesquite beans, and agave, which led to their elevated caries rate (Rose and Hartenady, 1991). This hunter-gatherer diet, high in carbohydrates, resulted in caries
levels that were higher than average for forager populations, and therefore, the adoption of maize, also a carbohydrate-rich food, did not cause a further increase in caries rates. Based on this experience, Watson (2008) urges that changes in oral health be studied at the local level and consider the availability of cariogenic wild foods.

Although the majority of studies from North America document increased stress associated with the transition to agriculture, there are a few exceptions in which little or no change in skeletal health is observed. For example, Danforth et al. (2007) examined enamel hypoplasias in Late Woodland (forager) and Mississippian (farmer) skeletal samples from across the southeastern United States. Foragers in the Mississippi Delta had a significantly higher prevalence of enamel hypoplasias than did later Mississippian agriculturalists from that region, while no difference was found in the rates of enamel hypoplasias when farmers and foragers were compared in Alabama. Similar results were obtained using porotic hyperostosis/cribra orbitalia, periostitis, and stature as measures of health (Danforth et al., 2007). This study indicates that in contrast to other regions of North America, the transition to agriculture in the southeastern United States did not appear to be detrimental to prehistoric populations. However, no potential explanations for this difference have been offered.

Another study providing an alternate perspective on the effects of agriculture on health in North America is that by Hodges (1987) using skeletal samples from the Valley of Oaxaca, Mexico. Although this study does not examine the actual transition to agriculture (as no skeletal remains of foraging populations are available for comparison) it provides evidence that physiological stress does not necessarily increase with agricultural intensification. Hodges (1987) examined skeletal samples of Early Formative
nonintensive agriculturalists and Late Formative intensive agriculturalists and found no significant differences between the two in terms of the prevalence of periostitis, cribra orbitalia, and enamel hypoplasias.

Hodges (1987) did note that when periostitis is considered only for the tibia, the intensive agriculturalists did have a significantly greater frequency of lesions than did the nonintensive agriculturalists, with 30.1% and 11.4% of tibia affected, respectively (Hodges, 1987). Overall, Hodges argues that the data supports her null hypothesis that the intensification of agriculture did not result in any change in health status in the Valley of Oaxaca (Hodges, 1987). She believes part of the reason for this may be that this area was a primary center of agricultural development, where the initial domestication of maize, beans, and squash took place. Because agriculture was developed here as opposed to being passed on from another population, it may have enabled the humans and plants to coevolve over an extended period of time, perhaps allowing agriculture to develop in a way that was uniquely suited for the Valley population (Hodges, 1987). According to Hodges, the detrimental effects of agriculture may only have arisen as it was exported to populations across North America (Hodges, 1987). Hodges (1987) also points to paleobotanical evidence that both Early and Late Formative populations in the Valley of Oaxaca maintained diverse diets that may have been more nutritionally sufficient than those of other regions that relied more heavily upon maize.

The studies by Danforth et al. (2007) and Hodges (1987) indicate that a decline in health did not universally accompany the transition to agriculture in prehistoric North America. While the majority of studies document an increase in at least one skeletal marker of stress following the adoption of agriculture, when all skeletal markers are
considered, most studies present complex mosaics of changing health. For example, while Larsen (1984) observed that adult stature declined and periostitis increased following the transition to agriculture in coastal Georgia, there was no corresponding increase in enamel hypoplasias. Similarly, Cassidy (1984) recorded an increase in enamel hypoplasias and porotic hyperostosis/cribra orbitalia with the transition to agriculture in the Ohio River Valley, but the prevalence of periostitis remained the same. Together the results of these studies demonstrate that the health consequences of the transition to agriculture should be considered on a case by case basis and include analysis of as many skeletal markers of stress as possible.

To summarize, the majority of studies examining the transition to agriculture in North America found it to be associated with an increase in physiological stress, although there are some exceptions (i.e. Danforth et al., 2007; Hodges, 1987). It is notable that most studies find at least one skeletal marker of stress to increase following the adoption of agriculture, however, this is typically not the case for all lesions examined. In the studies cited, enamel hypoplasias, cribra orbitalia/porotic hyperostosis, periostitis, and stature were affected in a variety of ways in different archaeological contexts, with no clear overarching pattern for each skeletal lesion. Studies of oral health, however, typically show an increase in prevalence of dental caries with the transition to agriculture, with the exception of some populations in the American Southwest.

South America

Prehistoric agriculture in South America was considerably different from that in North America. While populations on both continents relied heavily on maize, South
American farmers also cultivated potatoes and quinoa and kept domesticated animals such as llamas, alpacas, and guinea pigs. These differences provided South American farmers with increased dietary breadth and more sources of animal protein compared to North American farmers. However, most bioarchaeological studies (Figure 2.2) find the transition to agriculture in South America to also be associated with an increase in systemic stress. Like North America, studies here typically find a complex mosaic of changes in the frequencies of skeletal lesions, with at least one marker of stress increasing significantly.

South America is home to several biomes, including desert and alpine tundra, which provide excellent conditions for the preservation of human remains (Aufderheide, 2003). These environments provide bioarchaeologists with a unique opportunity to study soft tissue elements that provide an additional perspective to the skeletal materials typically recovered (Aufderheide, 2003).
The Atacama Desert is located along the Pacific coast of South America. It is the driest place on earth, and its aridity often results in the natural mummification of the deceased (Aufderheide, 2003). These conditions allowed Allison (1984) to study diseases of the soft tissues, as well as skeletal lesions and stature for the hunter gatherers and early agriculturalists in this area. By examining preserved lungs, he found that acute respiratory
disease was the most common cause of death for both foragers and farmers. Respiratory infections including pneumonia and tuberculosis remain major causes of mortality in the area in recent times (Allison, 1984). Allison also observed gastrointestinal disease to be more frequent among farmers than foragers. This health difference did not translate into a difference in average adult stature, however, as foragers and farmers were found to have statistically indistinguishable average heights. Similarly, foragers and farmers both displayed low rates of porotic hyperostosis and cribra orbitalia, suggesting they experienced similar rates of systemic physiological stress.

Other researchers have found skeletal markers to indicate a decline in health associated with the transition to agriculture in South America (Alfonso et al., 2007; Boston, 2009; Pechenkina et al., 2007; Ubelaker, 1984). Boston (2009) examined porotic hyperostosis/cribra orbitalia, periostitis, and dental caries in prehistoric foragers from the Chilean coast and compared them to Gentilar and Inka period agriculturalists. She found that porotic hyperostosis/cribra orbitalia and dental caries increased, whereas the prevalence of periostitis decreased with the adoption of agriculture (Boston, 2009). Altogether, Boston (2009) interprets the skeletal evidence as suggesting that the agriculturalists experienced more systemic physiological stress and dental disease than the previous forager populations. However, the results may not warrant such a straightforward interpretation, as the decrease in periostitis suggests infection declined following the adoption of agriculture in the region.

Ubelaker (1984) investigated the impact of the transition to agriculture on health using skeletal samples from Ecuador. He found that agriculturalists had a significantly higher prevalence of enamel hypoplasias and significantly shorter stature than foragers
Ubelaker (1984) argues that these patterns represent an increase in physiological stress resulting from insufficient nutrition associated with dependence on maize and poor sanitation caused by increased population density and sedentism. Ubelaker (1992) later examined the prehistoric skeletal samples from Ecuador for porotic hyperostosis and found that elevated lesion frequencies were found exclusively in coastal areas, while highland samples experienced lower rates. Ubelaker believes that the elevated prevalence of porotic hyperostosis along the coast is likely related to relatively higher population density in the region, which would have caused significant pollution and exposed individuals to parasitic infection, including hook worm. The disparate distribution of porotic hyperostosis in prehistoric Ecuador highlights the importance of considering environmental stressors in addition to cultural factors when reconstructing ancient health.

Pechenkina et al. (2007) found that Peruvian agriculturalists had higher rates of periostitis and enamel hypoplasias compared to foragers, but found stature to oscillate unpredictably over time. In fact, some populations of farmers actually had higher average statures than hunter-gatherer groups, complicating the assessment of health changes in the area.

Studies of oral health in South America indicate that, without exception, dental caries frequencies increased following the transition to agriculture (Alfonso et al., 2007; Boston, 2009; Kelley et al., 1991; Pechenkina et al., 2007; Ubelaker, 1984; Watson et al., 2010). Kelley et al. (1991) found dental caries prevalence to be significantly higher among agricultural populations compared to earlier groups reliant on foraging and fishing in Chile. Another Chilean study by Watson et al. (2010) found that agriculturalists
possessed carious lesions on 11.9% of teeth, a significantly higher rate than the 0.6% of forager teeth. As in North America, prehistoric agriculturalists from South America were heavily reliant on maize, and its high sucrose content is believed to have contributed to the elevated prevalence of dental caries in these populations as well.

Overall, the evidence from South America suggests that the transition to agriculture here was associated with a decline in oral health and an increase in physiological stress, although data on stature change did not always follow this trend. It is important to note that the majority of these studies focused on a small geographic region of this continent situated mainly along the Andes Mountain chain of Peru, Chile, and Ecuador. This may give a generally biased picture of prehistoric health, and future work is needed to diversify the regions studied. However, based on the current evidence it appears that the keeping of domesticated livestock and the cultivation of a wider variety of plants did not effectively buffer these populations from the stressors associated with the adoption of agriculture as compared to their North American counterparts. Rather, South American populations experienced a decline in health similar to those documented in North America.

Asia

Unlike North and South America, the transition to agriculture in Asia involved the adoption of a wide variety of domesticated crops and animals. Agriculture first developed in Southwest Asia with the initial domestication of several cereals, including barley and the wheat varieties of emmer, einkorn, and spelt, legumes, and flax. A variety of animals were also initially domesticated here, including dogs, cattle, pigs, goats, and sheep. Rice
and millet were the primary domesticated cultigens in South and Southeast Asia, Japan, and China. Additionally, the chicken, duck, yak, water buffalo, and cow were independently domesticated in South and Southeast Asia.

Figure 2.3- Bioarchaeological studies of the transition to agriculture in Asia:

Bioarchaeological studies (Figure 2.3) of the transition to agriculture have documented a variety of health changes during this period of prehistory, with some surprising results. For example, Tayles et al. (2000) examined changes in dental health following the transition to rice agriculture in prehistoric central Thailand, and found that the rate of dental caries declined. In their study, they calculated caries prevalence for three site: Khok Phanom Di, Ban Lum Khao, and Noen-u-Loke. Khok Phanom Di is a
settlement of sedentary hunter-gatherers, who consumed rice, although they did not likely
cultivate it, and it is believed to have been a relatively small component of their diet. Ban
Lum Khao is a later sedentary settlement from the Bronze Age in which rice is a
ubiquitous feature throughout the deposits, suggestive of its increased dietary importance.
Noen-U-Loke dates to the Iron Age and again, rice was commonly found, including in
graves, and is considered to be of great dietary importance. Although Tayles et al. (2000)
expected to find an increasing rate of caries over time as populations became more
dependent on rice, a carbohydrate-rich grain, they documented a decrease in caries
prevalence, from 11.4% of teeth at Khok Phanom Di, to 4.4% of teeth at Ban Lum Khao,
to 3.8% of teeth at Noen-U-Loke. These findings have called into question the presumed
straightforward relationship between dental caries and degree of agricultural dependence.

The authors point out that the caries rates at Ban Lum Khao and Noen-U-Loke are
very low for agriculturalists, while the rate for foragers at Khok Phanom Ki is extremely
high, compared to the averages calculated by Turner (1979) (Tayles et al., 2000).
Although Tayles et al. (2000) do not attempt to explain the high rates of dental caries
observed for the foragers at Khok Phanom Ki, they do note that rice is not very
cariogenic on its own. According to the authors, rice’s coarse texture stimulates salivary
flow and results in the rapid clearing of food debris from the surface of teeth, unlike other
staple crops (Tayles et al., 2000). In contrast to the simple sugars available in maize, rice
sugars are stored in long polymers. Perhaps as a result, rice has a low cariogenicity, and
is not as easily fermented by oral bacteria. The most important point made by Tayles et
al. is that the adoption of agriculture does not necessarily result in increased rates of
dental caries, and that for prehistoric Thailand, this economic transition appears to have
led to improved dental health. Similar results were obtained by Pietrusewsky and Douglas (2002) at the site of Ban Chiang, Thailand, where caries were observed on 7.6% of teeth of forager/horticulturalists and 2.2% of teeth of agriculturalists.

Unlike in Thailand, a study on Honshu Island, Japan by Temple and Larsen (2007) found rice cultivation to be associated with a significant increase in the rate of dental caries. When older adult dentitions were compared, 13.2% of teeth of Yayoi period agriculturalists were affected by caries, compared to 9.8% of teeth for Jomon period foragers, a statistically significant difference (Temple and Larsen, 2007). However, Yayoi agriculturalists from other islands in the Japanese archipelago, including northern Kyushu (8.0% of teeth) and Tanegashima (8.3% of teeth) were not significantly different from the Jomon foragers in terms of caries prevalence (Temple and Larsen, 2007). The transition to rice agriculture for prehistoric Japanese populations appears to have been detrimental to some groups, but not all, suggesting the relationship between oral health and agriculture is complicated for rice cultivators.

A number of studies have investigated the impact of the transition to agriculture for farmers focusing on cereals such wheat, barley, and millet. One such study by Eshed et al. (2006) compared caries rates of Epipaleolithic Natufian foragers with those of prepottery Neolithic agriculturalists in the Levant. They found that both groups displayed moderate rates of dental cares, with carious lesions on 6.4% of Natufian and 6.7% of Neolithic teeth, a difference that is not statistically significant (Eshed et al., 2006). While the results of this study seem to suggest that the transition to agriculture was not detrimental to the oral health of prehistoric populations in Asia, it is important to note that the Natufians intensively harvested wild cereals, while prepottery Neolithic
populations continued to gather wild foods. Therefore, the change in diet between the two periods may not have been as drastic as in other areas. Eshed et al. (2006) also compared the Natufian and prepottery Neolithic populations in terms of periodontal disease, and found the Natufians to be significantly more affected, with 38.4% of their tooth sockets observed to have alveolar bone destruction, compared to 19.0% of prepottery Neolithic teeth. While caries prevalence remained constant, Neolithic populations may have had better oral health, as they suffered from significantly less periodontal disease. This counters the hypothesis that oral health declines with agriculture. Eshed et al. (2006) were surprised by this result, and confused as to what caused the reduction in periodontal disease. They suggest, however, that based on their heavy dental attrition, the Natufians may have subjected their teeth to significant occlusal forces which may have inflamed the gingival tissues resulting in the higher observed rates of periodontal disease (Eshed et al., 2006).

Work by Lukacs (1992) and Lukacs and Minderman (1992) examining dental health during the transition to agriculture on the Indian subcontinent found that the agriculturalists at Bronze Age Harappa had significantly more dental caries (6.8% of teeth) than the Mesolithic foraging groups (ranging from 0.0% to 1.2% of teeth). Unlike studies from the Levant and Thailand, this data suggests that the transition to agriculture was detrimental to the oral health of early farmers.

In addition to studies of oral health, other studies of the transition to agriculture have examined markers of physiological stress experienced by prehistoric Asian populations. Studies of enamel hypoplasias indicate that stress increased following the adoption of agriculture in India and Thailand (Douglas and Pietrusewsky, 2007; Lukacs,
2007; Lukacs et al., 2001; Pietrusewsky and Douglas, 2002). For example, at Ban Chiang in Thailand, early mixed economy populations had enamel hypoplasias on 9.3% of teeth, while the rate increased to 15.8% among intensive agriculturalists (Pietrusewsky and Douglas, 2002). The increase in systemic stress at Ban Chiang has been explained as resulting from increases in population density and sedentism, which exposed these populations to human waste and contagious crowd diseases (Pietrusewsky and Douglas, 2002).

Not all studies observed a trend toward decreasing health, however. For example, Temple (2010) found that the rate of enamel hypoplasias decreased following the adoption of agriculture in Japan. Specifically, Yayoi farmers displayed one or more hypoplastic defects on only 30.3% of their teeth, as compared to 36.8% of teeth of Jomon foragers from eastern Japan and 56.7% of teeth of Jomon foragers from western Japan (Temple, 2010). Temple (2010) divided the Jomon forager samples geographically, as the eastern and western groups varied in their subsistence practices with eastern groups more reliant on marine resources. According to Temple (2010), Jomon foragers often relied on nutritionally poor fallback foods at times when preferred wild resources were scarce. This often resulted in periods of malnutrition and starvation. The introduction of rice agriculture and animal husbandry would have provided the prehistoric populations of Japan with a more secure food source, lowering the stress experienced by these groups. The transition to agriculture appears to have caused some aspects of health to improve rather than deteriorate for these populations.

In addition to enamel hypoplasias, Temple (2010) also used cribra orbitalia to examine the effects of the transition to agriculture on physiological stress. He found no
difference between the Yayoi agriculturalists and Jomon foragers in terms of this skeletal lesion, suggesting the adoption of agriculture resulted in a complex mosaic of changes in prehistoric Japan (Temple, 2010).

Unlike Temple’s (2010) research, the study of cribra orbitalia by Pietrusewsky and Douglas (2002) separated adults and subadults to control for the fact that lesions heal and remodel over the course of adulthood. They found the rates of individuals with cribra orbitalia to be significantly higher in adult agriculturalists (40.3%) than those with a mixed economy (8.7%) at Ban Chiang, Thailand (Pietrusewsky and Douglas, 2002). The data for subadults, however, indicates that rates of cribra orbitalia declined from 55.6% with the mixed economy, to 16.7% with intensive agriculture. However, the difference among subadults was not significant due to a small sample size of six from the agricultural population. Overall, Pietrusewsky and Douglas (2002) found the increase in cribra orbitalia among the adult sample to be consistent with their data on enamel hypoplasias supporting the theory of declining health following the transition to agriculture in Thailand. They believe this was likely due to sanitary problems and increased infectious disease related to population aggregation.

In contrast to Pietrusewsky and Douglas’s work in Thailand (2001), a study in Israel found the rates of cribra orbitalia to be statistically indistinguishable when comparing Natufian foragers to Neolithic farmers (Eshed et al., 2010). Specifically, Eshed et al. (2010) found 37.5% of Neolithic farmers to have cribra orbitalia as compared to 40% of Natufian foragers. Eshed et al. (2010) additionally found that the prevalence of periostitis significantly increased from 1.0% of Natufian individuals to 4.6% of Neolithic individuals, suggesting a higher level of systemic stress. Based on the increase in
periostitis, Eshed et al. (2010) argue that their data supports the hypothesis that physiological stress increased in Israel following the transition to agriculture. However, it seems that when the lack of change in cribra orbitalia is considered, Eshed et al.’s (2010) results are more ambiguous than claimed.

Studies of prehistoric health in Thailand used stature to measure changes in health, although the results suggest mixed changes following the transition to agriculture. For example, while stature increased from 166.3cm to 167.5cm among males following the adoption of agriculture in the skeletal samples from Ban Chiang, this difference was not significant (Douglas and Pietrusewsky, 2001). Likewise, female stature increased from 156.0cm to 158.0cm, but again this difference was not significant (Douglas and Pietrusewsky, 2001). These results suggest health did not change in Thailand following the adoption of agriculture.

In summary, studies of the transition to agriculture in Asia associate the adoption of farming with a variety of changes in skeletal health. The general pattern seems to be that physiological stress increased with agricultural production, although evidence in Japan suggests that the transition to farming may have actually benefitted the health of prehistoric populations there. One of the most intriguing findings was that rice agriculture was not typically associated with higher rates of dental caries, as is the case for many high-carbohydrate crops. The variable nature of these results from Asia do not seem to follow the models proposed based on studies in North and South America.

Africa
Compared with Asia and the Americas, even fewer studies have examined the health consequences of the transition to agriculture in Africa (Figure 2.4). Those that have, focus on the abundant human skeletal remains excavated from Egypt and Sudanese Nubia, where populations were dependent on the same domesticates as Southwest Asia. Bioarchaeological studies here have found significant increases in physiological stress and dental disease following the transition to agriculture. However, the limited number of studies from this region restricts the conclusions that can be made.

Starling and Stock (2007) used enamel hypoplasias to examine changes in systemic stress resulting from the adoption and intensification of agriculture in Egypt. They compared the prevalence of enamel hypoplasias between Paleolithic hunter-gatherers from Jebel Sahaba, early agriculturalists from the Badari culture, moderately intensive agriculturalists from predynastic
agriculturalists from Late Dynastic Kerma (Starling and Stock, 2007). In terms of the proportion of individuals with one or more enamel hypoplasias, there was a significant increase from the Paleolithic foragers of Jebel Sahaba at 39.5%, to the early agriculturalists of the Badari culture at 69.8%. The rate of affected individuals dropped off in the Naqada to 33.33%, slightly rose to 42.6% for Tarkhun, and then again dropped
to 21.3% at Kerma (Starling and Stock, 2007). When enamel hypoplasia prevalence was assessed as a proportion of all observed teeth, the general pattern remained, with 6.5%, 17.2%, 15.2%, 9.3%, and 6.1% of teeth displaying hypoplastic lesions at Jebel Sahaba, Badari, Naqada, Turkun, and Kerma, respectively (Starling and Stock, 2007). Starling and Stock (2007) interpreted their results as indicating that the transition to agriculture in Egypt was associated with increased physiological stress, but that cultural changes surrounding the intensification of agriculture and urbanization may have buffered these populations.

Rose et al. (1993) compiled studies and site reports on ancient Egyptian and Nubian dental health to demonstrate that the adoption of agriculture there was associated with declining oral health, including an increased rate of carious lesions. Surprisingly, no studies have been carried out that directly compare the dental health of prehistoric Egyptian and Nubian foragers and early farmers. Based on samples from Nubia, the rate of carious lesions appears to increases from 1% teeth for Mesolithic period foragers to 4.65% of teeth for dynastic period agriculturalists (Rose et al., 1993). Egyptian sources are more variable and do not include hunter-gatherer dentitions (Rose et al., 1993). However, Egyptian dynastic period agriculturalists have caries rates as high as 5.2% of teeth, much higher than the rate for Mesolithic Nubian foragers (Rose et al., 1993). Unfortunately, no comparative statistics were used in the reporting of this data, preventing the assessment of statistically significant differences.

Overall, the skeletal data from Egyptian and Nubian samples suggest that stress initially increased following the transition to agriculture, but this elevated stress was short lived (Starling and Stock, 2007). Based on the available evidence, oral health appears to
have declined following the transition to agriculture. Obviously much remains unknown about the adoption of agriculture in prehistory for the rest of Africa, and our knowledge of the period would benefit from additional studies.

Europe

The transition to agriculture in Europe largely resulted from the processes of diffusion and migration as people and the “Neolithic package” (of wheat, barley, legumes, sheep, goat, pigs, cattle, and pottery) spread to the continent from Anatolia (Milisauskas, 2011). The manner by which agriculture spread through Europe makes the transition to farming here relatively unique.

Until recently, archaeological research programs in Europe have largely overlooked the effects of the agricultural transition on the health of prehistoric populations (Figure 2.5) (Meiklejohn et al., 1984; Meiklejohn and Babb, 2011; Meiklejohn and Zvelebil, 1991). This has been especially true in Eastern Europe where Soviet-era bioarchaeological research was almost entirely concerned with craniometrics and ethnogenesis (Jacobs, 1993). This is unfortunate given the unique nature of the transition to agriculture in Europe and its rapid spread across the continent.

The health of early agriculturalists has been most thoroughly studied in Greece. Unfortunately, the small number of hunter-gatherer skeletal samples in the region has limited the investigation of health prior to and during the agricultural transition. Papathanasiou (2005; 2011; Papathanasiou et al., 2000) analyzed skeletal remains of a Neolithic farming population from Alepotrypa Cave and found relatively high rates of porotic hyperostosis (50% of crania) and cribra orbitalia (60% of crania). Unfortunately
no hunter-gatherer samples are available from Greece to examine how the adoption of agriculture affected health there, but the rates are quite high for the early farmers, suggesting they were suffering from substantial physiological stress (Papathanasiou, 2005). By contrast, Papathanasiou (2005) considered the prevalence of enamel hypoplasias (8.3% of teeth) to be relatively low, and interpreted this as demonstrating that the farmers experienced generally good health. This interpretation runs counter to the data presented on porotic hyperostosis and cribra orbitalia. Likewise, dental caries were found to be relatively low (3.8% of teeth)

Figure 2.5- Bioarchaeological studies of the transition to agriculture in Europe: (1) Bennike and Alexandersen, 2007 (2) Smits and van der Placht, 2009 (3) Papathanasiou, 2005; Papathanasiou, 2011; Papathanasiou et al., 2000 (4) Roberts and Cox, 2007 (5) O’Sullivan et al., 1993 (6) Cunha et al., 2007; Jackes et al., 1994; Cardoso and Gomes, 2009 (7) Jarosova and Dockalova, 2008.
suggesting the population experienced good dental health and were only marginally reliant on carbohydrate-rich staple crops.

Sufficient dental remains have been recovered from archaeological sites in Portugal, the British Isles, Scandinavia, the Netherlands, and the Czech Republic, to enable comparison of Mesolithic foragers and Neolithic farmers in terms of dental health. Agriculturalists in the British Isles, Scandinavia and the Czech Republic appeared to have suffered from an increased prevalence of dental caries as compared to earlier foragers (Bennike and Alexandersen, 2007; Cunha et al., 2007; O’Sullivan et al., 1993; Roberts and Cox, 2007). For example, Linear Pottery Culture (LBK) farmers from the Czech Republic have carious lesions on 4.12% of teeth, significantly more than hunter-gatherers from the region who have carious lesions on 1.0% of teeth (Jarošová and Dočkalová, 2008). Similar changes were found in Scandinavia, where caries increased from 0% of teeth among Mesolithic hunter-gatherers to as high as 5.5% of teeth for Neolithic farmers (Bennike and Alexandersen, 2007). This pattern does not hold true for all regions of the continent. Jackes et al. (1994) found some Mesolithic Portuguese sites to have dental caries rates above those of Neolithic sites. For example, 14.3% of hunter-gatherer teeth from the Mesolithic site of Moita have occlusal caries, while only 3.1% of farmer teeth from the Neolithic site of Casa da Moura have occlusal caries. Other studies have found no differences between farmers and foragers in terms of caries rates. For instance, Smits and van der Plicht (2009) found no carious lesions in either Mesolithic or Neolithic skeletal samples from the Netherlands. These variable results suggest that the transition to agriculture in Europe did not universally result in declining dental health.
In terms of physiological stress, Bennike and Alexandersen (2007) found 59.42% of Mesolithic foragers from Scandinavia to have at least one enamel hypoplasia. Following the transition to agriculture, the prevalence of hypoplasias increased to 63.2% of Neolithic farmers. However, the rate of hypoplasias did eventually decline in later Neolithic agricultural populations to 40.3% of individuals, suggesting that any increases in stress brought about by farming were short-lived (Bennike and Alexandersen, 2007).

Bennike and Alexandersen (2007) also compared stature between the foragers and farmers from Scandinavia, and found generally the same trend: that health initially deteriorated following the transition to agriculture, but later improved. Specifically, they found the average length of adult male femora to decline from about 425mm for Mesolithic foragers to 423mm for Early Neolithic farmers, and then increase to 460mm in the Late Neolithic. A similar pattern was observed for females. While the average length of adult female femora declined from about 402mm in the Mesolithic to 394mm in the Early Neolithic, it then increased to 420mm in the Late Neolithic (Bennike and Alexandersen, 2007). Smits and van der Plicht (2009) observed similar changes in stature using prehistoric samples from the Netherlands. They found average female stature to decrease from 169cm for Mesolithic foragers to 163.2cm among Early Neolithic farmers, but then increased to 173cm in the Late Neolithic. The male skeletal material from the Netherlands was too few in number to permit comparisons.

Other researchers have observed increases in stature in farming populations in Britain, Portugal, and the Netherlands (Cardoso and Gomes, 2009; Roberts and Cox, 2007). For instance, Roberts and Cox (2007) found both Mesolithic foragers and early farmers from the Neolithic period to have average statures of 165cm for males and
157cm for females in prehistoric Britain. However, as farming developed, these average statures increased in the Bronze Age to 172cm for males and 161cm for females (Roberts and Cox, 2007).

In a large regionally focused study, Meiklejohn and Babb (2011) used a database of skeletons from across Western Europe to demonstrate that stature did not statistically significantly change from the Mesolithic to Neolithic, suggesting no major differences exist between foragers and farmers in terms of health. They found that, on average, Western European Mesolithic foragers had long bone lengths that were statistically indistinguishable from later Neolithic farmers (Table 2.1).

<table>
<thead>
<tr>
<th>Long Bone</th>
<th>Mesolithic</th>
<th>Neolithic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male humerus</td>
<td>310.25mm</td>
<td>316.15mm</td>
</tr>
<tr>
<td>Male radius</td>
<td>237.95mm</td>
<td>241.50mm</td>
</tr>
<tr>
<td>Male ulna</td>
<td>257.08mm</td>
<td>261.63mm</td>
</tr>
<tr>
<td>Male femur</td>
<td>437.23mm</td>
<td>440.03mm</td>
</tr>
<tr>
<td>Male tibia</td>
<td>367.87mm</td>
<td>364.19mm</td>
</tr>
<tr>
<td>Male fibula</td>
<td>340.52mm</td>
<td>352.04mm</td>
</tr>
<tr>
<td>Female humerus</td>
<td>291.02mm</td>
<td>286.58mm</td>
</tr>
<tr>
<td>Female radius</td>
<td>221.15mm</td>
<td>218.33mm</td>
</tr>
<tr>
<td>Female ulna</td>
<td>236.67mm</td>
<td>233.50mm</td>
</tr>
<tr>
<td>Female femur</td>
<td>409.71mm</td>
<td>406.46mm</td>
</tr>
<tr>
<td>Female tibia</td>
<td>325.75mm</td>
<td>331.77mm</td>
</tr>
<tr>
<td>Female fibula</td>
<td>322.80mm</td>
<td>318.18mm</td>
</tr>
</tbody>
</table>

Table 2.1- Average long bone lengths from the Western European Mesolithic and Neolithic (after Meiklejohn and Babb, 2011).

When all stature studies are considered, the mixed results suggest the transition to agriculture in Europe was associated with a variety of biological consequences, ranging from deteriorating health, to stasis, to improvements in overall well-being.
As compared to other skeletal markers of stress, relatively few studies have examined the impact of the transition to agriculture on the prevalence of periostitis in prehistoric Europe. Cunha et al. (2007) report an increase in periostitis rates between Portuguese foragers and agriculturalists. Although they do not provide an actual rate, they claim periostitis among Mesolithic foragers is rare to nonexistent. By contrast, Neolithic farmers from the site of Paimogo I have periostitis on up to 20% of their tibiae. Roberts and Cox (2007) observed a small increase in periostitis as farming developed from the Neolithic to the Bronze Age in Britain. They found the rate of individuals affected by periostitis over that period to increase from 2.3% to 2.7%.

Outside of Papathanasiou’s studies from Greece, only Roberts and Cox (2007) provide data on changes in the frequency of cribra orbitalia around the transition to agriculture. They found the prevalence of cribra orbitalia to increase from 2.3% of individuals in the Neolithic to 5.8% of individuals during the Bronze Age, suggesting an increase in stress accompanied the development and intensification of agriculture in Britain.

To summarize, European populations were observed to have poorer dental health following the transition to agriculture. However, when it comes to systemic stress, the data on stature, enamel hypoplasias, periostitis, porotic hyperostosis, and cribra orbitalia suggests a range of health outcomes with the adoption of agriculture.

**Discussion**

The transition to agriculture is one of the most consequential periods in the history of our species. It is associated with dramatic changes in diet, population size,
degree of sedentism, economic practices, and social complexity. Bioarchaeological studies over the past 50 years have examined the health consequences of this transition for prehistoric human populations. By utilizing the general stress perspective and skeletal markers of physiological perturbations, researchers have assessed the ways in which agriculture has affected human health. Overall, these studies suggest that this transition was associated with higher levels of physiological stress and declines in oral health, although this is not the case for all regions (Armelagos et al., 1991; Larsen, 1995; 2006).

The evidence seems to indicate that the adoption of agriculture had varying effects on different populations. For example, although few studies have examined the transition to agriculture in prehistoric Europe, the data on stature suggest that agriculture was not necessarily associated with deteriorating health. This is in direct opposition to the majority of studies from North and South America, which associate agriculture with negative health effects. It is possible that populations undergoing the transition to agriculture in different regions may have been buffered by geographical or cultural factors that caused them to have differing reactions to the adoption of farming and its more sedentary lifestyle. Perhaps the type of agriculture practiced and its degree of dietary variation/sufficiency in prehistoric North and South America created more stressors than did agriculture in Europe. As Jackes et al. (1994) point out, the studies from the New World may represent the worst outcome of the transition to agriculture, as maize is especially nutritionally poor and cariogenic, and the region is generally lacking in domesticated animals. Since considerably more studies have been conducted in North and South America, improving our understanding of the health consequences of the transition to agriculture is dependent on new research in under-studied areas.
The goal of this dissertation is to address the lack of literature examining the health consequences of the transition to agriculture in Eastern Europe. Specifically, I will focus on the adoption of agriculture in Ukraine, and assess the health of the Tripolye, an early agricultural population in the region, using human skeletons that I have excavated over the past five years. In the next chapter I present the archaeological background of the transition to agriculture in Ukraine, with specific emphasis on the archaeology of the Tripolye.
Chapter 3: Archaeological Background

Introduction

The Tripolye are considered one of the most important early farming cultures in Southeastern Europe (Zbenovich, 1996). They are well-known for their distinctive pottery and their highly stylized ceramic female figurines. The Tripolye are notable for constructing massive settlements, which have been termed the “proto-cities” of the continent (Kruts, 2012; Videiko, 2004). The Tripolye’s arrival on the territory of Ukraine brought about major changes for the region. For example, they were the first group in the area to possess the full “Neolithic package” of agriculture, animal husbandry, and pottery, and were the first to establish population-dense, large, permanent settlements (Korvin-Piotrovskiiy, 2012). Prior to the arrival of the Tripolye, most populations in Ukraine were mobile, and subsided primarily on hunting, fishing, and gathering (Korvin-Piotrovskiy, 2008). The aim of this study is to investigate the ways in which the agricultural and sedentary lifestyle of the Tripolye altered health in the populations inhabiting prehistoric Ukraine. This research will not only contribute to our understanding of the biological consequences of the transition to agriculture, but also address the lack of European studies on the topic.

To achieve this goal, it is necessary to understand what life was like in Ukraine prior to the Tripolye’s arrival. This chapter will discuss the archaeology of prehistoric Ukraine, focusing specifically on the Mesolithic and Neolithic groups inhabiting the area prior to and following the appearance of the Tripolye. Following this discussion, the archaeological background of the Tripolye will be presented, detailing their chronology,
economy, settlements, houses, and burial customs. The final section of this chapter will describe the Tripolye mortuary site of Verteba Cave, the source of the skeletal remains which constitute the material evidence of my assessment of Tripolye health.

**Archaeology of the Ukrainian Mesolithic and Neolithic**

Human groups occupied the territory of Ukraine for millennia prior to the arrival of the Tripolye ca. 4900 calBC (Rassamakin, 2012). Mousterian stone tools and dwellings constructed of mammoth bones, evidence of Paleolithic Neanderthal populations, have been recovered from sites in the Dniester River Valley (Demay et al., 2012). Some of the most well-studied prehistoric populations from Ukraine date to the Mesolithic and Neolithic periods (10,400–4580 calBC), and come from sites along the Dnieper River.

It is important to note that in Ukrainian archaeological terminology “Neolithic” does not denote the arrival of agriculture as it does in Western Europe, but rather, refers to the appearance of pottery (Jacobs, 1993). At many sites designated as Neolithic in Ukraine, pottery may be limited to a few small pieces, or be absent altogether (Lillie, 1996). The assumption behind this use of the term Neolithic is that the manufacture of pottery is linked to increased social complexity (Jacobs, 1993), however, research has shown Mesolithic and Neolithic groups from Ukraine’s Dnieper Rapids region to be very similar (Lillie, 1996; Lillie and Richards, 2000; Lillie et al., 2011). For this reason, they will be discussed together here.

Much of what is known concerning the Mesolithic/Neolithic in Ukraine’s Dnieper Rapids region comes from excavations of mariupol-type cemeteries in the area (Telegin,
Lillie and colleagues (Lillie, 1996; Lillie and Jacobs, 2006; Lillie and Richards, 2000; Lillie et al., 2003; Lillie et al., 2011) carried out a research program reconstructing the diets of the prehistoric people of this region using stable isotope analysis. They found that dietary practices remained stable throughout the Mesolithic/Neolithic (Lillie et al., 2011). Specifically, the results of the stable isotope analysis point to a diet focused on terrestrial animals and freshwater resources (Lillie and Richards, 2000; Lillie et al., 2011). Analysis of grave goods from the cemeteries support the conclusions drawn from the stable isotope studies, as fish and wild animal teeth were found in many graves (Lillie et al., 2011). The consumption of a diet rich in protein and low in carbohydrates is further supported by analysis of dental pathology in the Dnieper Rapids Mesolithic/Neolithic skeletal samples, which have been found to be universally free of dental caries (Lillie, 1996). Based on the dietary reconstructions, the ephemeral nature of the Mesolithic/Neolithic settlements in the area, and the lack of domesticated cultigens in the archaeological record, researchers conclude that these people were fairly mobile hunter-fisher-gatherers (Lillie, 1996; Lillie et al., 2011; Zvelebil and Lillie, 2000). Studies by Lillie (1996) and Jacobs (1993) have assessed the health status of these Dnieper Rapids hunter-fisher-gatherers.

In his analysis of dental health in the Mesolithic/Neolithic cemeteries form the Dnieper Rapids region, Lillie documents and interprets the occurrence of enamel hypoplasias. He found enamel hypoplasias throughout the sample, although at a relatively low prevalence. Specifically, Lillie observed at least one enamel hypoplasia on the teeth of 16.66% of Mesolithic individuals and 11.42% of Neolithic individuals for a pooled rate of 12.77%. When examined as a proportion of teeth, Lillie found 1.22% of
Mesolithic teeth and 2.25% of Neolithic teeth to have one or more of these lesions. According to Lillie, the rates of enamel hypoplasias indicate suboptimal levels of subadult health during the Mesolithic/Neolithic period, although the low frequencies do not represent severe systemic stress, suggesting a generally healthy existence for the Mesolithic/Neolithic Ukrainian hunter-fisher-gatherers.

Jacobs (1993) reconstructed stature using long bone lengths from postcranial elements found at Mesolithic/Neolithic cemeteries of the Dnieper Rapids region. The average height of these hunter-fisher-gatherers was found to be quite tall. In fact, these people were some of the tallest in European prehistory, suggesting the existence of a generally healthy population. The results of Jacobs’ stature analysis are in general agreement with the results of Lillie’s (1996) enamel hypoplasia analysis.

In addition to the hunter-fisher-gatherers of the Dnieper Rapids region, the Mesolithic/Neolithic Bug-Dniester Culture occupied areas along the Bug-Dniester interfluve in western Ukraine (Telegin, 1987). The Bug-Dniester Culture can be divided into two phases, an aceramic phase (7500-7000 uncalibrated BP) and a ceramic phase (7000-6000 uncalibrated BP) (Zvelebil and Dolukhanov, 1991). Based on similarities in ceramic decoration, it is thought that the Bug-Dniester acquired the art of pottery production from the Cris-Koros culture in Romania and Moldova (Zvelebil and Lillie, 2000). The economy of the Bug-Dniester was primarily focused on wild resources (Zvelebil and Dolukhanov, 1991). For instance, the majority of their faunal assemblages are composed of wild animals such as wild pig, red deer, roe deer, and fish (Zvelebil and Lillie, 2000). The contacts with the Koros-Cris culture that brought about ceramic production likely also led the Bug-Dniester Culture to import some domesticates,
although domesticated fauna are few in number and comprise less than 20% of zooarchaeological assemblages (Zvelebil and Lillie, 2000). Although domesticated cereals have been recovered from Bug-Dniester sites, it is likely that they formed only a small fraction of the diet (Zvelebil and Lillie, 2000).

The Bug-Dniester Culture has been categorized as a transitional, indigenous foraging society beginning to experiment with agriculture (Zvelebil and Dulukhanov, 1991). However, they never fully embraced the agricultural lifestyle, at least not while classified as the Bug-Dniester Culture. These populations were absorbed into the expanding Tripolye culture which came to occupy the majority of western Ukraine by the end of the 5th millennium calBC (Korvin-Piotrovskiy, 2012).

Other Neolithic cultures occupied smaller portions of the territory of western Ukraine. The Linear Pottery Culture (LBK), one of the earliest farming cultures in Europe (5600-4740 calBC) (Milisauskas, 2011; Stadler and Lenneis, 1996) established settlements in the Volyn region (Telegin, 1987). The LBK cultivated domesticated cereals including emmer, einkorn, and spelt wheat, as well as the hulled and non-hulled varieties of barley (Milisauskas, 2011). They also kept herds of domesticated animals including cattle, pigs, goat, and sheep (Oelze et al., 2011). In terms of settlement, the LBK established small hamlets comprised of a few long houses (Milisauskas, 2011). Over the course of their existence, the LBK occupied territory stretching across much of central and northern Europe. In Ukraine, they occupied a small portion of the western half of the country, pushing into the region from Poland, and disappeared after just a few centuries (Telegin, 1987; Zvelebil and Lillie, 2000).
The Cris-Koros culture also occupied a small portion of western Ukraine during the Neolithic. This group established settlements in the Transcarpathian region, and like the LBK, possessed domesticated cereals and animals (Zvelebil and Lillie, 2000). The Cris-Koros lived in semi-sunken houses that were grouped together in hamlets (Telegin, 1987). These dwellings were very similar to those which were later constructed by the Tripolye. As will be discussed in the next section, the Cris-Koros were influential in the formation of the Tripolye.

Unlike the cemeteries of the Mesolithic/Neolithic hunter-fisher-gatherers from the Dnieper Rapids region, only isolated individual burials are known from the Bug-Dniester, LBK, and Cris-Koros groups in Ukraine. As of yet, no studies examining the health status of these populations have been carried out.

**Origin of the Tripolye**

Archaeologists regard the transition from the sixth to fifth millennia calBC in southeast Europe as a period of major change (Ryzhov, 2012). The initial Neolithic farming cultures of the Danube River Valley were ending and new Eneolithic (Copper Age) populations were beginning to develop. In addition to changes in material culture, this time period is marked by widespread population movements and increased interaction between different archaeological cultures (Ryzhov, 2012). It was during this dynamic period of prehistory that the Tripolye culture formed (Zbenovich, 1996).

The Neolithic Dudești culture had settled along the Danube River in the Romanian province of Muntenia during the fifth millennium calBC. As the fifth millennium calBC came to an end, this culture came into contact with late-period Linear
Pottery Culture populations migrating south from Moldova. The combination of these two cultures gave rise to the Boian archaeological culture (Ryzhov, 2012). The Boian quickly expanded their territory as some populations crossed the southern spur of the Carpathian Mountains, establishing settlements in Transylvania. From here, other Boian groups crossed the Carpathian Mountains to the east, settling in the foothills of Romania and Moldova (Ryzhov, 2012). In pre-Carpathian Moldova, the Boian interacted with local Neolithic groups that were remnants of the Linear Pottery Culture, giving rise to a new archaeological culture designated as the Precucuteni (Comșa, 1974; Marnescu-Bilcu, 1974; Ryzhov, 2012). The Precucuteni would eventually give rise to the Cucuteni-Tripolye cultural complex that would come to dominate the region by occupying the western half of Ukraine, all of Moldova, and the eastern portion of Romania (Videiko, 2004).

Although the Boian played the primary role in the formation of the Tripolye, other regional archaeological cultures are believed to have also been influential. The Eneolithic Vinča culture of the Balkan Peninsula constructed wattle-and-daub structures and crafted anthropomorphic ceramic figurines similar to those observed among the contemporary Precucuteni, possibly indicating contact between the two groups (Titov, 1971). Likewise, it has been suggested that the Neolithic Cris-Koros culture of Romania influenced the Tripolye, as Precucuteni anthropomorphic figurines and vessels display “pinched” decorative patterns that are characteristic of the Cris-Koros.

Following the formation (ca. 5400 calBC) of the Precucuteni culture, groups recognized as distinctively Tripolye in terms of material culture are found along the Prut
River and in the Prut-Dniester interfluve beginning around 4900 calBC (Rassamakin, 2012).

Relative Chronology for the Tripolye

Before further discussing the Tripolye culture, it is necessary to describe the system used for categorizing their relative chronology. Historically, researchers have divided the chronology of the Tripolye into three major sections: the Early (Tripolye A), Middle (Tripolye B), and Late (Tripolye C) Periods (Passek, 1935). This relative chronology was developed for Tripolye sites based on the typological analysis of pottery, as Tripolye sites lack extensive stratigraphic development (Zbenovich, 1996). However, studies of stratified Cucuteni sites have confirmed that the relative chronology reflects the actual chronological development of the Tripolye (Zbenovich, 1996). Alternatives to the three period system have been proposed, including the division of the Middle and Late Periods into the independent BI, BII, CI, and CII phases (Ryzhov, 2012), and the addition of an intermediate BI-BII phase (Vinegrodova, 1983). Other researchers believe that many sites designated as CI phase more closely align with the Middle Period than the Late Period and, therefore, a new BIII phase has been proposed (Dergachev, 1980; Movsha, 1979; Zbenovich, 1972).

To avoid chronological issues and prevent the use of a rigid dating scheme, many researchers have begun to use the concept of the “site-type” (Ryzhov, 2012; Zbenovich, 1996). Site-types have very similar artifact assemblages and have distinct spatial and temporal boundaries (Zbenovich, 1996). These groups of similar sites are usually named
after the most thoroughly studied site and represent a stage of development for a specific region (Zbenovich, 1996). Dozens of site-types exist for the Tripolye.

All of the above chronological classifications are still in use by scholars of the Tripolye and regularly appear in publications. For this reason, I will use all of the available classifications in my discussions of the Tripolye archaeological culture and the site upon which my dissertation focuses.

**Archaeology of the Tripolye Culture**

*Early Tripolye Period (A- start of BI)*

The Early Tripolye period began at the turn of the fifth millennium calBC and continued until the last quarter of the fifth millennium calBC (Korvin-Piotrovskiy, 2012). At the start of this period the Tripolye occupied the area between the Prut and Dniester Rivers, as well as land along the west-bank of the Prut. As the period progressed, the Tripolye expanded their territory to the east, settling the Dniester-Bug interfluve (Korvin-Piotrovskiy, 2008). This territorial expansion is believed to be the result of population increases and a search for new arable land for agriculture (Korvin-Piotrovskiy, 2012). As the Tripolye moved to the east, local inhabitants of the Bug-Dniester culture were assimilated into the Tripolye (Zbenovich, 1989).

All early Tripolye settlements were located in a forest-steppe ecological zone, were established near permanent sources of water, and were typically situated on the first river terrace (Zbenovich, 1996). In the Bug River region, settlements were also found along creeks and on the slopes of gullies (Zbenovich, 1996). These Early Period settlements typically averaged around 1.5 hectares, although settlements are known to
have been as small as half a hectare and as large as 6 hectares (Zbenovich, 1996). The typical Early Period village or hamlet was organized with houses arranged in parallel rows or in a circle (Bibikov, 1953; Zbenovich, 1989). These settlements averaged around 10 houses. For example, Bernashevka was composed of 7 residential structures, while Alexandrovka was composed of 13 (Korvin-Piotrovskiy, 2012).

The Early Period Tripolye constructed two types of houses. The first were semi-sunken pit-houses, which were common throughout Neolithic Europe (Milisauskas, 2011). These houses were typically circular or oval, between 3-6 meters in diameter, and ranged from 1-3 meters in depth (Korvin-Piotrovskiy, 2012). In some instances, pit houses were built by merging two sunken circles together, giving the dwelling the shape of a figure-8 (Korvin-Piotrovskiy, 2012). The presence of postholes along the edges of the pit-houses suggests these were used to support the roof (Zbenovich, 1996). Hearths, storage pits, grinding stones for cereal processing, pottery, and faunal bones have been found inside the pit-houses (Zbenovich, 1996).

The second type of house constructed by the Early Period Tripolye has been referred to as a “ground-house” (Korvin-Piotrovskiy, 2008). Ground-houses were rectangular, built above ground, and measured 7-10 meters in length and 3-5 meters in width (Zbenovich, 1996). The walls of the ground-house were built using wattle-and-daub, in which a wooden lattice is covered with clay. The floors of ground-houses were also constructed of wattle and daub, and are recognized archaeologically as a layer of baked clay, known to researchers as ploshchadka (house remains) (Zbenovich, 1989). Early Period ground-houses were partitioned into either one or two rooms and contained a hearth and an elevated podium for storing items (Zbenovich, 1989).
Passek (1938) suggested that when groups of Tripolye entered a new area, they first constructed semi-sunken pit-houses or lightly built ground-houses, and only later switched to more substantial ground-houses. Therefore, it is believed that at sites where both pit-houses and ground-houses are found, the two represent different periods of the site’s occupation (Korvin-Piotrovskiy et al., 2012).

The Tripolye are well known for particular aspects of their material culture, especially their distinctively decorated pottery. During the Early Period, pottery production was a household activity, and pottery was manufactured using coils or slabs of clay without a wheel (Korvin-Piotrovskiy, 2012). Pottery forms dating to this Period include bowls, pots, chalices, spoons, plates, lids, and ladles (Zbenovich, 1996). Typically, vessels for storage and cooking were undecorated, while ceremonial vessels from this Period were marked by finger-pinched designs and incisions. These incised designs have origins in the preceding Boian culture (Zbenovich, 1996). Some pottery from this period is decorated with a “dragon-snake”, which has an elongated narrow body, horned head, and exaggerated eyes.

In addition to pottery, the Tripolye are also well known for their anthropomorphic figurines. In the Early Period, these figurines are highly stylized and most frequently depict women (Pogozhova, 1983). Typically a female figurine is narrow and cylindrical, has an exaggerated hips/buttocks area, breasts molded from two small clay balls, and facial features marked with incisions or pinched clay (Korvin-Piotrovskiy, 2012; Pogozhova, 1983). These figurines are considered to be ritual objects representing revered ancestors or deities of a fertility cult. The connection with a fertility cult may be
reinforced by the fact that some figurines were manufactured with a mixture of clay and grain (Zbenovich, 1996).

A variety of stone tools are known from Early Period Tripolye sites. Flint is widely available in the Dniester area, and flint tools are therefore more common in this area as compared to other river drainages (Zbenovich, 1996). Tools made from flint include sickles, knives, scrapers, saws, and arrowheads (Korvin-Piotrovskiy, 2008). Other types of stone were used to create axes, adzes, hoes, and querns (Korvin-Piotrovskiy, 2008). The Tripolye also used bone and antler to make needles, fish hooks, awls, and hammers (Korvin-Piotrovskiy, 2008).

Although the Tripolye are classified as Eneolithic (Copper Age), relatively few copper artifacts are known from the Early Period. The copper artifacts that have been found originated from areas outside the Tripolye homeland. Most copper ores used in Tripolye artifacts originate from the Balkan-Danube and Carpathian regions (Chernysh, 1978; Zbenovich, 1996). The majority of Early Period copper artifacts come from the site of Carbuna, where 444 copper items were found in a large pot (Sergeyev, 1963). This horde of artifacts included many items of personal adornment, and two axes.

By the start of the Early Period, the Tripolye economy was based on the cultivation of domesticated cereals (Korvin-Piotrovskiy, 2008). Tripolye agriculture focused on growing hulled wheats, including: emmer (Triticum dicoccum), einkorn (Triticum monococcum), spelt (Triticum spelta), hulled and non-hulled barley (Hordeum vulgare, Hordeum vulgare nudum), bitter vetch (Vicia ervilia), and lentils (Pisum sativum). Paleobotanical studies of carbonized seeds and impressions of grains on
ceramics have indicated that these plants were cultivated throughout the existence of the Tripolye culture (Pashkevych, 2008; 1980; Zbenovich, 1996). In Ukraine, it appears that emmer wheat was the cereal of primary importance to the Tripolye (Pashkevych, 2008). Cultivated cereals were likely consumed as porridges, as indicated by crushed grains found in a pot at the site of Maydanetske (Pashkevych, 2008).

The Tripolye thrived during the Holocene Climatic Optimum, a time period marked by warmer temperatures and more rainfall than experienced in modern times (Kremenetskii, 1991). The combination of the conditions of the Climatic Optimum and the loess soil of Ukraine’s forest-steppe would have made the Tripolye agricultural economy particularly successful (Korvin-Piotrovskiy, 2008). However, studies of pollen profiles indicate that the intensive slash-and-burn agriculture practiced by the Tripolye, as well as the felling of trees for fuel and timber, resulted in extensive deforestation and environmental degradation (Kremenetskii, 1991).

In addition to domesticated cultigens, the Tripolye also gathered wild plants such as cornelian cherry, wild pear, and apple (Korvin-Piotrovskiy, 2008; Pashkevych, 2004). The identification of these plants at Tripolye sites indicates that foraging remained a component of subsistence (Lillie, 2008).

Faunal assemblages at Tripolye sites include domesticated animals such as cattle, goat, sheep, and pig (Markova, 2008). The relative importance of each species varies between sites, but cattle tend to dominate the faunal collections of Early Period settlements, usually comprising over 50 percent of the domesticated animal assemblage.
(Zbenovich, 1996). An exception would be the site of Luka-Vrublevetskaya, at which pigs make up 54% of the domesticated animal assemblage (Ellis, 1984).

Hunting and fishing also played important roles in Tripolye subsistence during the Early Period. Deer, wild boar, auroch, brown bear, wolf, beaver, and hare were all hunted (Marinsecu-Bilcu, 1981: 183). At the sites of Luka-Vrublevetskaya, Bernovo and Bernashevka, wild animals make up over 50% of the total faunal remains (Zbenovich, 1996).

The Middle (Tripolye BI-BII/CI) Period

The Middle Period of the Tripolye culture spanned from the last quarter of the fifth millennium calBC to the third quarter of the forth millennium calBC and was characterized by territorial expansion, demographic growth, and population movement (Korvin-Piotrovskiy, 2012). During this period the Tripolye expanded their territory east of the Dniester-Bug interfluve to the Dnieper River’s west bank (Korvin-Piotrovskiy, 2012). This territorial expansion is believed to be the result of population growth, as the number of sites increases dramatically (Korvin-Piotrovskiy, 2008). The population density in the Dniester area has been reconstructed to be as high as 12 persons per square kilometer, making it one of the most densely settled regions in Europe at the time (Korvin-Piotrovskiy, 2012).

The first Tripolye groups to settle the Bug-Dnieper interfluve used pottery decorated in the typical Tripolye A Period style, with incised and pinched patterns (Kruts, 2012). At nearly the same time, however, Tripolye groups in the western part of the territory replaced these types with painted pottery (Kruts, 2012). Despite the adoption of
painted ceramics in the Prut-Dniester and Dniester-Bug interfluves, the more easterly groups in the Bug-Dnieper interfluve continued to use incised designs to the exclusion of painted ceramics (Korvin-Piotrovskiy, 2012). These different pottery styles have led researchers to refer to independent East Tripolye and West Tripolye branches beginning in the Middle Period (Korvin-Piotrovskiy, 2012; Kruts, 2012; Ryzhov, 2007).

The settlements of the East and West Tripolye differ in their placement within ecological zones. Whereas Western Tripolye settlements were located near the southern border of the forest-steppe zone, East Tripolye settlements were located further to the north, perhaps to leave an empty barrier between themselves and nomadic pastoralists further south (Kruts, 2008; 2012).

The Eastern Tripolye are also distinguished from the Western Tripolye by the size of their settlements. Even early on in the Middle Period, Eastern sites such as Veselyi Kut were as large as 150 hectares, much larger than western sites which were typically smaller than 50 hectares (Kruts, 2012). Like the empty forest-steppe barrier, these large settlements may have served a defensive purpose (Kruts, 2012).

Throughout the Middle Period the population in the Dniester area of Western Tripolye is believed to have increased to the point that overpopulation may have caused groups to leave in search of new territory (Kruts, 2012). These groups of Western Tripolye eventually settled in the previously empty buffer zone in the southern forest-steppe of the Bug-Dnieper interfluve (Kruts, 2012). The arrival of the Western Tripolye in the Bug-Dnieper interfluve is recognized archaeologically by the appearance of painted pottery at these new settlements (Ryzhov, 2012). Like their Eastern Tripolye
neighbors to the north, the intrusive groups of Western Tripolye built very large settlements. However, these settlements were even larger than those previously established, reaching up to 450 hectares (Kruts, 2008). These massive settlements were the largest in Europe at the time, and have been referred to as “giant-settlements” and Europe’s “proto-cities” (Kruts, 2012).

The giant-settlements were discovered by Soviet Union military topographers in the late 1960s and 1970s. Aerial photographs of Ukraine revealed large circular areas of abnormal coloration that drew the attention of local authorities. Ground surveys and excavations revealed these to be Tripolye settlements. The largest of the giant-settlements is Talyani (450 hectares), which belongs to the Tomashovskaya site-type along with the sites of Dobrovody (250 hectares), Maidanetske (270 hectares), Shushkovka (250 hectares) and Chicherkozovka (300 hectares) (Kruts, 2012). None of these sites were occupied at the same time, and they may represent the consecutive resettlements by a single group (Kruts, 2012). Giant-settlements were likely occupied for around 50 years because sites of such size may have quickly exhausted the local natural resources or contaminated the surrounding environment with human waste (Kruts, 2008). Kruts (2012) suggests that the giant-settlements of the Tomashovskaya type-sites followed a Shushkovka-Dobrovody-Talyani-Maidanetske-Tomashova chronology of successive settlement.

The giant-settlements were all organized in a similar fashion, with houses arranged in one or more circles enclosing an empty center. At Talyani, two concentric rows of houses surround the central open area. The inner rows of houses have doors facing away from the site center, while the outer row of houses have doors facing toward
the site center, creating a street (Kruts, 2012). At Maidanetske, two streets encircle the site, with a total of four concentric rows of houses (Kruts, 2012). In addition to the large circular streets surrounding the giant-settlements, some sites have streets radiating out of the open central area. These streets can be seen on the site maps of Talyanki and Dobrovoy (Kruts, 2012).

Population estimates for the giant-settlements are based on surveys using ground penetrating radar and limited excavations (Kruts, 2008). To date, all excavated structures have been residential, suggesting the giant-settlements are composed entirely of domiciles or structures associated with domestic activities (Zbenovich, 1996). Based on this research, the site of Talyanki is believed to have 2,700 residential structures and a population estimated between 14,000 and 25,000 people (Korvin-Piotrovskiy, 2012; Krutz, 2012). However, despite their size, the giant-settlements are not considered urban centers due to the lack of evidence for craft specialization, social stratification, or monumental architecture (Kruts et al., 2001).

The high population densities of the giant-settlements and the intensive nature of the Tripolye agricultural economy resulted in significant environmental degradation. Deforestation was extensive, and had reduced tree cover by over 40% (Kruts, 2012). Life in the giant-settlements would have made subsistence activity difficult, forcing the residents to travel greater distances to farm and collect timber. These hardships indicate that giant-settlements were created for a non-economic purpose. Giant settlements were most likely constructed for defense, either from outside groups such as the Sredne Stog (Kruts, 2012), or from other Tripolye populations (Videyko, 1998). Besides providing strength in numbers, the conformation of the outer ring of houses in each giant-
settlement, which were likely built wall-to-wall, created an impenetrable barrier of protection.

Settlement size in the Prut-Dniester and Dniester-Bug interfluves also increased during the Middle Period. However, sites only reached 20-40 hectares, and contained up to 200 residential structures, far smaller than the giant-settlements to the east (Zbenovich, 1996). Nevertheless, these settlements were still large compared to other contemporary European populations.

Both semi-sunken pit-houses and wattle-and-daub ground-houses are found during the Middle Period. The first reconstruction of Tripolye ground-houses was suggested by Passek (1940; 1938) based on her study of houses at Kolomyishchina I, a Tripolye CI settlement. According to Passek, the \textit{ploshchadka} was the floor of the structure, built by applying clay to a structure of wooden planks which was then baked with fire. More clay structures were placed on the \textit{ploshchadka}, including an elevated shelf for storing objects, an oven, benches, and an altar. These internal structures were also baked. The walls of the house were constructed with wattle-and-daub, and the roof was gabled straw thatch.

Passek’s reconstruction of the Tripolye house was universally accepted until the 1960s when it was suggested that the structures were two-story (Markevich, 1964). This suggestion has given rise to three models promoting the existence of two-story houses at Tripolye sites. All three of these models differ from Passek’s original reconstruction by claiming that the baked nature of the clay \textit{ploshchadka} resulted from ritual destruction of
the house by fire prior to the abandonment of settlements (Korvin-Piotrovskiy et al., 2012).

The first model of two-story houses at Tripolye sites claims that the ground floor contained the oven and benches and was surrounded by walls of wattle-and-daub (Markevich, 1964). A deck made of wooden planks covered by clay formed the roof of the ground floor and the floor of the second story. The ritual burning of the house would have resulted in the thorough baking of the platform which would have collapsed and formed the *ploshchadka* recognized archaeologically. According to this model’s proponents, this better explains the complete baking of the *ploshchadka* than does Passek’s reconstruction, in which fire was only applied to the top of the clay deck (Korvin-Piotrovskiy et al., 2012).

The second model proposes that the ground floor served as a workspace, and that only grinding stones, storage pits, and weaving looms were located there (Korvin-Piotrovskiy et al., 2012). The walls of the ground floor were either built of wattle-and-daub or mudbricks and supported the platform deck of the first floor (Korvin-Piotrovskiy et al., 2012). On the deck of the second floor, the ovens, altars, shelves, and benches were placed, making the second floor the primary area of habitation (Chernovol, 2012). The walls of the second floor were constructed with wattle-and-daub and a second deck was built to separate the second-story from the thatched roof above.

The third model is very similar to the second, with the only difference being that the walls of the ground-floor were built with cross-laid timber in the manner of a log cabin (Kruts, 2003). According to proponents of this model, only log walls could support
the wood and clay deck of the first floor, which weighed between 15-75 tons (Korvin-Piotrovskiy et al., 2012). Wattle-and-daub walls would buckle under the weight of the deck. Additionally, it appears that animals were stabled in the first floor of Tripolye houses (Korvin-Piotrovskiy et al., 2012). If this was the case, pigs would easily destroy wattle-and-daub walls, making the log construction necessary (Korvin-Piotrovskiy et al., 2012).

Arguments have been advanced both in support of the single-story and two-story models. Proponents of the two-story models point out that the ploshchadka is thoroughly baked on both the top and bottom sides, something that would only occur if it served as the second floor deck and was exposed to fire on all surfaces during the destruction of the house. Furthermore, the destructive use of fire is supported by traces of burning on the pottery, stone, and bone recovered from house remains (Korvin-Piotrovskiy et al., 2012). The finding of artifacts under the platform is also cited as evidence that the wood and clay structure served as the floor of the second-story, which then collapsed following the burning of the house (Korvin-Piotrovskiy et al, 2012).

Proponents of the single story model addressed these theories, arguing that the platform was baked during the construction process in order to waterproof the floor by suspending it on blocks and baking it from all sides (Korvin-Piotrovskiy et al., 2012). Although traces of fire are found on artifacts, it only occurs on about 15 percent of objects, calling into question the destructive role of fire (Korvin-Piotrovskiy et al., 2012). Additionally, supporters of the single-story model argue that the presence of artifacts under the ploshchadka does not mean it had to have served as the deck of the first floor,
but could have resulted from the construction of a house on an area of prior occupation (Korvin-Piotrovskiy et al., 2012).

Scholars have used miniature ceramic models of Tripolye houses recovered from sites to evaluate these competing views. Although some show the interior of the house while others only show the exterior (Cuik, 2008), each portray houses as single story structures, although many are propped up on posts (Korvin-Piotrovskiy et al., 2012).

Experimental archaeological studies have also been carried out to assess Kruts’ (2003) suggested log cabin-style two story house. Korvin Piotrovskiy et al. (2012) describe a full-scale house that was built in 2003, and following Kruts’ model, the walls of the ground floor were built with cross-laid logs. The structure measured 7m by 4m. Ten beams were used to construct each wall, and the ground floor was about 2m high. Gaps between the logs were filled with clay. Wooden beams covered in clay were used for the second floor deck. Wattle-and-daub walls were built along the edge of the second story. The size of all of the wood used in the construction was based on the imprints of poles and beams examined in archaeological house remains. Based on the study of houses excavated at Tomashovskya-type-sites, the second floor was divided into two sections using a wattle-and-daub partition. The first section was a porch and the second section was the living room. The living room contained a podium made of clay along the wall to the left of the entrance. This podium is believed to have been used for storing pottery and tools. Along the living room wall to the right of the entrance a domed oven was built of wattle-and-daub. Against the short wall opposite the entrance a raised area was constructed of clay. This raised platform has been referred to as the “altar.” An open circular window was also constructed above the altar in the style of ceramics house
models that display this feature. A second deck was also built to separate the second-story from the roof, which was gabled and covered with reeds.

Following its construction, the full-sized reconstruction was set on fire to simulate the theoretical ritual destruction of the building. Following the fire, the remains were left alone for two years, at which point the area was excavated. The results demonstrated that setting fire to the house reconstructed according to Kruts’ model, resulted in ploshchadka-like remains, matching what has been observed archaeologically at Tripolye sites. Interestingly, out of the tools and pottery left in the house during the fire, only three displayed traces of burning, lending further support to the notion that fire was used in the destruction of Tripolye houses. Based on this experimental work, it appears that Kruts’ model is the most plausible reconstruction of Tripolye domestic architecture.

The tools used by the Tripolye during the Middle-Period are similar to those of the preceding Tripolye A Period (Korvin-Piotrovskiy, 2012). However, the number of copper artifacts increases, and includes axes, adzes, jewelry, and hammers (Korvin-Piotrovskiy, 2012).

During the Middle Period, the ceramic figurines manufactured by the Tripolye become less stylized and more realistic, and begin to include detailed hairstyles and facial features (Korvin-Piotrovskiy, 2012). Most figurines are anthropomorphic and are predominantly of females, although more zoomorphic figurines were made during this time period, especially those representing bulls (Korvin-Piotrovskiy, 2012).

The economy of the Middle Period is similar to that of the Early Period (Korivn-Piotrovskiy, 2012; Zbenovich, 1996). Subsistence farming focused on the same crops,
and animal husbandry continued, although less emphasis may have been placed on hunting, as wild animals make up relatively smaller proportions of faunal assemblages (Zbenovich, 1996).

**Late Tripolye Period (Tripolye CI-CII)**

The Late Period of the Tripolye culture begins during the last quarter of the fourth millennium calBC and ends at the beginning of the third millennium calBC (Korvin-Piotrovskiy, 2012). The Late Period (especially the CII phase) is associated with the decline of the Tripolye. The favorable climatic conditions of the Holocene Climatic Optimum come to an end, and a new period of cooler temperatures and less precipitation begins, with potentially negative effects on agricultural activity (Korvin-Piotrovskiy, 2012). The cooler, drier climate allowed the steppe ecological zone to shift farther to the north, changing the environment of many Tripolye groups. As a result of climate change, the economy of more southerly located Tripolye groups, especially those of the Usatovo-type sites, become adapted to the conditions of the steppe, with an increased focus on animal husbandry (Petrenko, 2008). Settlements in other areas during this period decrease in size, and either relocate to more naturally defensible locations or construct ditches and ramparts for protection (Korvin-Piotrovskiy, 2012; Zbenovich, 1996). These developments suggest that the threat of conflict was a reality for Tripolye populations in the Late Period. This threat is likely related to an increase in copper weaponry during this time (Korvin-Piotrovskiy, 2012).

The Late Period also marked a shift in home construction from wattle-and-daub ground-houses to semi-sunken pit-houses. There was continuity between the Middle and
Late Periods in the tools used, although the amount of copper artifacts again increases (Korvin-Piotrovskiy, 2012). Pottery also remains similar to the Middle Period, however, the quality of the wares is said to decline. Another notable characteristic of the Late Period is that, for the first time, cemeteries associated with the Tripolye are found. The next section describes these burial grounds.

*Tripolye Burials*

There are no known cemeteries dating to Tripolye Periods A or B (Korvin-Piotrovskiy, 2008; Zbenovich, 1996). The human remains that have been attributed to the Tripolye from these periods were individuals buried under house floors (Debets, 1983; Gerasimov, 1960; Hokhman, 1958). These isolated burials are few in number and poorly preserved (Kruts, 2008). The lack of burials from the majority of the Tripolye culture’s existence has limited the study of their biology and burial customs.

Kruts (1989) has suggested that the Early and Middle Period Tripolye must have disposed of their dead in an archaeologically invisible manner, such as scattering cremated remains in fields surrounding settlements. More recently he suggested that cremated remains were placed into the “sacred river” (Kruts, 2012), which would also be archaeologically undetectable. Zbenovich (1996), however, points out that other Neolithic-era early farming cultures in southeastern Europe had diverse burial practices, including the use of cemeteries within, near, and far from their settlements. It remains possible that Tripolye A and B Period cemeteries were located far from settlements and have not been discovered.
Unlike Periods A and B, Tripolye cemeteries have been found dating to the Late Period, most of which date to the final Late Period (CII) (Nikitin et al., 2010). These are primarily concentrated along the shores of the Black Sea and Dnieper River and (Zbenovich, 1996).

Large burial grounds from the steppe area along the northwest shore of the Black Sea have been associated with Usatovo type-sites, a variant of the Tripolye heavily influenced by steppe-dwelling cultures. It was from these cultures that the Usatovo adopted the construction of large kurgan burial mounds containing several burial pits (Petrenko, 2008). In kurgan mounds, the dead were typically interred in a flexed position on their left sides with their heads oriented to the east or northeast (Zbenovich, 1996). At the Usatovo-type sites of Usatovo and Mayaki, large kurgans were found in addition to non-mound cemeteries (Petrenko, 2008; Zbenovich, 1996). Grave goods at these cemeteries included pottery and copper objects, such as axes (Petrenko, 2008). It is important to note that the Usatovo-type sites were quite different from those of other Tripolye groups, as the Usatovo were adapted to life on the steppe, focused on pastoralism, and built large monumental structures (Petrenko, 2008).

A second type of burial custom practiced during the Tripolye CII Period was cremation. Cemeteries exclusively containing cremated remains have been found at the Sofievsko-type sites of Sofievsko, Chernova, Kensd Kar, Zavadd, along the Dnieper River in the area of Kiev (Zbenovich, 1996). Artifacts including ceramics, lithics, and copper items accompany these burials (Kruts, 1977; Zbenovich, 1996).
In the same area near Kiev, a cemetery associated with the village of Chapaevka dates to the CI Period. Excavations here uncovered 31 burials, all extended and in a supine position. These burials are associated with a variety of grave goods including ceramics and lithics (Kruts, 1977; Zbenovich, 1996).

A number of burial grounds from the CII Period have also been found in the Dniester region, including the cemetery at Vykhvitinski, the burials at Bilshivtsy, and the remains from Verteba Cave (Bilche Zolote).

Vykhvitinski is a large cemetery with over 70 excavated burials (Dergachev, 1978). Individuals here were buried on their left sides in a flexed position with their crania oriented northeast. The majority of the burials are subadults, many of which are accompanied by ceramic figurines (Dergachev, 1978). Ceramic grave goods are common and pottery is found with nearly every individual (Zbenovich, 1996). It is interesting to note that hoes are found exclusively in the burials of males (Dergachev, 1978), and may reflect a sexual division of labor. Many of the burials were also surrounded by, and covered with stone (Dergachev, 1978).

The Tripolye settlement site of Bilshivtsy was home to a burial treatment not observed at any other sites (Kruts, 2011). Near a house wall, the crania of one male and two females were placed in a cluster overlaying the burial of a small dog (Tkachuk, 2001). The male individual had evidence of trauma, including a healed depression fracture on the left parietal and a fractured mastoid process. The healed depression fracture of the parietal displayed reactive bone suggestive of inflammation and infection.
(Kruts, 2011). The same burial also contained the completely articulated body of a fourth individual, also likely female (Kruts, 2011; Tkachuck, 2001).

Late Period burials provide valuable information concerning Tripolye treatment of the dead. Burial treatments varied by site and included interment in single extended primary graves, in single flexed primary graves, in secondary burials, in urns following cremation, in kurgans, and under house floors. The small number of cemeteries excavated to date limits our understanding of the circumstances that may have led to differential burial treatment. An effort to actively search for Tripolye cemeteries needs to be undertaken.

The skeletal remains of cemeteries have the potential to provide information concerning the biology and health status of the Tripolye. For example, by examining Tripolye osteological material for markers of systemic stress, bioarchaeologists can determine the ways in which certain aspects of their culture, economy, and environment influenced their health and wellbeing. To date, Tripolye skeletal material have not been utilized for this purpose, as research priorities have focused on craniometrics, ethnogenesis, and the racial composition of the population (Kruts, 2008). Curation practices reflect these priorities in both the field and museums, where crania have been preserved and postcranial elements have been discarded (Jacobs, 1993).

The next section of this chapter discusses the Tripolye mortuary site of Verteba Cave, at which the skeletal material forming the focus of this study was recovered. Recent excavations at Verteba Cave have been carried out with the specific intention of
improving our understanding of how the Tripolye’s unique cultural adaptation affected health in prehistoric Ukraine.

Verteba Cave

Verteba Cave is located about 1.5 kilometers from the town of Bilche Zolote, in Ternopil Oblast, Ukraine (Figure 3.1).

Figure 3.1- Location of Verteba Cave.
The main entrance to the cave is located in a depression in a large agricultural field on the first terrace above the Seret River (Figure 3.2). Verteba is a gypsum cave consisting of a labyrinth of tunnels with a combined length of 8,555 m (Nikitin et al., 2010). Out of the many caves in the region, Verteba is the only one found to have been utilized in prehistory (Sokhatsky, personal communication).

A series of excavations have taken place at Verteba over the previous two centuries. The first excavations occurred in 1876 and were carried out by a Polish team that removed a number of human remains and associated material culture, including diagnostic Tripolye pottery, lithics, and ceramic figurines. The excavations by Polish archaeologists continued sporadically into the early 20th century, and the material they removed is now housed at the Museum of Archaeology in Krakow, Poland (Nikitin et al., 2010). Unfortunately, these early excavations occurred prior to the use of modern archaeological methods and detailed information is not available regarding provenience.
or association of particular items.

Excavations at Verteba since 1996 have been carried out under the direction of Mykhailo Sokhatsky of the Borschiv Regional Museum of the Ukrainian Ministry of Culture and Arts. In 2008, a collaborative project was formed between the Borschiv Regional Museum and Grand Valley State University in Michigan, with the goal of excavating and studying human remains at

Figure 3.2- Opening to Verteba Cave
Excavations were carried out by the international team during the summers of 2008 and 2012.

Over the past two centuries, a number of areas have been excavated both inside the cave and on the surface near its entrance. These areas have yielded different types of artifacts and human remains, and are associated with pottery from different time periods and type-sites. While incompletely documented, 19th-century excavations are known to have focused on the area near the cave’s main entrance. This area has been designated as Sites 1 and 2 within the cave, and is dominated by a massive boulder, weighing over two tons, which was placed on stone supports by the Tripolye (Figure 3.3). Its function is

Figure 3.3- Monolith placed by the Tripolye near the entrance to Verteba Cave.
unknown, but may relate to the ritual nature of the mortuary site. The human remains housed at the Museum of Archaeology are primarily thought to have come from Sites 1 and 2, although this is not certain.

Nikitin et al. (2010) carried out a comprehensive study to provide absolute dates for the different sites within the cave. Radiocarbon dating of human bone, charcoal, and organic inclusions within pottery originating from Sites 1 and 2 date to 3795-2936 calBC (Table 3.1). Analysis of pottery from Sites 1 and 2 has linked these deposits to the Koshylovetska-type sites of the Tripolye CII period.

Table 3.1- Radiocarbon dates from Sites 1 and 2 from Verteba Cave (Nikitin et al., 2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Code</th>
<th>Sample Material</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ki-13388</td>
<td>Human bone</td>
<td>3619-2936 calBC</td>
</tr>
<tr>
<td>2</td>
<td>Ki-13070</td>
<td>Pottery</td>
<td>3620-3021 calBC</td>
</tr>
<tr>
<td>2</td>
<td>Ki-14947</td>
<td>Human bone</td>
<td>3511-3099 calBC</td>
</tr>
<tr>
<td>2</td>
<td>Ki-13071</td>
<td>Charcoal</td>
<td>3631-3036 calBC</td>
</tr>
<tr>
<td>2</td>
<td>Ki-13069</td>
<td>Pottery</td>
<td>3703-3341 calBC</td>
</tr>
<tr>
<td>2</td>
<td>Ki-13068</td>
<td>Pottery</td>
<td>3795-3365 calBC</td>
</tr>
</tbody>
</table>

Over the field seasons of 2008 and 2012, excavations focused on an area of Verteba Cave labeled Site 7 (Figure 3.4). Site 7 was chosen for excavation following a survey of the cave revealing that this area had a high surface concentration of human remains (Figure 3.5). Radiocarbon dates on human and faunal bone, and organic inclusions in pottery date the use of this area of the cave to 3950-2573 calBC (Table 3.2). Ceramic types here, including pots
Table 3.2- Radiocarbon dates from Site 7 from Verteba Cave (from Nikitin et al., 2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Code</th>
<th>Sample Material</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Ki-16153</td>
<td>Animal bone</td>
<td>2902-2573 calBC</td>
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<tr>
<td>7</td>
<td>Ki-16152</td>
<td>Human bone</td>
<td>3006-2578 calBC</td>
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<td>7</td>
<td>Ki-15037</td>
<td>Human bone</td>
<td>3350-2920 calBC</td>
</tr>
<tr>
<td>7</td>
<td>Ki-15763</td>
<td>Animal bone</td>
<td>3380-3020 calBC</td>
</tr>
<tr>
<td>7</td>
<td>Ki-16156</td>
<td>Human bone</td>
<td>3631-3036 calBC</td>
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<tr>
<td>7</td>
<td>Ki-14682</td>
<td>Pottery</td>
<td>3655-2943 calBC</td>
</tr>
<tr>
<td>7</td>
<td>Ki-15762</td>
<td>Pottery</td>
<td>3380-3020 calBC</td>
</tr>
<tr>
<td>7</td>
<td>Ki-14307</td>
<td>Human bone</td>
<td>3634-3358 calBC</td>
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<tr>
<td>7</td>
<td>Ki-15039</td>
<td>Human bone</td>
<td>3628-3366 calBC</td>
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<td>7</td>
<td>Ki-15038</td>
<td>Human bone</td>
<td>3635-3374 calBC</td>
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<tr>
<td>7</td>
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<td>3665-3359 calBC</td>
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<td>7</td>
<td>Ki-15760</td>
<td>Pottery</td>
<td>3694-3367 calBC</td>
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<td>7</td>
<td>Ki-15758</td>
<td>Pottery</td>
<td>3710-3360 calBC</td>
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<td>7</td>
<td>Ki-15036</td>
<td>Human bone</td>
<td>3710-3490 calBC</td>
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<td>7</td>
<td>Ki-15757</td>
<td>Pottery</td>
<td>3790-3370 calBC</td>
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<tr>
<td>7</td>
<td>Ki-15761</td>
<td>Pottery</td>
<td>3800-3350 calBC</td>
</tr>
<tr>
<td>7</td>
<td>Ki-15759</td>
<td>Pottery</td>
<td>3950-3500 calBC</td>
</tr>
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</table>
Figure 3.4- Location of Site 7 within Vertebra Cave
associated with the Schypynetska and Koshlyovetska-type sites, correspond to Periods CI and CII and suggest that this portion of the cave was used over an extended period of time.

Excavations of Site 7 in 2008 divided it into Areas 1 and 2 (Figure 3.6). Area 1 is a short tunnel connecting two large halls. The tunnel has three openings to halls within the cave, one of which was blocked in antiquity with the placement of boulders. The northeastern entrance was completely blocked with sediment. Eight 1m x 1m units were excavated in the southern portion of the tunnel. Another set of four 1m x 1m units were
Figure 3.6- Schematic of Site 7 excavations by field season.

- Green: Excavated in 1997
- Light blue: Excavated in 1999
- Yellow: Excavated in 2008
- Red: Excavated in 2012
- Cave wall
excavated just outside and to the east of the south entrance. The units were excavated in arbitrary 20cm levels and were taken down to a culturally sterile level of sandy clay. The depths of the deposits varied from 40cm to 1m. The soil matrix in this area was a thick mud with small pieces of charcoal and burnt gypsum scattered throughout. Secondary human remains were found intermixed with faunal remains, stone and bone tools, ceramic figurines, and pottery in the excavation of units placed here. This area also showed evidence of rodent tunneling, which may have influenced the location of the objects. Additionally, the finding of a food wrapper and small flash bulb from a camera of the mid-20th century raises the possibility of looting. However, the wrapper and flashbulb may have originated through rodent action, and no other evidence of burial disturbance was noted.

Although human remains were found throughout the units excavated in 2008, four crania were found in a distinct cluster (Figure 3.7). The femur of an infant was found inside one of the crania and the horn of an auroch was placed next to the cluster. Outside the cluster, an additional two complete crania, and six partial crania were found, placed along the walls of the tunnel (Figure 3.8).

Excavations in Site 7 Area 1 recommenced in 2012. The initial focus was the sediment-filled northeastern part of the tunnel which had not been excavated in 2008. However, when excavation revealed that additional artifacts were located under the culturally sterile sandy clay layer, ten 1mx1m units were opened across the entirety of Area 1. These units were also excavated in arbitrary 20cm levels, and by the end of the field season had been taken down an additional two meters from what they were in 2008.
Like those excavated in 2008, the units excavated in Area 1 during 2012 also included secondary human remains intermixed with faunal material, bone (Figure 3.9) and stone tools, and ceramics. One notable artifact recovered from Unit 1D was a large, complete, ornately painted ceramic vessel dating to the CII Period (Figure 3.10). This vessel contained fragments of two smaller vessels as well as human ribs. Unit 2A also contained another complete vessel which had been placed upside down (Figure 3.11). Unit 2A also included a cluster of five complete crania, and an additional four crania were recovered from along the cave wall.

Site 7 Area 2 is a large open hall east of Area 1. When Area 2 was initially examined in 2008, the entire hall was filled with black muddy sediment from the floor of the cave to the ceiling. Area 2 was selected for excavation after the concentration of
human skeletal elements in the deposit, particularly an adult femora protruding from the sediment, was noted. Excavation of Area 2 began in 2012. Eight 1m x 1m units were excavated to the level of the cave’s modern walking path, a depth of about 2 meters. These units were also excavated in arbitrary 20cm
Figure 3.8- Excavation finds from Area 1 of Site 7.
Figure 3.9- Antler hammers and tooth ornaments from Area 1 of Site 7.
Figure 3.10- Illustration of complete ceramic vessel excavated from Area 1 of Site 7.
levels. The sediment was muddy clay, and charcoal was found throughout the deposit.

Mollusk shells from the Black Sea were also common in the units, and were anthropogenic in origin. Rodent tunnels were also noted throughout these units, suggesting that bioturbation may have affected these deposits as well.

Two high concentrations of bone in Area 2 were designated as features. These were located in Unit 7C and in Units 6D/7D and contained secondary human remains intermixed with faunal bones, stone and bone tools, and ceramics. The bone concentration in Unit 7C was situated between two layers of CII Period ceramics, one atop and one beneath. In addition to a smashed cranium, articulated material was also

Figure 3.11- Illustration of complete ceramic pot found overturned in Area 1 of Site 7.
found, including two arms, one hand, a foot, and a leg. A ceramic sheep figurine (Figure 3.12), a stone axe head, a ceramic female figurine (Figure 3.13), four flint sickles (Figure 3.14), two flint scrapers, and faunal vertebrae were associated with the skeletal remains.
The feature in Units 6D/7D also included an articulated forearm and vertebral column, as well as a cranium and scattered postcranial elements. Together with the
material from Unit 7C, these are the only articulated human bones excavated at the cave. The skeletal material in Units 6D/7D were intermixed with various faunal postcranial elements, an unfinished piece of ground stone, pottery fragments, and a dense concentration of charcoal.

Human bones, faunal remains, and a variety of other artifacts were recovered elsewhere in Area 2 (Figures 3.15, 3.16, 3.17). These human bones were intermixed with the other objects, including bone awls (Figure 3.18), ceramic spindle whorls and counting pieces (Figure 3.19), an unused mortar, a stone axe head, anthropomorphic figurines (Figure 3.20), and a ceramic house model. Large white boulders were positioned in an upright manner blocking the space between Areas 1 and 2, perhaps to cordon off the burial features in Area 2. These stones were not part of the cave’s rock formation and must have been brought into the cave in antiquity.

Excavation of four 1m x 1m units also took place at Site 15 during 2012 (Figure 3.21). Two of the units were only partially excavated due to a bend in the cave wall (Figure 3.22). Like at Site 7, charcoal was found throughout these units. The soil at this site was dark tan, dry, and sandy. Three human bones were recovered, including a postcranial subadult bone and two postcranial adult bones. Pottery fragments were found throughout the site. A hearth was additionally noted in the northeast unit. No radiocarbon dates have been performed on material from this site, and the pottery recovered is not diagnostic of a particular period.

The final area excavated during 2012 was Site 16 (Figure 3.21) at which ten 1m x 1m units were excavated (Figure 3.23). Secondary human burials were found intermixed
with faunal bone and other artifacts associated with a thin layer of red clay at a depth of between 30-50cm.

Figure 3.15- Finds from layer one of Area 2 of Site 7.
Figure 3.16- Finds from layer two of Area 2 of Site 7.
Figure 3.17- Finds from layer three of Area 2 of Site 7.
Figure 3.18 - Bone awls from Site 7.
Figure 3.19- Ceramic spindle whorls and counting pieces from Site 7.
Figure 3.20- Anthropomorphic figurines from Site 7.
Figure 3.21 - Location of Sites 7, 15, and 16.
Figure 3.22 - Finds from Site 15.
The human remains included metacarpals and ribs, while other artifacts included a ceramic bull figurine, a ceramic counting piece, and numerous pottery fragments. No radiocarbon dates have been performed on material from Site 16, but analysis of the pottery indicates that it dates to the CII Period.

The excavations at Verteba Cave have resulted in its being one of the largest collections of Tripolye skeletal material. As such, it is especially valuable for studying the health status of the Tripolye. The next chapter will describe the sample of human remains from Verteba and the methods used to assess the health of this group.
Chapter 4: Materials and Methods

Introduction

In this chapter I present the materials and methods used to test my hypothesis that the adoption of agriculture was detrimental to human health. To assess the health of early Eastern European farmers, the skeletal material excavated from Verteba Cave is examined following the general stress perspective and utilizing a suite of skeletal indicators, including enamel hypoplasias, porotic hyperostosis, cribra orbitalia, periostitis, stature, dental caries, and periodontal disease. The first section of this chapter describes the skeletal sample from Verteba Cave, including the types of osteological elements present and the sample’s demographic characteristics. The second section reviews the bioarchaeological methods employed to assess the health of the Tripolye agriculturalists. Finally, the third section is devoted to explaining the statistical procedures used to test my hypothesis.

Materials

As noted in Chapter 3, the Verteba Cave skeletal materials were recovered during two phases of excavation, the first of which was carried out in the late 19th and early 20th centuries by Polish archaeologists. These excavations were performed without the use of modern archaeological techniques, and provenience of artifacts within the cave was not recorded. Unfortunately, no postcranial material was saved, and only crania, mandibles, and teeth were kept and stored at the Krakow Museum of Archaeology in Poland. The skeletal collection housed in Krakow includes six subadult crania, three partial adult crania, ten mostly complete adult crania, three complete mandibles, and 21 loose teeth,
representing a minimum of 19 individuals. In addition to the 21 loose teeth, an additional 89 teeth are present in mandibles and maxillae, for a combined total of 110 teeth in the Krakow dental sample.

Before examining these skeletal remains for indicators of systemic stress, I analyzed the sample in terms of sex and age at death. The most accurate methods for estimating these characteristics in adult human skeletal remains involve the assessment of morphological features of the pelvis (Brooks and Suchey, 1990; Phenice, 1969). Since no postcranial elements were retained, however, my estimation of demographic characteristics relied on cranial analysis, a method, which unfortunately, tends to be more error prone (Boldsen et al., 2002).

Sex was not estimated for subadult individuals, as no methods with sufficient accuracy are available. In order to determine sex of the adult material, I used the scoring system outlined by Buikstra and Ubelaker (1994). This system uses five morphological features, including size and rugosity of the nuchal crest, size of the mastoid process, sharpness of the supraorbital margin, prominence of the supraorbital torus and glabellar region, and prominence of the mental eminence. In general, males tend to have larger muscle attachments (mastoid process, nuchal crest), larger, more blunt supraorbital margins, and larger, more prominent supraorbital tori/glabella and mental eminences than do females. I compared the crania from the Krakow collection to images depicting the variability of each trait in terms of gracility and robusticity (Buikstra and Ubelaker, 1994) and independently gave each trait an ordinal score between 1 and 5, where 1 is the most gracile and 5 is the most robust. I then evaluated the total score of each skull to determine its sex according to the following scale developed by Buikstra and Ubelaker (1994: p.20):
(1) Female
(2) Probable female
(3) Ambiguous sex
(4) Probable male
(5) Male

Walker (2008) tested the accuracy and replicability of the cranial sex estimation method developed by Buikstra and Ubelaker (1994) on a skeletal sample in which sex was known. He found that the five scores of individual traits produce correct sex estimation between 69% and 83% of the time. Specifically, scores from the glabella/supraorbital torus region resulted in a correct sex determination 82.6% of the time, the mastoid process in 78.6%, the mental eminence in 76.6%, the nuchal crest in 71.4%, and the orbital margin in 68.8% of cases. In addition to his test of accuracy, Walker (2008) also examined the intra- and interobserver error associated with this method, and found that both were negligible, making the technique highly replicable. In fact, Walker (2008) found that with the aid of the graphic examples published in Buikstra and Ubelaker (1994), individuals with no prior osteological experience often arrived at the same scores as professional bioarchaeologists.

Walker (2008) improved this method with the development of a predictive equation based on the gracility/robusticity scores. Using a skeletal sample of known sex and age, Walker (2008) developed a discriminant function combining the three most accurate morphological traits. Using the “leave one out” test, Walker (2008) found his discriminant function to correctly classify sex 88.4% of the time. Specifically, the discriminant function is:
Y = (-1.375 glabella score/supraorbital torus score) + (-1.185 mastoid process score) + 
(-1.151 mental eminence score) + 9.128

in which the value of Y is the discriminant function score and 0 is the cutoff point
between males and females. Individuals with scores higher than 0 are likely female and
individuals with scores less than 0 are likely male. This multivariate method significantly
improves the accuracy of sex estimation using morphological characteristics. Walker
(2008) cautions, however, that this discriminant function was developed using a specific
population, and its applicability to other archaeological samples may be inappropriate, as
different populations often display sexual dimorphism in distinct ways, with different
baselines for each trait. Therefore, when the model is applied to any population that
differs from Walker’s (2008) sample in its expression of sexual dimorphism, the
discriminant function may misclassify the sex of some individuals. However, Walker did
apply the discriminant function to prehistoric California Native American skulls of
unknown sex that had associated pelves. He found the discriminant function to result in
the same sex assessment as pelvic methods in 78% of these cases, suggesting the method
is widely applicable. Unfortunately, no associated crania and mandibles were present in
the Krakow collection, preventing the use of this discriminant function here, however, I
did use it to sex some of the more recently excavated skulls described below.

Ubelaker (1989) developed a comprehensive sequence of human dental formation
and eruption which can be used to accurately estimate the age-at-death for subadults.
Because human tooth development and eruption follow a strict schedule under strong
genetic control, age can be assessed with associated error ranges typically fewer than two
years (Ubelaker, 1989). This is the method I used to obtain age estimates for the
subadults that possessed dental elements. For the subadult cranial material lacking dental elements, I estimated age using cranial size and development (Bass, 1995). This is generally accurate for infants and young children, but error increases in the assessment of older subadults (Bass, 1995). Because age-at-death estimates for subadults are highly accurate, I subdivided these individuals into three age categories: infant/young child (0-5 years), child (6-10 years), and adolescent (11-18 years).

Unlike subadults, the estimation of age-at-death for adults is a more error prone process that relies on the observation of degenerative processes which operate at variable rates in different individuals and rarely follow uniform patterns. The most accurate methods require analysis of postcranial elements, such as pelves (Boldsen et al., 2002; Brooks and Suchey, 1990), which are not present in the Krakow collection. Therefore, I employed methods of age estimation using aspects of the cranium, mandible, and teeth. I derived age estimates for the adult cranial elements by assessing dental wear using Lovejoy’s (1985) seriation method. After seriating the dentitions in order of increasing attrition, I grouped individuals into similar phases of wear based on average wear scores for each tooth following the method of Smith (1984) for the incisors, canines, and premolars, and Scott (1979) for the molars. Both of these scoring methods give progressively higher scores as the enamel wears away to reveal wear facets and dentin exposure. Functional rates of dental wear were calculated using subadult dentitions, where age was established using dental development. By examining subadult dentitions in this manner, the time necessary for facet formation, dentin exposure, and enamel obliteration could be determined for each type of tooth. The wear rates could then be applied to the seriated adult dentitions to calculate age-at-death. Lovejoy (1985) found
the age assignments of this method to strongly correlate with age estimates derived from other methods, including those based on morphological changes to the pubic symphysis and auricular surface. However, due to the substantial error ranges associated with age estimations based on dental wear (Boldsen et al., 2002), I classified the adults in one of only two age categories: young adult (18-40 years), and old adult (40+ years).

For the Krakow crania lacking dentition, I utilized an age estimation technique involving analysis of cranial suture closure. However, as Buikstra and Ubelaker (1994) point out, although cranial sutures tend to fuse with increasing age, there is high interindividual variability in closure rates and times. For example, closure of the sphenofrontal and sphenotemporal sutures can occur at any time between 28-51 years of age. For this reason, age estimates based on cranial suture closure must be treated with caution.

I used the cranial suture closure method created by Meidl and Lovejoy (1985), which examines the degree of closure for ten ectocranial sutures, four palatine sutures, and three endocranial sutures. Ectocranial and palatine sutures are scored for closure at the points of midlambdoid, lambda, obelion, anterior sagittal, bregma, midcoronal, pterion, sphenofrontal, inferior sphenotemporal, superior sphenotemporal, incisive suture, anterior medial palatine suture, posterior medial palatine suture, and the transverse palatine suture. Endocranial suture closure was observed using a light source and looking through the foramen magnum along the sagittal suture, the left lambdoidal suture, and the left coronal suture. At each of the above mentioned sutures, a 1 cm length of suture is examined and scored based on the following four point scale (Buikstra and Ubelaker, 1994: p.32):
(0) Open- there is no evidence of any suture closure at this site

(1) Minimal closure- some closure has occurred. Score is assigned to any minimal to moderate closure i.e. for a single bony bridge across the suture, to about 50% closure.

(2) Significant closure- marked degree of closure but some point of the suture is still not completely fused.

(3) Complete obliteration- the site is completely fused.

I used photographic examples (Buikstra and Ubelaker, 1994) as a reference to aid in assigning these scores.

Following Meindl and Lovejoy (1985), I determined chronological age by calculating separate composite scores for locations characterized as “vault sites” and “lateral-anterior sites”. A composite score for the vault sites is determined by summing the scores from midlambdoidal, lambda, obelion, anterior sagittal, bregma, midcoronal, and pterion sites. Because all sites can receive a score between 0 and 3, the vault composite scores range between 0 and 21. The composite vault scores were then compared to a chart displaying the age range associated with each score based on observations of crania from individuals of known age-at-death (Buikstra and Ubelaker, 1994). Likewise, a composite score for the lateral-anterior sites was calculated by summing the scores for pterion midcoronal, sphenofrontal, inferior sphenotemporal, and superior sphenotemporal. The lateral-anterior composite scores range between 0 and 15, and were compared to a chart displaying the possible age ranges associated with each score (Buikstra and Ubelaker, 1994). Because Meindl and Lovejoy (1985) suggest that lateral-anterior composite scores are more accurate than vault composite scores based on
a test of the method on a skeletal collection of known age-at-death, I preferentially used them to estimate age-at-death.

Preservation issues arose in the application of the ectocranial suture closure method to the Verteba Cave skeletal material. In some cases, a segment of suture was missing and no composite score could be calculated. In these instances, I used scores from the palatine and endocranial sutures, when available, as Buikstra and Ubelaker (1994) suggest. Age can be assigned by assessing the closure at each of the available palatine and endocranial sutures. For instance by early adulthood (20-34 years), the incisive suture has closed, with likely partial closure of the transverse palatine and posterior median palatine segments, while full closure of all of the incisive, transverse palatine, and posterior median palatine segments, with an open median palatine suture is characteristic of middle adulthood (35-49 years) (Mann et al., 1987). Complete fusion of all palatine sutures is indicative of an older adult (>50 years) (Mann et al., 1987). Likewise, the beginnings of endocranial suture closure are common in young adults, partial closure is a trait of middle adulthood, and full closure is characteristic of old crania (Krogman and Iscan, 1986).

I classified all six subadult crania as infant/young child. This is not surprising as infant mortality was high in prehistoric populations. Adult crania are equally distributed between the sexes, with five male and five female. Two of the mandibles were classified as male and one as female, while the single partial cranium was estimated to be female. Of the five male crania, three were classified as young adults and two as old adults, while four female crania were classified as young adults and one was classified as an old adult. The two male mandibles were estimated to be young adults, and the single female
mandible was aged as an old adult. An attempt was made to fit the mandibles with the crania, however no matches were found.

I will now describe the elements of the Krakow collection which were preserved to an extent enabling their examination for skeletal markers of health. Details of the examination methods used will follow in the next section. A total of 110 teeth (21 loose and 89 associated with a mandible or maxilla) representing a minimum of 16 individuals, were used to evaluate dental pathology. Ten complete adult cranial vaults, one partial adult cranial vault, two adult parietal fragments, and six subadult cranial vaults were examined for evidence of porotic hyperostosis. Four subadult crania (both right and left orbital roofs) were assessed for cribra orbitalia, and nine (five females and four males) adults had at least one orbital roof available for analysis (9 left, 8 right). Because the Krakow collection contained no postcranial remains, no materials were available with which to examine stature or periostitis in this sample.

In addition to the skeletal materials excavated by the Polish archaeologists and stored in Krakow, skeletal material was also recovered from Verteba Cave during two field seasons in 2008 and 2012. The material is housed on site by the Borschiv Regional Museum, Ukrainian Ministry of Culture and Arts. Unlike the Krakow sample, the more recently excavated skeletal material includes postcranial as well as cranial elements, including two complete skulls, 11 nearly complete crania, four complete mandibles, 11 adult cranial fragments, two adult maxillary fragments, and six subadult partial crania, representing a minimum of 36 individuals. Every type of postcranial element is represented in the sample, for a total of 1,094 bones.
Although postcranial materials were present, due to the secondary nature of the burials, they were not associated with any of the cranial elements, and were therefore not useful in determining demographic information for any of the crania, mandibles, or teeth. As a result, I applied the same age and sex estimation techniques discussed above (in reference to the Krakow collection) to the Borschiv collection, with the addition of Walker’s (2008) discriminant function for assessing sex in skulls. The Borschiv skeletal material is evenly distributed between the sexes, the majority of which were classified as young adults.

The bioarchaeological analysis of material from Verteba Cave focuses primarily on stress markers of the crania, mandibles, and teeth, such as enamel hypoplasias, dental caries, periodontal disease, porotic hyperostosis, and cribra orbitalia. To evaluate these stress markers, I used the following skeletal materials from the Borschiv collection: 121 teeth (13 of which were not associated with a mandible or maxilla) belonging to a minimum of 19 individuals to assess dental health; 20 adult and 2 subadult cranial vaults to assess porotic hyperostosis; 25 adult orbital roofs (12 left, 13 right) and 6 subadult orbital roofs (3 left, 3 right) to assess cribra orbitalia. I additionally used the following postcranial material: 7 femora (4 left, 3 right), 6 tibiae (1 left, 5 right), 12 humeri (6 left, 6 right), 17 radii (8 left 9 right), and 16 ulnae (8 left, 6 right) to assess stature. Because stature is expressed in a sexually dimorphic manner, I used the methods outlined by Bass (1995) to estimate sex for each femur, tibia and humerus. Unfortunately, no accurate methods exist for estimating sex using individual radii, or ulnae, and therefore I was not able to assess sex for these elements.
I additionally assessed all postcranial material for age at death and evidence of periostitis. Bone fusion can be used to determine age at death in these elements. In long bones, the epiphyses fuse with the diaphysis, while in flat and irregular bones the primary centers of ossification fuse together by the end of growth and development. Unfused elements are therefore indicative of subadult status. To arrive at a more specific age estimate for subadult bones, I used the method for scoring fusion using a three point scale (Buikstra and Ubelaker, 1994: p.41):

(0) Open- epiphyses and diaphysis or primary centers of ossification are completely separate. There is no bony union.

(1) Partial union- some union has occurred.

(2) Complete union- all visible aspects are fused.

I then compared the scores of individual subadult osteological elements to formation schedules developed by different researchers (Krogman and Iscan, 1986; McKern and Stewart, 1952; Redfield, 1970; Suchey et al., 1984; Ubelaker, 1989a; 1989b) and compiled by Buikstra and Ubelaker (1994). For example, a score of (1) on a proximal radius indicates an age-at-death of between 14 and 19 years of age.

When combined, the Krakow collection and the Borschiv collection constitute a skeletal sample representing a minimum of 60 individuals with 231 teeth from Verteba Cave, the most substantial Tripolye (non-Usatovo) skeletal sample available for study. I will now move to a discussion of the bioarchaeological methods employed to assess the health of the early farmers from Verteba Cave.
Methods

*Enamel hypoplasias*

As described in Chapter 2, enamel hypoplasias are deficiencies in enamel thickness caused by the disruption of enamel producing cells. The methods for analyzing enamel hypoplasias, therefore, rely on recognizing deviations from normal enamel formation. During normal enamel formation, cells called ameloblasts secrete enamel in multiple layers beginning at the occlusal surface of the tooth crown (Goodman and Rose, 1990). The first layers laid down by ameloblasts compose the cusps and occlusal surfaces of each tooth. These layers are deposited one atop the other in a dome-like, appositional manner, with each layer increasing in size. Following the completion of the occlusal portion of the tooth crown, enamel secretion progresses cervically toward the cemento-enamel junction, where the crown ends and the root begins (Goodman and Rose, 1990). As the activity of the ameloblasts progresses cervically, the layers of enamel on the sides of the tooth crown are laid down in a tile-like, or imbricational manner (Goodman and Rose, 1991). Throughout the tooth crown, each layer of enamel is demarcated by dark incremental lines called the striae of Retzius. Due to the appositional nature of the occlusal and cuspal enamel formation, the individual striae of Retzius are not observable on the outer layer of the teeth (Guatelli-Steinberg et al., 2004). However, surface manifestations of the striae of Retzius, called perikymata, are visible on the more cervically located imbricational enamel. In normal imbricational enamel, adjacent perikymata are similarly spaced, while in deficient enamel, perikymata are spaced more widely than normal (Guatelli-Steinberg et al., 2004). Because of the characteristics of enamel structure and hypoplasia formation, enamel hypoplasias are typically observed
only in areas of imbricational, rather than appositional, enamel. These structural characteristics also lead some tooth classes to be more susceptible to hypoplasia formation than others. Anterior teeth (incisors and canines) have proportionally more imbricational enamel than do posterior teeth (premolars and molars), which are composed of more appositional enamel (Guatelli-Steinberg et al., 2004).

Using the standard method of macroscopic observation outlined by Buikstra and Ubelaker (1994: p.56), I examined the teeth from Verteba Cave for the presence of enamel hypoplasias and assigned each tooth one of the following scores:

(0) Absence

(1) Linear horizontal groove

(2) Linear vertical groove

(3) Linear horizontal pits

(4) Nonlinear array of pits

(5) Single pit

In cases where a tooth had more than one defect, I assigned it multiple scores, one for each defect, separated by a slash. Following the suggestions of Lukacs (1989) and Goodman and Rose (1990), I made these observations using diffuse lighting with a second incandescent light source positioned at an oblique angle to the specimen. I also used a handheld 10X magnifier for optimal perikymata detection. When possible, I compared adjacent perikymata to avoid mistaking a normal perikymata for an enamel defect (Skinner et al., 2005). I also assigned each individual a score of “affected” (if a hypoplastic lesion was present) and “unaffected” (if all teeth were lesion free).
Following Lukacs (1992), I present the data on enamel hypoplasias using two methods. The first is the individual count method, in which the number of individuals with at least one enamel hypoplasia is presented as a percentage of the total number of individuals observed. This method reports the proportion of the population that experienced events physiologically stressful enough to cause a disruption in enamel formation, and has the advantage of focusing on the individual, the primary unit upon which selection acts (Lukacs, 1992). One disadvantage of using this method with prehistoric skeletal samples, is that it often results in small sample sizes and reduces the power of statistical analysis (Lukacs, 1992). As described in the previous section, the skeletal sample from Verteba Cave includes both maxillae and mandibles that are associated with their occluding half and others that were found in isolation. When associated, upper and lower jaws are counted as single individuals. In cases where isolated mandibles and maxillae were not definitively associated with their occluding jaw, the isolated element is treated as a distinct individual. This potentially overestimates the number of individuals present in the sample, however, it provides the most parsimonious way to organize the available dental material for analyzing pathology. Loose teeth were not included in the individual count.

The second method I used to organize data on enamel hypoplasias is the tooth count method, in which the total number of teeth with at least one enamel hypoplasia is presented as a ratio of the total number of teeth observed. This method has the advantage of using a larger sample size (total teeth), which increases the power of statistical analysis (Lukacs, 1992). One drawback to the tooth count method, however, is that it may overestimate stress, as single stress events are recorded on all of an individual’s teeth.
developing at the time of a physiological insult. The tooth count method may, therefore, overestimate the stress experienced by a population by treating all of the defects resulting from one stress episode as representing independent stress events. Despite this methodological issue, this method is frequently employed in bioarchaeological studies, and in combination with other reporting styles, as it helps provide a more comprehensive picture of health for a given population. I used the tooth count method to permit comparisons between this and other data, especially that of Lillie (1996) who used it to report enamel hypoplasia rates in Mesolithic and Neolithic hunter-gatherers from Ukraine.

Temple (2010) notes that use of both the individual and tooth count methods can help control for the presence of hypoplasias caused by localized trauma and hereditary abnormalities. As episodes of systemic stress affect all teeth forming at the same time, antimeric teeth in each jaw should display the same hypoplasia if stress was the cause. Therefore, Temple suggests recording the proportion of affected maxillary central incisor and mandibular canine antimeric pairs, to see if patterns observed using the tooth count and individual count methods hold true. Temple’s suggestion is followed here, although preservation issues limited the number of observations that could be made.

A recent study by Hassett (2012) revealed that microscopic methods may be better at identifying abnormally spaced perikymata than macroscopic methods. Because the equipment for microscopic analysis was not available for this study, it is worth noting that the macroscopic observations used should be considered a minimum estimation of hypoplasia prevalence (Hassett, 2012; Hillson and Bond, 1997). In an examination of two teeth from the same individual, Hassett observed one set of enamel hypoplasias
macroscopically, but three sets of hypoplasias using microscopy. According to Hassett, microscopic methods can better identify abnormally spaced perikymata, especially in the more cervical regions of teeth where perikymata are more tightly spaced and difficult to differentiate with the naked eye. For this reason, quantification of growth disruption based on macroscopic observations of enamel hypoplasias must be considered minimum estimates.

Since enamel hypoplasias affect only the portion of enamel that is forming during a physiological insult, it is possible to use their location to determine the age at which a stress event occurred. Both macroscopic and histological methods have been developed to estimate the time at which enamel hypoplaisas formed. However, a comparison of the two types of methods by Ritzman et al. (2008) suggests that histological methods are most accurate. Likewise, Reid and Dean (2000) have shown histological methods to better estimate the timing of enamel formation. Unfortunately, histological studies require the destruction of human remains, which was not allowed by the Ukrainian authorities, leaving macroscopic estimates as the only option. To estimate the age at which enamel hypoplasias formed, the distance from the center of a hypoplastic defect to the cement-enamel junction was measured to the nearest tenth of a millimeter using digital calipers (Goodman et al., 1980; 1985). These distances are then converted into half year intervals using tooth-specific enamel formation schedules developed by Swardstedt (1966), based on the work of Massler et al. (1941).
Porotic Hyperostosis and Cribra Orbitalia

Porotic hyperostosis and cribra orbitalia are frequently recognized in bioarchaeological studies as porotic lesions occurring on the cranial vault and orbital roof, respectively (Larsen, 1997). As described in Chapter 2, these lesions are commonly thought to reflect the expansion of spongy bone as a result of anemia induced marrow hypertrophy, although they may also be caused by inflammatory responses.

In this study, porotic hyperostosis and cribra orbitalia were recorded following the standardized method of macroscopic observation described by Buikstra and Ubelaker (1994: p.121). This is the most commonly employed approach and its use here ensures comparability with other bioarchaeological studies. This method is based on the work of Stuart-Macadam (1985) and records the severity of the lesions based on the size of individual pores and the degree to which they interconnect. Following this method, all cranial vaults and orbital roofs were assigned one of the following scores:

(0) Absent- no abnormal porosity present

(1) Light- scattered fine foramina

(2) Medium- large and small isolated foramina that have linked to form a trabecular structure

(3) Severe- outgrowth in trabecular structure from the normal contour of the outer bone table

In addition to lesion severity, the location of the lesion on either the cranial vault or orbital roof was also recorded. For any crania receiving a score of 1-3, the degree of
healing was also assessed. A lesion was recorded as “active” if the pores were open and “healed” if the pores had been partially filled with new cortical bone.

Although this scoring method for recording porotic hyperostosis and cribra orbitalia has been the standardized method for nearly 20 years, its replicability and reliability have only recently been assessed. In a study examining the interobserver error between 20 scorers with varying degrees of experience, Jacobi and Danforth (2002) found high levels of agreement (>80%) between participants when recording a lesion present. However, in situations where lesions were not present, nearly 50% of observers continued to score the skulls as having evidence of either porotic hyperostosis or cribra orbitalia. The level of interobserver agreement was similarly poor when considering the severity of lesions, with more than half of the skulls eliciting 50% or less agreement. Finally, when asked to assess the degree of healing present in each lesion, interobserver error was high, with 19 out of 21 skulls receiving every possible score.

The high rates of interobserver error recorded by Jacobi and Danforth (2002) were not simply due to inexperienced researchers. Surprisingly, some of the highest levels of disagreement were between the most experienced osteologists. The results of this study call into question the reliability and replicability of the standardized method. As a result, Jacobi and Danforth (2002) suggest using photographic examples of the different levels of severity of porotic hyperostosis and cribra orbitalia to improve interobserver agreement. Photographs of this type are supplied in Buikstra and Ubelaker (1994) as well as in the computer program Osteoware (Smithsonian Institution, 2011), and these were employed in the examination of the material from Verteba Cave. To assess the level of intraobserver error in this sample, the crania from Verteba Cave were examined twice
over the course of three weeks, without reference to the original evaluation. The level of intraobserver agreement was assessed using the kappa statistic. Interobserver error was also assessed using a kappa statistic, comparing observations made by myself, Dr. Gwyn Madden, and Sarah Heins, a graduate student with substantial experience in osteological analysis.

As discussed in Chapter 2, radiographic and histological studies have demonstrated that not all macroscopically recognized cases of porotic hyperostosis and cribra orbitalia are caused by anemia (Stuart-Macadam, 1987; Wapler, 2004). While histology is a preferred method, it requires the destruction of a portion of the affected bone, which was not permitted by the Ukrainian authorities. However, a subsample of five crania and partial crania were taken to the United States and examined radiographically according to criteria outlined by Stuart-Macadam (1987). This analysis took place at St. Mary’s Hospital in Grand Rapids, Michigan, with assistance from Dale Schippers, a medical physicist.

In her study, Stuart-Macadam (1987) used seven clinical radiographic indicators of anemia to assess archaeological skulls, including hair-on-end trabeculation, outer table thinning, texture change, diploic thickening, horizontal plate thickening, orbital rim changes, and degree of frontal sinus development. Hair-on-end trabeculation refers to the arrangement of trabecular bone perpendicular to the cortical bone, giving the trabecular bone the appearance of radiating out of the skull on an X-ray. In individuals with anemia, the thinning of the outer table of bone is recognizable in radiographs, and this thinning results from the external pressure applied by the expanding diploe on the outer cortical layer, leading to the latter’s resorption. Radiographic texture change occurs when the
trabecular demineralization that accompanies diploic expansion makes the outer part of the skull appear coarse rather than homogenous. Diploic thickening is assessed on radiographs as the ratio of compact to diploic bone as compared to a normal ratio of 1:1.4. Horizontal plate thickening refers to an increased thickness of the orbital roof on radiographs in cases of anemia, and the normal contours are often obliterated. Finally, the degree of frontal sinus development on radiographs reflects the extent that the frontal sinus is destroyed by trabecular bone expansion. The presence of any of these radiographic markers is considered indicative of anemia. All five specimens that were analyzed radiographically were scored as having either porotic hyperostosis or cribra orbitalia.

_Periostitis_

As discussed in Chapter 2, in the bioarchaeological literature, periostitis is synonymous with nonspecific infection and considered an indicator of physiological stress. I macroscopically examined all bones for evidence of periostitis, recognized as any distinctive patch of woven or sclerotic bone laid down on the cortical surface (DeWitte and Bekvalac, 2011). Bones with periostitis were scored as “affected”, while bones without any evidence of periostitis were scored as “unaffected”. Any bones where taphonomic damage destroyed more than 50% of the bone’s surface and no periostitis was observed on the intact portion were scored as “unobservable” (DeWitte and Bekvalac, 2011).

I additionally recorded the size and degree of healing for each periosteal lesion. The size of each lesion was quantified by measuring along its long and short axes in
millimeters using digital calipers. Using this information, I then calculated the area of each lesion in relation to the size of the affected bone, providing an objective evaluation of each lesion’s severity. Degree of healing was assessed by examining each periosteal lesion for evidence of remodeling (Larsen, 1997). To control for interobserver error, observations were made by both myself and Dr. Gwyn Madden, and the degree of concordance was assessed using the kappa statistic.

**Stature**

Stature is regularly used in studies of health in living populations, and its correlation with nutritional status and physiological wellbeing is well established (Bogin, 1999; Eveleth and Tanner, 1976). Because shorter stature is associated with reduced biological wellbeing, average terminal adult stature can be used as a proxy for the overall health of a population.

The most common methods of bioarchaeological stature reconstruction involve regression equations developed from the long bone measurements from individuals of known stature (Larsen, 1997). These formulae include the widely used regression equations developed by Trotter and Gleser (1952; 1958) for white and black Americans. While these equations are useful for the populations from which they were developed, serious methodological issues can result from their application to other groups (Pinhasi et al., 2011). Because human populations vary in their proportions of limb length to stature (Pinhasi et al., 201), stature estimates using regression equations developed on different populations are often inaccurate (Raxter et al., 2008; Ruff, 2002). Additionally, researchers use various equations to estimate stature, and often neglect to specify which
equation was used. These facts make cross-study comparisons of stature data problematic (Mummert et al., 2011).

To avoid the methodological issues surrounding stature estimation using regression equations, I used long bone lengths as a proxy for stature in the Verteba Cave population, an approach applied in other bioarchaeological studies (Jacobs, 1993; Pinhasi et al., 2011). Using long bone lengths also makes my data directly comparable to published values for Ukrainian Mesolithic and Neolithic hunter-gatherers (Jacobs, 1993). All measurements were taken with an osteometric board and following the standard definitions for maximum length provided by Buikstra and Ubelaker (1994) for the femur, tibia, humerus, ulna, and radius. For each long bone, data on maximum length is presented by sex as mean values with standard deviations, except for radii and ulnae, for which sex could not be estimated. The average long bone lengths of radii and ulnae are presented for the entire sample.

Dental Caries

As discussed in Chapter 2, dental caries is a disease process that results in the focal demineralization of the dental hard tissues through exposure to organic acids produced by bacterial fermentation of dietary carbohydrates (Hillson, 1979). In this study, carious lesions were diagnosed and recorded using the visual inspection method (Buikstra and Ubelaker, 1994) based on the work of Moore and Corbett (1971). Unlike, radiographic techniques and the “explorer method,” visual inspection has been shown to result in lower instances of interobserver error (Rudney et al., 1983).
Using this method, I visually inspected each erupted tooth within maxillae and mandibles, as well as loose teeth, for dental caries. Carious lesions were recognized as darkly stained, irregularly walled pits in the enamel or root cementum, and were only recorded as present if the cavity had fully penetrated the surface enamel or cementum (Moore and Corbett, 1971). To ensure high replicability, observations were made by myself and Sarah Heins and interobserver error was assessed using the kappa statistic (Landis and Koch, 1977; Viera and Garrett, 2005).

Following visual inspection, I assigned each tooth one of the following scores according to the location of carious lesions (Buikstra and Ubelaker, 1994: p.55):

(0) No lesion present
(1) Occlusal surface lesion- all grooves, pits cusps, dentin exposures, and the buccal and lingual grooves of the molars
(2) Interproximal surface lesion- mesial and distal surfaces, including cervical regions
(3) Smooth surface lesion- buccal and lingual surfaces
(4) Cervical lesion- originate at the cemento-enamel junction, except interproximal region
(5) Root lesion- below the cemento-enamel junction
(6) Large lesion- cavities that have destroyed so much of the tooth they cannot be assigned a surface of origin
(7) Noncarious pulp exposure
When multiple carious lesions were present on a single tooth, slashes were used and scores were assigned for each lesion.

Recording the location of dental caries is important because some surfaces are more susceptible to caries than are others. The highly complex occlusal surfaces of molars and premolars have many pits, fissures, and grooves that allow for bacterial colonization and the buildup of food residue, both of which promote dental caries formation. The simple sides of molars and premolars are much less susceptible to dental caries. Likewise, the simple morphology of incisors and canines make dental caries formation on these teeth a relatively rare occurrence, as they are easily cleaned through normal processes such as salivary flow.

The progression of individual dental caries can lead to exposure and infection of the pulp chamber of the affected tooth. Pulp infection, in turn, can lead to the tooth’s exfoliation. For this reason, bioarchaeological studies of dental caries must take antemortem tooth loss (AMTL) into consideration (Nelson et al., 1999; Watson, 2008). AMTL can also be caused by other factors including trauma, periodontal disease, and severe dental wear that expose the pulp chamber. In order to account for this in my sample, I examined the skeletal material for AMTL, and recorded it as “present” for any tooth socket where partial or complete resorption of the alveolus was observed (Buikstra and Ubelaker, 1994). I also applied Lukacs’ (1992; 1995) caries correction factor in order to estimate the proportion of AMTL caused by dental caries and correct for its effects on dental caries rates. To do this, I recorded the proportion of teeth with pulp exposure caused by dental caries and attrition, then multiplied these rates by the number of teeth lost antemortem to estimate the number of teeth lost prior to death due to dental caries
and extreme wear, respectively (Lukacs, 1992; 1995). I then added the estimated number of teeth lost due to dental caries to the observed number of carious lesions in order to generate the corrected number of carious teeth, presented as a ratio to the sum of observed teeth and teeth lost antemortem to give the corrected caries rate.

I have presented the dental caries data in a variety of ways to ensure its comparability to other data sets and prevent biased interpretations. Following Lukacs (1992), I used the tooth count method which presents the number of teeth with at least one carious lesion as a ratio to the total number of observed teeth. The tooth count rate is presented both with and without application of the caries correction factor, in order to enable comparisons to other published data. This method has the advantage of using a large total sample size (total number of teeth) and therefore increases the power of statistical analysis. The tooth count method can be broken down by tooth class, and provide information on the differential susceptibility of each tooth type to dental caries development. The tooth count method can additionally be broken down by sex and by age in order to account for sex-specific differences in susceptibility to caries development and the age-dependent nature of the disease, in which longer periods of exposure to acidic bacterial byproducts leads to greater likelihood of caries formation.

I have also presented the dental caries data using the individual count method, in which each dentition representing a single individual is scored either as having one or more dental caries or as lacking dental caries altogether. This method has the advantage of focusing on the individual, the primary unit upon which selection acts (Lukacs, 1992). One disadvantage, however, is that its use with prehistoric skeletal samples often results in small sample sizes and reduces the power of statistical analyses (Lukacs, 1992).
Individual count data can also be broken down by age and sex, and has been presented here both with and without application of the caries correction factor.

**Periodontitis**

Periodontal disease results from bacterial infection of the gums that causes inflammation of the gingival tissues (Li et al., 2000). Skeletally, periodontal disease has been recognized as the destruction of the alveolar bone surrounding individual teeth (Hildebolt and Molnar, 1991). There are two methods that are widely accepted in the bioarchaeological literature for use in the detection and documentation of periodontal disease, both of which are used here. The first method is simply recording periodontal disease as present for any tooth where the cortical alveolar bone has been lost and the underlying trabecular bone has been exposed (Clarke and Hirsch, 1991; Hildebolt and Molnar, 1991). The second method involves evaluating the resorption of alveolar bone at each tooth by measuring the distance between the cemento-enamel junction of the tooth and the alveolar crest. If the distance between the cemento-enamel junction and alveolar crest exceeds 2mm, periodontal disease is recorded as present (Clarke and Hirsch, 1991).

Although the 2mm criteria is a more objective method of evaluating periodontal disease, it can also lead to false diagnoses in older individuals and in individuals experiencing heavy dental attrition. In cases of severe dental wear, human teeth continue to erupt to maintain proper occlusion and the normal height of the face (Clarke and Hirsch, 1991; Hildebolt and Molnar, 1991). This “super-eruption” increases the distance between the cemento-enamel junction and the alveolar crest to greater than 2mm, but is not related to periodontal disease. It is important to control for the dental attrition of
comparative samples to account for this potential source of error. To control for the super-eruption effects of extreme wear, any individuals with heavy dental attrition will be excluded from comparisons of periodontal disease.

The data on periodontal disease in the Verteba Cave sample is presented using both the individual count and tooth count methods as mentioned above. As with dental caries, this data has been broken down by sex and age in order to examine the influence of these factors on dental health.

**Statistical comparisons and hypothesis testing**

The goal of this dissertation is to assess the impact of the transition to agriculture on human health in prehistoric Ukraine, and based on the results of previous studies, I will test the hypothesis that the adoption of farming was detrimental to health. To do this, I compare the health of the early farmers from Verteba Cave to pre-agricultural hunter-gatherers from the region using data published by Lillie (1996) and Jacobs (1993) on the rates of dental caries, enamel hypoplasias, and long bone lengths. No data have been published on the rates of porotic hyperostosis, cribra orbitalia, periostitis, and periodontal disease for these hunter-gatherers. However, I present the rates of these pathologies for the Tripolye farmers to better assess their overall health.

I compared the rates of enamel hypoplasias between the Tripolye farmers from Verteba Cave and the Mesolithic/Neolithic foragers (Lillie, 1996) using a $\chi^2$ test ($\alpha=0.05$). I carried out these comparisons using both the tooth count and individual count reporting methods. As Lillie (1996) found the hunter-gatherer dental sample to be universally free of carious lesions, dental caries rates will be compared using Fisher’s
exact test. The inclusion of a zero in the two-way contingency tables of a $\chi^2$ test violates that test’s assumptions, but is permissible in the Fisher’s exact test. Like enamel hypoplasias, dental caries rates are compared using the tooth count and individual count methods. I will also compare data on long bone lengths from the Verteba Cave sample to those published by Jacobs (1993) on the Dnieper Rapids region hunter-gatherers using two-sample t-tests ($\alpha=0.05$).

Since dental caries rates are typically higher among females in early agricultural populations, I will additionally test the hypothesis that females in the Verteba Cave sample will have significantly more dental caries, using a $\chi^2$ test to compare the sex-specific rates.

The results of my analyses are presented in the next chapter.
Chapter 5: Results

*Enamel hypoplasias*

When considered using the tooth count method of reporting, the Tripolye farmers from Verteba Cave have at least one enamel hypoplasia on 18.18% of the teeth examined (Table 5.1). By comparison, the Mesolithic and Neolithic period hunter-gatherers from Ukraine have enamel hypoplasias on 1.88% of teeth (Lillie, 1996). The comparison of the agriculturalists and foragers using a $\chi^2$ test of the tooth count rates revealed them to be significantly different ($\chi^2 = 168.993$, $p<0.001$). A similar difference was found using the individual count method for comparing the prevalence of enamel hypoplasias. Among the Tripolye, 48.57% of observable individuals had at least one enamel hypoplasia, as compared to 12.77% of individuals in the hunter-gatherer sample (Lillie, 1996). The difference between the two populations in terms of the prevalence of enamel hypoplasias at the individual level was also found to be significant ($\chi^2 = 20.58$, $p<0.001$).

When the tooth count data is broken down by sex, 11.54% of male teeth display at least one enamel hypoplasia, while 16.67% of female teeth were found to have at least one hypoplastic lesion (Table 5.2). This difference between the sexes is not significant ($\chi^2 = 0.9076$, $p= 0.3407$). When the sexes are considered separately using the individual count data, 35.71% of males and 55.56% of females displayed at least one enamel hypoplasia. Again, there is no significant difference between the sexes from Verteba Cave ($\chi^2 =0.878$, $p= 0.349$). Sex specific rates were not available for the hunter-gatherer data (Lillie, 1996).
When the tooth count data from Verteba Cave is broken down by tooth class, canines are found to be affected at the highest prevalence (45.83%), followed by incisors (32.0%), premolars (19.67%), and molars (10.24%) (Table 5.3). This pattern of prevalence by tooth type is not unexpected based on their known differences in susceptibility (Goodman and Rose, 1990). No tooth specific rates were published for the hunter-gatherers.

The rates of subadult (2/4 individuals) and adult (15/31 individuals) dentitions with at least one enamel hypoplasia are very similar. When examined by individuals who could be assigned to a specific age class, 0% of infant/young child, 50% of child, 100% of adolescents, 40% of young adults, and 50% of old adults were found to have at least one enamel hypoplasia. When the tooth count data is broken down by age category, 0% of infant/young child, 25% of child, 100% of adolescent, 12.42% of young adult, and 50% of old adult teeth displayed at least one enamel hypoplasia. It is important to note that only two adolescents were observed.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ratio Of Teeth With At Least 1 Hypoplasia to Total Teeth Observed</th>
<th>Ratio Of Individuals With At Least 1 Hypoplasia to Total Individuals Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verteba Cave Tripolye</td>
<td>42/231</td>
<td>17/35</td>
</tr>
<tr>
<td>Agriculturalists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ukrainian Foragers (Lillie, 1996)</td>
<td>43/2284</td>
<td>18/141</td>
</tr>
</tbody>
</table>

Table 5.1- Enamel hypoplasia rates in Tripolye farmers and Mesolithic/Neolithic foragers.
Following Temple (2010), enamel hypoplasias were also examined using antimeric mandibular canines and maxillary incisors. Only three pairs of mandibular canine antimeres were observable in the population from Verteba Cave, and two of the three pairs were found to have matching hypoplasias. The third pair was found to be hypoplasia free. A single antimeric pair of maxillary central incisors was observed, and this pair was found to have matching hypoplasias.

<table>
<thead>
<tr>
<th>Group from Verteba Cave</th>
<th>Hypoplastic Teeth</th>
<th>Total Teeth</th>
<th>Individuals with at least One Hypoplasia</th>
<th>Total Individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripolye males</td>
<td>12</td>
<td>108</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Tripolye females</td>
<td>9</td>
<td>54</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Tripolye sex unknown</td>
<td>21</td>
<td>69</td>
<td>5</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 5.2- Enamel hypoplasias by sex in the Verteba Cave sample.

<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>Hypoplastic Teeth</th>
<th>Total Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canines</td>
<td>11</td>
<td>24</td>
</tr>
<tr>
<td>Incisors</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Premolars</td>
<td>12</td>
<td>61</td>
</tr>
<tr>
<td>Molars</td>
<td>13</td>
<td>127</td>
</tr>
</tbody>
</table>

Table 5.3- Enamel hypoplasias by tooth type in the Verteba Cave sample.
Due to the lack of preserved mandibular canine and maxillary central incisor antimeres, nine antimeric pairs of maxillary lateral incisors, maxillary canines, mandibular incisors, and maxillary premolars were observed. All of these antimeric pairs had at least one hypoplasia. Of the nine pairs, all nine were found to have matching hypoplasias on each of the antimeres.

In terms of the timing of the stress events which led to enamel hypoplasia formation, 78.57% of defects occurred during the second year of life. All canine and incisor lesions, as well as eight enamel hypoplasias observed on first premolars and eight enamel hypoplasias observed on first molars were found to occur between the distances from the cemento-enamel junction attributed by Swardstedt (1966) to correspond to between one and two years of age. These distances from the cemento-enamel junction are 7.04 to 8.32mm on the maxillary canines, 6.8 to 9.067mm on the mandibular canines, 6.6 to 8.25 on the maxillary central incisor, 3.867 to 5.8mm on the mandibular central incisor, 6.767 to 8.7mm on the maxillary lateral incisor, 4.27 to 6.4mm on the mandibular lateral incisor, 7.8 to 9.533 on the mandibular first premolar, 5.2 to 6.93mm on the maxillary first molar, and 3.47 to 5.2mm on the mandibular first molar. The remaining 21.43% of enamel hypoplasias occurred during the third and fourth years of life, which corresponded to distances from the cemento-enamel junction of between 5.4 to 8.1mm for the maxillary first premolar, 2.6 to 7.8mm for the mandibular first premolar, 5.2 to 7.2mm for the maxillary second premolar, 4.35 to 7.5mm for the mandibular second premolar, 0 to 5.2mm for the maxillary first molar, 0 to 3.7mm for the mandibular first molar, and 4.6 to 6.9mm for the mandibular second molar.
Both intra- and interobserver agreement were substantial with kappa statistics of .93 and .81, respectively.

Stature

The average long bone lengths for each sex from Verteba Cave are presented in Table 5.4, while the average long bone lengths for each sex from the Dnieper Rapids region are presented in Table 5.5. Since sex was not able to be determined for Verteba Cave radii and ulnae, average lengths were calculated for the entire sample. For femora, tibiae and humeri, male and female farmers from Verteba Cave had, on average, shorter long bone lengths than the Mesolithic and Neolithic period hunter-gatherers. Small sample size for some long bones precludes statistical comparisons between the

<table>
<thead>
<tr>
<th>Long Bone</th>
<th>Average Length Males (n)</th>
<th>Standard Deviation</th>
<th>Average Length Females (n)</th>
<th>Standard Deviation</th>
<th>Average Length Indeterminate Sex (n)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femur</td>
<td>425 (7)</td>
<td>17.37</td>
<td>342 (1)</td>
<td>23.88</td>
<td>301 (9)</td>
<td>14</td>
</tr>
<tr>
<td>Tibia</td>
<td>365 (5)</td>
<td>23.88</td>
<td>342 (1)</td>
<td>23.88</td>
<td>301 (9)</td>
<td>27.71</td>
</tr>
<tr>
<td>Humerus</td>
<td>314 (3)</td>
<td>27.71</td>
<td>342 (1)</td>
<td>27.71</td>
<td>301 (9)</td>
<td>27.71</td>
</tr>
<tr>
<td>Radius</td>
<td>240.47 (17)</td>
<td>11.67</td>
<td>259.86 (14)</td>
<td>9.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ulna</td>
<td>259.86 (14)</td>
<td>9.61</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.4- Long bone lengths from Verteba Cave.
Long Bone | Average Length Males | Standard Deviation | Average Length Females | Standard Deviation |
---|---|---|---|---|
Femur | Mesolithic | 469.8 (20) | 17.17 | 439.4 (14) | 19.95 |
| Neolithic | 471.3 (31) | 21.09 | 441.2 (23) | 13.41 |
Tibia | Mesolithic | 394.5 (12) | 17.17 | 374.3 (3) | 12.01 |
| Neolithic | 398.4 (22) | 19.58 | 366.9 (18) | 14.93 |
Humerus | Mesolithic | 344.0 (15) | 16.93 | 319.0 (8) | 17.68 |
| Neolithic | 342.0 (34) | 13.41 | 315.7 (22) | 11.77 |
Radius | Mesolithic | 265.6 (9) | 9.13 | 241.2 (4) | 6.29 |
| Neolithic | 264.6 (15) | 14.31 | 242.3 (12) | 9.60 |
Ulna | Mesolithic | 247.8 (5) | 13.06 | 229.5 (2) | 9.19 |
| Neolithic | 256.4 (21) | 12.90 | 230.0 (6) | 9.59 |

Table 5.5- Long bone lengths for foragers from the Mesolithic and Neolithic periods in Ukraine.

Two-sample t-tests reveal that all differences where statistical tests could be employed are significant. Specifically, male femora from Verteba Cave are significantly shorter than femora from both Mesolithic period (t= -5.89, p<0.0001) and Neolithic period (t= -6.1085, p<0.0001) male foragers; male tibiae from Verteba Cave are significantly shorter than tibiae from both Mesolithic period (t= -2.506, p= 0.024) and Neolithic period (t= -2.913, p= 0.016) male foragers; male humeri from Verteba Cave are significantly shorter than humeri from Mesolithic period (t= -2.547, p=0.01) and Neolithic period (t= -3.182, p= 0.0015) male foragers; and female humeri from Verteba Cave are significantly shorter than humeri from both Mesolithic period (t= -2.34, p=0.017) and Neolithic period (t= -2.99, p<0.003) female foragers (Figure 5.1).
Although radii and ulnae could not be sexed, it is interesting to note that the average length of all radii from Verteba Cave is slightly less than the average length of female radii from Mesolithic and Neolithic foragers.

*Porotic hyperostosis and cribra orbitalia*

A total of thirty individuals had at least one orbital roof or partial cranial vault that could be examined for evidence of porotic hyperostosis or cribra orbitalia. Of these 30 individuals, 43.33% were affected with some form of porotic hyperostosis and/or cribra orbitalia (Table 5.6). Porotic hyperostosis was the more commonly observed lesion, with 26.32% of the cranial vaults affected. Cribra orbitalia was less frequent, with 13.9% of the observable individuals affected. Of the ten crania observed to have porotic hyperostosis, eight had at least one orbital roof preserved to allow for the assessment of cribra orbitalia. Only a single individual was found to have both cranial vault and orbital roof lesions.
Figure 5.1- Comparison of average long bone lengths between Mesolithic and Neolithic hunter-gatherers from Ukraine and Eneolithic Tripolye farmers from Verteba Cave. (A) male femora (B) male tibiae (C) female tibiae (D) male humeri (E) female humeri.
In terms of severity, 60% of individuals with porotic hyperostosis were scored as having “light” lesions (Figure 5.2), where pores are small and scattered, while 40% of individuals were documented as having lesions of “medium” severity, which include both large and small pores that coalesce to form trabecular structure. For individuals recognized as having cribra orbitalia, 75% of lesions were scored as light (Figure 5.3) and 25% were scored as medium. No lesions of either porotic hyperostosis or cribra orbitalia were scored as severe.

In individuals where preservation allowed for sex estimation, 30.77% of male crania were found to have porotic hyperostosis, while 23.1% of female crania were affected. This difference is not significant ($\chi^2 = 0.19549$, p= 0.658). For cribra orbitalia, 13.3% of females individuals with at least one orbital roof preserved were found to have the lesion, while no male crania were found with the lesion. This difference between the sexes was also not significant ($\chi^2 = 2.432$, p=0.119).

By age, porotic hyperostosis was found on five individuals classified as young adult, one cranium classified as old adult, and four on cranial fragments simply classified as “adult” based on the fusion of primary ossification centers. A more precise age

<table>
<thead>
<tr>
<th>Sample</th>
<th>Individuals with Evidence of either Cribra Orbitalia or Porotic Hyperostosis</th>
<th>Total Individuals with at least an Orbital Roof or Cranial Vault Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripolye from Verteba Cave</td>
<td>13</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 5.6- Rate of porotic hyperostosis/cribra orbitalia in the Tripolye farmers from Verteba Cave.
classification was not possible for these individuals. All observed cases of porotic hyperostosis were scored as having evidence of healing. Cribra orbitalia was observed on one individual classified in the child age.

Figure 5.2- Human parietal from Verteba Cave displaying porotic hyperostosis of “light” severity.

Figure 5.3- Human frontal from Verteba Cave displaying cribra orbitalia of “light” severity.
category, as well as one individual in each of the adolescent, young adult, and old adult age categories. The lesion on the child was scored as active, while the adolescent, young adult, and old adult individuals had lesions with evidence of healing.

Radiographic analysis showed none of the crania examined displayed evidence of active anemia at the time of death (Figures 5.4, 5.5).

Figure 5.4- Radiograph of a frontal bone with cribra orbitalia from Verteba Cave. The orbital roof’s thickness is within the normal range and not reflective of active anemia at the time of death.

Published data on hunter-gatherers do not include information on the rates of porotic hyperostosis and cribra orbitalia. Therefore, no comparison between farmers and foragers could be made.
Periostitis

Out of the 1,094 skeletal elements analyzed for periostitis, only a single right rib fragment was found to have a lesion. The lesion measured 10mm in length by 6mm in width.

Figure 5.5- Radiograph of a cranium from Verteba Cave with porotic hyperostosis. The thickness of the diploe is within the normal range and not reflective of current anemia at the time of death.

Periostitis was not reported in the studies of Ukrainian Mesolithic and Neolithic period hunter-gatherers and therefore, no comparisons between foragers and farmers can be made.
Periodontal disease

Periodontal disease was observed as present at 95.8% of the alveoli available for scoring, and in all individuals with at least one tooth observable in its original alveoli (Table 5.7) (Figure 5.6). When examined by sex, 89.89% of the alveoli belonging to females showed evidence of periodontal disease, as compared to 99.05% of observable male alveoli. A $\chi^2$ test indicates that this difference is significant ($\chi^2=8.83$, p=0.03). When examined by age, periodontal

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ratio of Teeth with Periodontal Disease to Total Teeth Observed</th>
<th>Ratio of Individuals with Periodontal Disease to Total Individuals Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripolye farmers from Verteba Cave</td>
<td>229/231</td>
<td>35/35</td>
</tr>
</tbody>
</table>

Table 5.7 – The rate of periodontal disease in the sample of Tripolye farmers from Verteba Cave.
Disease was found on 100% of infant/young child, 100% of child, 100% of adolescent, 94.4% of young adult, and 100% of old adult teeth.

No information on periodontal disease was published on the hunter-gatherers from the Dnieper Rapids region and, therefore, no comparisons between farmers and foragers could be carried out.

**Dental caries**

Before application of the caries correction factor, a total of 9.52% of teeth from the Verteba Cave sample were observed to have at least one carious lesion (Table 5.8). Broken down by tooth type, 20% of mandibular molars, 11.96% of maxillary molars, 11.11% of mandibular premolars, and 4.7% of maxillary premolars had at least one carious lesion (Table 5.9). No cavities were observed on any incisors or canines. When carious teeth are considered,

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ratio of Teeth with at least One Carious Lesion to Total Teeth Observed</th>
<th>Ratio of Individuals with at least One Carious Lesion to Total Individuals Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripolye farmers from Verteba Cave</td>
<td>22/231</td>
<td>11/35</td>
</tr>
<tr>
<td>Mesolithic/Neolithic foragers</td>
<td>0/2284</td>
<td>0/141</td>
</tr>
</tbody>
</table>

Table 5.8- The rates of dental caries in samples of farmers and foragers from Ukraine.
<table>
<thead>
<tr>
<th>Tooth Type</th>
<th>Caries</th>
<th>Teeth</th>
<th>Tooth Type</th>
<th>Caries</th>
<th>Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary</td>
<td></td>
<td></td>
<td>Mandibular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incisors</td>
<td>0</td>
<td>17</td>
<td>Incisors</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Canines</td>
<td>0</td>
<td>19</td>
<td>Canines</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Premolars</td>
<td>2</td>
<td>43</td>
<td>Premolars</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Molars</td>
<td>11</td>
<td>92</td>
<td>Molars</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>Molars Corrected</td>
<td>15</td>
<td>96</td>
<td>Molars Corrected</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>Total Maxillary</td>
<td>13</td>
<td>171</td>
<td>Total Mandibular</td>
<td>9</td>
<td>60</td>
</tr>
<tr>
<td>Maxillary Corrected</td>
<td>17</td>
<td>175</td>
<td>Mandibular Corrected</td>
<td>10</td>
<td>61</td>
</tr>
</tbody>
</table>

Table 5.9- Caries rates by tooth type in the Tripolye sample from Verteba Cave.

Figure 5.7- Two mandibular molars displaying occlusal/interproximal surface carious lesions from Verteba Cave.
45.5% are located on the occlusal surface (Figure 5.7), 31.8% are interproximal caries (Figure 5.8), 9.1% are smooth surface caries and 4.54% were too large to determine their location of origin. When the tooth count method is broken down by sex, females had carious lesions on 12.96% of teeth, followed by males on 9.25% of teeth, and those of indeterminate sex on 7.24% of teeth (Table 5.10). The difference between males and females when comparing their tooth count rates was not significant (p= 0.5929). When the tooth count method is reported by age category, old adults had the highest rate of caries at 16.67% of teeth, followed by young adults at 11.19% of teeth, and adolescents at 4.35% of teeth (Table 5.11). No carious lesions were found in individuals classified in the infant/young child or child age categories. Teeth from individuals of unknown age-at-death had a caries rate of 2.94%.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Carious Teeth</th>
<th>Percent Carious</th>
<th>Total Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>10</td>
<td>9.25%</td>
<td>108</td>
</tr>
<tr>
<td>Males Corrected</td>
<td>12</td>
<td>10.9%</td>
<td>110</td>
</tr>
<tr>
<td>Females</td>
<td>7</td>
<td>12.96%</td>
<td>54</td>
</tr>
<tr>
<td>Females Corrected</td>
<td>10</td>
<td>17.54%</td>
<td>57</td>
</tr>
<tr>
<td>Indeterminate</td>
<td>5</td>
<td>7.24%</td>
<td>69</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>9.52%</td>
<td>231</td>
</tr>
<tr>
<td>Total Corrected</td>
<td>27</td>
<td>11.44%</td>
<td>236</td>
</tr>
</tbody>
</table>

Table 5.10- Carious lesion tooth count rates by sex in the sample from Verteba Cave.

Interobserver agreement for caries diagnosis in the Tripolye sample was substantial based on a kappa statistic of 0.877.

Before application of the caries correction factor, eleven individuals were observed to have at least one carious lesion, yielding a rate of 31.4%. When examined by sex, 40% of females, 38.5% of males, and 6.87% of individuals of unknown sex were
found to have at least one carious lesion (Table 5.12). Differences between the sexes in caries rates using the individual count method were not significant (p= 0.940). When presented by age, the most affected in terms of dental caries rate were the adolescents at 50% of individuals, although only two individuals were observed. The next most affected were the young adults at 40% of observed individuals. Old adults were affected at a rate of 25%, while 14.29% of individuals of unknown age had at least one carious lesion (Table 5.13).

Figure 5.8- A mandible displaying cervical and root caries from Verteba Cave.
Only five teeth were found to be lost antemortem, three teeth belonging to a female individual characterized as an old adult. One young adult male and one old adult male were each found to have lost a single tooth antemortem. All teeth lost antemortem were molars. Dental wear in the Verteba Cave population was not heavy, and all observed pulp exposure was the result of dental caries. The corrected tooth count caries rate is 11.44% (27/236).

The caries correction factor only adds a single person to the individual count method for reporting dental caries, increasing the rate to 34.29% (12/35). The corrected individual count rate for old adults is 50%, making this the most caries age group along with the adolescents.

<table>
<thead>
<tr>
<th>Age at Death</th>
<th>Carious Teeth</th>
<th>Total Teeth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>10-17</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Young Adult (18-40)</td>
<td>16</td>
<td>143</td>
</tr>
<tr>
<td>Young Adult Corrected</td>
<td>17</td>
<td>144</td>
</tr>
<tr>
<td>Old Adult (&gt;40)</td>
<td>4</td>
<td>24</td>
</tr>
<tr>
<td>Old Adult Corrected</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Unknown</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>231</td>
</tr>
<tr>
<td>Total Corrected</td>
<td>27</td>
<td>236</td>
</tr>
</tbody>
</table>

Table 5.11- Tooth count carious lesion rates by age in the sample from Verteba Cave.
The published caries rates for Mesolithic and Neolithic period Ukrainian hunter-gatherers do not use the caries correction factor. Therefore, the uncorrected rates from this study are used in the comparison with the earlier foragers. Lillie’s (1996) analysis of caries for the Mesolithic/Neolithic hunter-gatherers found no caries in 2284 examined teeth belonging to 141 individuals. Fisher’s exact tests using both the tooth count (p<0.001) and individual count (p<0.001) rates, demonstrate that the Tripolye agriculturalists have a dental caries rate significantly higher than their hunting and gathering predecessors.
Chapter 6: Discussion

The Impact of Farming on Human Health in Ukraine

The results of my statistical analyses demonstrate that the Tripolye population from Verteba Cave displayed significantly more enamel hypoplasias and dental caries than earlier hunter-fisher-gatherers from Ukraine. Additionally, the statistical comparisons of long bone lengths indicate that the Tripolye were significantly shorter than their foraging predecessors. Furthermore, bioarchaeological analysis demonstrated that the Tripolye suffered from high rates of both periodontal disease and porotic hyperostosis/cribra orbitalia. Of all the skeletal markers employed in this study, only periostitis was found to affect the Tripolye farmers at a low level. Based on the combined results, I accept the hypothesis that the transition to agriculture was detrimental to human health in prehistoric Ukraine.

Growth Disruption

Enamel hypoplasias and adult stature provide different but complimentary information on growth disruption caused by suboptimal health (Clark et al., 2013). As discussed in Chapters 2 and 4, enamel hypoplasias reflect stress that occurs during the years of enamel formation, from birth to around eight years of age (Hillson, 2008). Therefore, enamel hypoplasias can be conceptualized as monitoring general health during the period of early childhood (Clark et al., 2013). Most growth contributing to adult stature occurs during the adolescent growth spurt, which takes place between approximately 7 years of age and physical maturation (sometime between 17-21 years of age)(Bogin, 2012; Clark et al., 2013; Scheuer and Black, 2004). Adult stature, therefore,
can be considered to primarily reflect health during the adolescent period (Clark et al., 2013). When used together, enamel hypoplasias and adult stature allow bioarchaeologists to monitor stress throughout the entire period of growth and development.

In my comparison of Tripolye agriculturalists with earlier hunter-fisher-gatherers from Ukraine, enamel hypoplasias were found to be significantly more prevalent among the farmers. Likewise, adult long bone lengths, used as a proxy for stature, were significantly shorter among the agriculturalists. Together, this data suggests the Tripolye experienced more stress across the entire subadult period as compared to the hunter-fisher-gatherers that preceded them.

While all enamel hypoplasias are typically regarded as reflecting general physiological stress in bioarchaeological studies, as pointed out in Chapter 2, they can also result from localized trauma and hereditary abnormalities. Hypoplasias caused by localized trauma usually affect only a few adjacent teeth, while those caused by systemic stress affect all teeth forming at the time of a physiological insult. To control for the potential confounding effects of trauma, antimeric pairs were examined for evidence of matching hypoplasias. Since antimeres form at the same time, matching hypoplasias on antimeric teeth reflect defects caused by a systemic stress event. When observation was possible, all hypoplastic teeth with antimeres present were found to have matching hypoplasias. Therefore, it is highly likely that the hypoplasias observed in this study resulted from systemic physiological stress.

Small sample size precluded sex-specific comparison of some long bone lengths, but statistical tests indicate that both male and female Tripolye had significantly shorter
femora, tibiae, and humeri as compared to earlier hunter-fisher-gatherers. For instance, on average, the Tripolye male femur is 46mm shorter than that of a male Neolithic forager. This reflects the generally shorter stature of the Tripolye farmers relative to their foraging predecessors.

According to Goodman and Martin’s (2002) model (discussed in Chapter 2), stress is the product of the complex interaction between environmental stressors, the ability of the cultural system to buffer those stressors, host resistance, and stressors created by the cultural adaptation. Both the Tripolye and Mesolithic/Neolithic foragers lived in the same forest-steppe environment and were biologically similar. Therefore, the higher stress observed among the Tripolye farmers likely resulted from cultural factors. Based on archaeological evidence, the most likely cultural factors contributing to the relatively poor health of the Tripolye are dietary composition, sanitation issues, close contact with domesticated animals, and high population density.

As mentioned above, enamel hypoplasias are growth disruptions that reflect stressors experienced during early childhood. The majority of enamel hypoplasias observed among the Tripolye occupied the middle of the anterior teeth, a region where enamel forms around two years of age. The timing of these defects suggests that they likely represent stress during the period of weaning. Cereals were a major component of the Tripolye diet, and may have been a primary weaning food in the form of porridges (Pashkevych, 2008; Zbenovich, 1996). For example, at the site of Maydanetske, crushed hulled wheat grains were found inside a pot, indicating porridge was eaten (Pashkevych, 2008). Although easily consumable by infants, cereals are exceptionally poor weaning foods, as they lack essential amino acids, such as lysine, are generally poor sources of
protein, and are deficient in vital minerals such as iron (Abdul-aal and Hacl, 2002; Baynes and Bothwell, 1990). Reliance on cereals as weaning foods by the Tripolye likely resulted in malnutrition, which would have contributed to the growth disruptions recorded as enamel hypoplasias. As compared to the Tripolye, Mesolithic/Neolithic foragers from Ukraine had diets highly focused on the meat of terrestrial animals and fish, with a lesser focus on vegetation (Lillie, 1996; Lillie and Richards, 2000). Incorporation of these protein and nutrient-rich foods into the weaning process would have provided the hunter-fisher-gatherer children with a nutritionally adequate diet, contributing to the lower incidence of systemic stress among these foragers.

A nutritionally poor diet during early childhood would have reduced the immunocompetence of Tripolye subadults, increasing their susceptibility to infection. This would have been especially problematic for the Tripolye farmers, as aspects of their settled agriculturalist lifestyle would have exposed them to more infectious agents. As compared to the sedentary Tripolye, Mesolithic/Neolithic hunter-fisher-gatherers from Ukraine maintained a mobile lifestyle, living in temporary camps occupied by small bands. Their frequent movement and low population density would have prevented widespread environmental contamination with human waste and limited the number of associated infections. By contrast, the densely settled Dniester region of the Tripolye territory, filled with large villages, would have easily met the threshold for the maintenance of contagious crowd diseases such as measles, influenza, smallpox, and mumps (Armelagos, 1990). Furthermore, population-dense sedentary Tripolye villages would have quickly contaminated their local environments with waste, leading to sanitary problems (Larsen, 1995). Common health hazards associated with poor settlement
sanitation include parasites such as the protozoan *Giardia lamblia*, which causes chronic diarrhea and the malabsorption of nutrients (Olivares et al., 2002; Walker et al., 2009). Parasites like *Giardia lamblia* are spread via contaminated drinking water and commonly touched surfaces. This contamination typically results from the buildup of fecal matter near water sources and areas of occupation (Olivares et al., 2002; Walker et al., 2009). Sanitation problems associated with sedentary settlements can also result in bacterial contamination, including by the diarrheal disease causing *Campylobacter, Salmonella, Shigella*, and *Escherichia coli*. All of these contaminants also originate from the buildup and spread of human waste. Weaning subadults, in particular, would have been at a heightened risk for infection due to the poor quality of their diets and because their immune system isn’t fully developed. The resulting diarrheal disease would have exacerbated their malnutrition by lowering the efficiency of nutrient absorption by the digestive system. Sedentism and its impact on local sanitary conditions at Tripolye settlements obviously had a deleterious effect on the health of young children and likely contributed to the elevated frequency of enamel hypoplasias observed in the sample from Verteba Cave.

While the data on enamel hypoplasias suggest the Tripolye farmers experienced elevated stress during early childhood, reduced adult long bone lengths indicate that the Tripolye also experienced high levels of stress during adolescence. This later stress may have also resulted from an overreliance on nutritionally poor cereals or sanitary issues related to sedentism as mentioned above. However, there are other potential sources of physiological disruption. One source of disease may have been the domesticated animals kept in the Tripolye livestock herds. Close contact with animals would have exposed all
Tripolye to novel zoonotic diseases and infections including viruses and bacterial pathogens (Armelagos, 1990). These diseases may have jumped to humans from animals and spread throughout the dense Tripolye population, likely resulting in significant morbidity and mortality. Some unique perforated pottery from Verteba Cave suggests that the Tripolye practiced dairying, and if adolescents carried out this task, they would have had frequent access to raw milk. The consumption of raw milk is a pathway for contracting *Mycobacterium bovis*, a bacterial pathogen causing tuberculosis.

One specific cultural practice may have made the risk of zoonotic diseases especially severe for the Tripolye, including their adolescents. Although the construction of the house has been controversial in Tripolye archaeology, it seems that they constructed two-story domiciles where the ground floor served as a stable for animals and the top floor was used for human habitation (Korvin-Piotrovskiy et al., 2012). The ground floors were built using timber to create a log cabin-like frame that would have provided a sturdy structure to contain animals, unlike wattle-and-daub walls, which are easily destroyed by pigs (Korvin-Piotrovskiy et al., 2012). By keeping farm animals in their homes, the Tripolye greatly increased their proximity to the beasts and their risk of contracting zoonotic diseases. Furthermore, by penning livestock in each house, the Tripolye would have been in near constant contact with animal waste, which would have exposed them to gastrointestinal parasites. Two such parasites that likely afflicted a large portion of the population are the pork (*Taenia solium*) and beef (*Taenia saginata*) tapeworms. These parasites are most frequently transmitted through contact with animal feces, although they can also be contracted through the consumption of tainted meat. Tapeworms prevent normal nutrient absorption, cause chronic diarrhea, and lead to blood
loss. Zoonotic diseases and parasites would have interacted synergistically with a nutritionally poor diet to result in the suboptimal health of the Tripolye adolescents observed in this study as depressed adult stature. As compared to the Tripolye farmers, the Mesolithic/Neolithic foragers would have had limited contact with large populations of living animals and their waste. This would have prevented the spread of zoonotic infections among these hunter-fisher-gatherers.

The practice of long distance trade is another source of disease that likely resulted in increased physiological stress among Tripolye of all ages. Copper axe heads have been recovered from Tripolye CII period deposits less than 5km from Verteba Cave. These axe heads were made of copper ore from the Balkans and were produced by specialized Balkan blacksmiths who utilized a standard set of axe-head casts. The Tripolye engaged in long distance trade with cultural groups as far away as Bulgaria to obtain these copper items. In exchange for the axes, the Tripolye sent flint and salt. Other evidence for long distance trade comes from pottery recovered from within Verteba Cave itself, such as that manufactured by the Baden culture of Poland and Slovakia. In antiquity, as today, contact with far away peoples can lead to the introduction of novel diseases and previously unencountered strains of known pathogens. Once introduced into a population, these diseases can have a devastating impact and lead to significant morbidity and mortality. Therefore, long distance trade and its ability to introduce new pathogens may have contributed to the elevated level of stress observed in the Tripolye population from Verteba Cave. While earlier Ukrainian foragers also undoubtedly engaged in trade, they were more self-sufficient, and trade was not as widespread.
Porotic Hyperostosis and Cribra Orbitalia

The Tripolye farmers from Verteba Cave were found to have a relatively high rate of porotic hyperostosis/cribra orbitalia. Generally, the porotic lesions observed among the Tripolye were light to medium in severity, with all individuals but one living long enough for them to remodel and show evidence of healing. This suggests that the stress that caused the lesions was not severe enough to result in early mortality.

Bioarchaeological studies typically regard porotic hyperostosis and cribra orbitalia as skeletal evidence of anemia. However, as discussed in Chapters 2 and 4, the lesions can also be caused by inflammatory responses, other pathological conditions such as scurvy, and taphonomic alterations. To investigate whether the porotic hyperostosis and cribra orbitalia observed among the Tripolye resulted from anemia, a sample of three affected cranial elements were examined radiographically for evidence of marrow hypertrophy. Interestingly, no such evidence was found. However, it remains possible that some of the healed lesions do represent past conditions of anemia, as the marrow could have atrophied following the restoration of homeostasis.

Any cases of porotic hyperostosis and cribra orbitalia that were caused by anemia reflect the occurrence of the condition during childhood. The bones of the cranium are filled with red marrow and are involved in erythropoiesis only during childhood, as red blood cell production shifts to the lower axial skeleton during adulthood (Stuart-Macadam, 1985). Childhood anemia can result from a variety of different causes. Some forms of anemia can be caused by hereditary conditions. However, these types of anemia, such as thalassemia and sickle cell anemia, lead to severe widespread lesions covering the
facial and postcranial skeletons. No widespread lesions characteristic of hereditary anemias were observed in the skeletal sample from Verteba Cave. Therefore, if anemia was present among this group of Tripolye farmers, it would have been acquired. Dietary insufficiencies would have been one of the most likely causes of anemia for Tripolye subadults. As mentioned above, the Tripolye likely relied on cereals as a primary weaning food, and while preparations such as porridges would have provided the children with a good source of calories, cereals are exceptionally poor sources of iron. Furthermore, the limited iron present in cereals is in the hard to digest non-heme form, limiting the iron’s bioavailability. Cereals also contain chemicals known as phytates, which bind to iron and prevent its absorption by the human gastrointestinal tract. For these reasons, a childhood diet heavily reliant on cereals would have led the Tripolye subadults to be at a high risk of developing iron-deficiency anemia. Over reliance on cereals in the diet would have also placed the Tripolye children at risk for developing megaloblastic anemia. This type of anemia results from an insufficiency in vitamin B12, which leads to the production of abnormal red blood cells. To compensate, marrow hypertrophy is stimulated in erythropoietic bone. Vitamin B12 is only found in meat and animal products such as milk, cheese, and eggs. A diet high in plant foods and low in animal products elevate the chances of developing megaloblastic anemia.

Both iron-deficiency and megaloblastic anemia can also result from diarrheal diseases and gastrointestinal parasites. Diarrheal disease caused by parasites like *Giardia lamblia* or bacterial infections were likely common features of life in the population-dense sedentary Tripolye settlements. Infections by these pathogens prevent efficient absorption of iron and vitamin B12 by the gastrointestinal tract. Likewise, parasites such
as tape worms, round worms, and hook worms actually remove nutrient-rich blood from circulation, leading to both iron- and vitamin B12-deficiency. The likely occurrence of both diarrheal disease and parasitic infection, in combination with a childhood diet heavily reliant on cereal foods, would have led to both iron-deficiency and megaloblastic anemia for Tripolye children.

The Mesolithic/Neolithic foragers likely suffered from less anemia than did the Tripolye, based on characteristics of their diet and generally high mobility. Studies by Lillie have shown that these hunter-fisher-gatherers consumed a diet heavily reliant on freshwater fish, mollusks, and terrestrial animals. Such a diet would have easily met the nutritional requirements for iron and vitamin B12. Furthermore, fish and animal meat contains iron in its heme-form, which is more easily digested than the non-heme form found in plants. Additionally, the mobile nature of these foragers’ adaptation would have prevented the contamination of the local environment by limiting the buildup of human waste. That, in combination with a lack of domesticated animals, would have limited the likelihood of contracting a diarrheal disease causing pathogen, further reducing the risk of anemia in these hunter-fisher-gatherers.

As discussed in Chapters 2 and 4, cribra orbitalia and porotic hyperostosis can be caused by processes other than anemia. These include diseases such as scurvy, inflammatory reactions leading to porotic hyperostosis, and taphonomic changes. In individuals with scurvy, porotic lesions can be found on the cranial vault as well as the orbital roofs. However, scurvy also tends to include porous lesions on the lateral wings of the sphenoid, none of which were observed in the material from Verteba Cave. This makes it very unlikely that scurvy caused any of the recorded instances of porotic
hyperostosis or cribra orbitalia. It is possible that some of the cases from Verteba Cave were caused by inflammatory responses. Without microscopic observations, however, this can only remain speculation. Similarly, determining cases caused by taphonomic alterations also requires microscopic investigation. It seems unlikely that post-depositional degradation caused any of the lesions, as all bones recovered are in excellent condition, with very few taphonomic changes.

**Dental Health**

Statistical analysis reveals that the Tripolye agriculturalists suffered from significantly worse dental health as compared to the foragers that preceded them. The Tripolye were found to have higher rates of dental caries and periodontal disease when compared to earlier Mesolithic/Neolithic hunter-fisher-gatherers. This pattern holds true when using both tooth count and individual count methods, and suggests the adoption of agriculture led to poor dental health in prehistoric Ukraine.

Analysis of dentitions from Verteba Cave demonstrates that, in general, the Tripolye population experienced a moderately high rate of dental caries and limited AMTL. Paleobotanical and archaeological studies have shown that a wide variety of plant and animal foods were available to the Tripolye. The dental caries evidence suggests that cariogenic carbohydrate-rich foods were especially important to the Tripolye diet. Cariogenesis among the Tripolye was probably primarily driven by the consumption of carbohydrate-rich staple crops such as wheat and barley. Biomedical studies have demonstrated the high cariogenicity of these plants (Buttner and Muhler, 1958; Firestone et al., 1982). In addition to domesticated crops, Watson (2008) points out
the importance of considering the contribution of wild plants to cariogenesis. For the Tripolye, the consumption of wild fruits, such as cherries, and wild products like honey, probably contributed to dental caries (Pashkevych, 2004). It is important to point out, however, that the caries rates observed here do not mean that protein-rich foods were not consumed. Rather, the Tripolye simply consumed enough carbohydrate-rich foods to allow carious lesions to develop and affect a large proportion of the population.

Interestingly, the large sample of Mesolithic/Neolithic hunter-fisher-gatherers was found to be universally free of carious lesions. Stable isotope analysis suggests that the diet of these foragers consisted primarily of riverine resources, such as fish, and hunter terrestrial mammals (Lillie and Richards, 2000). A high protein diet focused on fish may have prevented the formation of dental caries in these hunter-fisher-gatherers by keeping the environment of the oral cavity more basic than normal. The sharp contrast between the foragers and farmers in terms of dental caries rates highlights the deleterious impact of the adoption of agriculture on oral health and the dependence of the Tripolye on carbohydrate-rich plants.

Comparison of dental caries rate by sex shows that males and females suffered from similar rates of cavities. Therefore, I reject my additional hypothesis that the adoption of agriculture led to higher rates of dental caries among females. Ethnographic analogy is helpful in interpreting these results. Walker and Hewlett (1990) studies how behaviorally mediated sex differences affect dental caries rate among pygmy foragers and Bantu farmers in Africa. Walker and Hewlett quantified the amount of carbohydrates and proteins consumed by each sex, and found both pygmy and Bantu females to consume significantly more carbohydrates than their male counterparts. They linked the observed
difference in consumption to the sexual division of labor. In both societies, females were responsible for collecting and preparing plant foods, while males were involved in the keeping of domesticated animals and hunting. This division of labor gave females constant access to carbohydrate-rich plant foods throughout the day, while males had more access to animal meat. Females were found to snack on available plant foods regularly throughout the day, while males consumed food much more infrequently. Walker and Hewlett linked these behavioral differences to the elevated frequency of dental caries that they observed in the female portion of both populations. According to Walker and Hewlett, the higher consumption of carbohydrates resulted in increased cariogenesis for females, and their constant snacking would have significantly contributed to caries formation by maintaining an acidic oral environment throughout the day. By contrast, the infrequent snacking and protein-rich diet of males limited their caries burden. The data from Verteba Cave point to similar caries rates for the male and female subgroups of the Tripolye population. This suggests that access to cariogenic foods was approximately equal for males and females, and may reflect a sexual division of labor where different aspects of plant processing were shared by the sexes. Analysis of Tripolye grave goods by sex from Vykhvitintsi cemetery shows that agricultural implements such as sickles and hoes are only associated with male graves (Dergachev, 1978). With this added archaeological information, it seems most likely that males carried out farm work, while females may have been involved in processing and cooking plants. The end result of this division of labor was equal access to cariogenic foods, and roughly equal consumption of carbohydrate-rich cereals.
Although the application of the caries correction factor to the Verteba Cave dental sample did not substantially change our results, it allowed us to control for the confounding effects of AMTL on the study of dental caries rates, improving the strength of the study.

Consistent with the dental caries results, periodontal disease was also observed at a high rate among the Tripolye. This is not surprising, as the carbohydrate-rich diet of the Tripolye would have encouraged the proliferation of dental plaque, the bacterial colonies of which cause the infection of the gingival tissue. Periodontal disease was so widespread among the Tripolye that it affected every individual and nearly every alveolus. As discussed in Chapter 2, this high rate of periodontal disease reflects serious health issues for the Tripolye, as periodontal disease is a risk factor for respiratory and gastrointestinal infection, as well as heart disease.

**Periostitis**

Only a single skeletal element out of more than 1000 was found to have evidence of periostitis. No comparison was possible with the Mesolithic/Neolithic foragers, as data on periostitis was not published. However, the very low rate in the Verteba Cave sample seems to be at odds with the rest of the bioarchaeological analysis. All other skeletal indicators point to compromised health among the Tripolye, while the data on periostitis suggests a population generally free of inflammatory response-causing infections. Following a traditional bioarchaeological interpretation, the low rate of periostitis suggests the Tripolye were a healthy population, a position in conflict with the results of all other statistical tests. Enamel hypoplasias, porotic hyperostosis, cribra orbitalia and
reduced adult stature are all caused by infection and malnutrition. Low levels of infection seem to be at odds with what is known concerning the sedentary lifestyle and population dense settlements of the Tripolye. As discussed above, these factors would have exposed these early farmers to multiple sources of infection, ranging from contagious crowd diseases to pathogens in the accumulating waste of the permanent villages. DeWitte and Bekvalac (2011) observed high rates of periostitis in historical skeletal samples from London that also exhibited high rates of periodontal disease. They suggested these rates may have reflected a population with highly reactive immune systems, where inflammatory responses were easily triggered by slight physiological insults. Based on that interpretation, the low rates of periostitis among the Tripolye may indicate a depressed immunocompetency among the early farmers. This fits well with the data provided by other skeletal markers.

Summary

The bioarchaeological comparison of foragers and farmers from prehistoric Ukraine demonstrates that the adoption of agriculture in this region was detrimental to human health. As compared to earlier Mesolithic/Neolithic period hunter-fisher-gatherers, Tripolye agriculturalists experienced higher rates of systemic stress as indicated by enamel hypoplasias and stature. Based on archaeological data, this stress was most likely caused by the Tripolye’s reliance on nutritionally poor cereals as weaning foods and dietary staples, their close contact with domesticated animals, sanitation issues related to life in permanent settlements, diseases introduced by long distance trade, and the contagious crowd diseases associated with high population densities. Additionally, the Tripolye were found to have significantly worse dental health
than their foraging predecessors. Higher rates of dental caries among the farmers reflect their reliance on highly processed carbohydrate-rich cereals, which promoted oral bacteria proliferation and their destruction of the dental hard and soft tissues. While the Tripolye are recognized for the cultural developments they brought to Eastern Europe, their introduction of an agricultural subsistence system resulted in the deterioration of human health for prehistoric populations in Ukraine.

**Contextualizing the Ukrainian Agricultural Transition within an European Perspective**

As discussed in Chapter 2, previous studies have found a wide variety of results when examining the biological impacts of the transition to agriculture in prehistoric Europe. Compared to these studies, the results obtained for Ukraine present the best evidence in support of the hypothesis that the adoption of farming was detrimental to human health. In this section, I discuss how the data on the agricultural transition in Ukraine compares to studies in other regions of Europe.

One of the most striking differences between the Ukraine data and that of the rest of the continent is the more severe impact of agriculture on dental health. As compared to other early European agricultural groups, the Tripolye have a much higher rate of dental caries. Using the tooth count method of reporting, the Tripolye were observed to have carious lesions on 9.52% of teeth (11.44% corrected). This is about twice the 4.2% average caries rate calculated by Meiklejohn and Zvelebil (1991) for early European agriculturalist using samples from the Netherlands, Belgium, France, and Portugal. Outside of Ukraine, the highest dental caries rate comes from Neolithic/Chalcolithic
Portugal, where 8.0% of teeth were found to display carious lesions (Cuhna et al., 2007; Silva, 2002). The high rate of tooth decay in Portugal is believed to have been caused by the consumption of highly cariogenic fruits such as figs and carobs, in addition to carbohydrate-rich cereals (Cunha et al., 2007; Silva, 1996a; 1996b). This suggests that as compared to other European early agriculturalists, the Tripolye were highly reliant on cariogenic foods, a factor that likely contributed to both poor physiological and oral health. Overall, the changes observed across the transition to agriculture in Ukraine are consistent with the results from other regions of Europe, including increases in dental caries found in studies of archaeological skeletons from some sites in Portugal, Scandinavia, the Czech Republic, and the British Isles. However, no such increase was observed in the Netherlands, and the opposite pattern was found at other sites in Portugal. Together, these results indicate that early agricultural adaptations varied across the continent, with some groups, such as the Tripolye, suffering from high caries rates, while other groups experienced a much more limited caries burden.

Like dental caries, the Tripolye are also at the high end of early European farming populations in terms of enamel hypoplasias. Using the tooth count method, the Tripolye had enamel hypoplasias on 18.18% of teeth, and 48.57% of observable individuals had at least one hypoplastic tooth. These rates are much higher than those observed by Papathanasiou for Neolithic Greece, where 8.3% of teeth were observed to have enamel hypoplasias. Likewise, the Tripolye had a rate of enamel hypoplasias over 30 times greater than the 0.6% of teeth found to be hypoplastic among early farmers from Britain. However, the Tripolye were similar to Early Neolithic and Late Neolithic farmers from Scandinavia in terms of their individual count rate of enamel hypoplasias, at 59.4% and
63.2%, respectively. These comparisons suggest that the Tripolye experienced some of
the highest rates of childhood stress during the early agricultural period of European
prehistory. Their high reliance on nutritionally poor cereals and settlement in the most
population dense villages in Europe contributed to these relatively high rates.

Besides the data from Ukraine, Wittwer-Backoffen and Tomo (2008) were the
only researchers to find an increase in stress following the transition to agriculture using
enamel hypoplasias. Their study focused on foragers and LBK farmers from the Czech
Republic. Bennike and Alexandersen (2007) found an increase in the rate of enamel
hypoplasias in their study from Scandinavia, however, this difference was not significant.

The Tripolye were affected by a generally high rate of porotic hyperostosis/cribra
orbitalia, with 43.33% of observable individuals displaying at least one of the two
conditions. Broken down, this included porotic hyperostosis in 26.32% of individuals and
cribra orbitalia in 13.9% of individuals. These rates appear to fall somewhere in the
middle of those observed for early European farmers. On the low end, Roberts and Cox
(2007) report cribra orbitalia in 2.3% of Neolithic and 5.8% of Bronze Age
agriculturalists, while Papathanasiou found porotic hyperostosis on 50% and cribra
orbitalia on 60% of Neolithic crania from Greece. The high rates observed in Neolithic
Greece are believed to reflect dietary stress most probably resulting from a diet focused
on nutritionally-poor cereals. Ubelaker and Pap (2009) report the rates of cribra orbitalia
and porotic hyperostosis observed among Copper Age pastoralists from Hungary. They
found 4.3% of observable individuals to have cribra orbitalia, while porotic hyperostosis
was completely absent from the sample. According to Ubelaker and Pap, the relatively
low rates likely reflect low population density and a diet rich in highly nutritious animal
products. As compared to other European studies, the Tripolye from Verteba Cave appear to fall in the center of the observed rates for porotic hyperostosis and cribra orbitalia. This suggests that although the Tripolye had dietary and infectious problems leading to the manifestation of the lesions, they fall well below the high rates observed among early farmers from Greece.

The Tripolye from Verteba Cave were observed to have periostitis on only a single bone out of 1094 skeletal elements observed (0.091%). Roberts and Cox (2007) found similarly low levels of periostitis in their samples from Great Britain. They found 0.1% of ribs and 0.3% of maxillae to be affected by periostitis among their Neolithic skeletons. Likewise, Papathanasiou (2005) reports periostitis on less than 1% of postcranial bones from Greece. In their study of the transition to agriculture in Portugal, Cunha et al. (2007) found periostitis to increase following the adoption of agriculture, although they claim that Neolithic populations continue to display low levels of the lesion. However, while they report that the Mesolithic period is characterized by few cases of periostitis, they provide no specific rates, precluding the use of statistical tests. At the Portuguese Neolithic site of Paimogo I, 20% of left tibiae and 16% of right tibiae were observed with periostitis, representing one of the highest rates in Europe for the time period. With the exception of the data from Portugal, periostitis seems to have been an infrequent occurrence among early European farmers, perhaps because they experienced low levels of systemic infection.

Bioarchaeological studies of agriculture’s impact on stature have yielded variable results. The data from Ukraine shows that following the adoption of farming, average long bone lengths significantly declined for both males and females. Similar results were
obtained by Bennike and Alexandersen (2007) in Scandinavia, who also found the initial transition to agriculture to be associated with a decline in long bone lengths. However, their data show that after farming took hold across the region during the Early Neolithic, stature rebounded and average long bone lengths actually increased during the Middle/Late Neolithic. At present, the limited skeletal data in Ukraine precludes a similar diachronic analysis for the Tripolye. The results from Ukraine and Scandinavia differ from those obtained by Meiklejohn and Babb (2011), who used a large database of skeletons from across Western Europe to show that stature did not differ significantly between Mesolithic foragers and Neolithic farmers (Table 2.1). This suggests that unlike the transition to agriculture in Ukraine, which resulted in increased physiological stress, the adoption of farming in Western Europe may not have had an appreciable impact on human health. The average male Tripolye long bone lengths are fairly similar to average lengths from Western Europe, with the exception of the femur. On average, femora from Western European Neolithic male farmers measure 440.03mm, as compared to just 425mm for Tripolye males. This likely indicates a generally shorter stature for the Tripolye males, perhaps reflecting the relatively high level of systemic stress experienced by early Ukrainian farmers. Within Europe, the Tripolye’s specific cultural adaptation, including their high reliance on nutritionally-poor carbohydrate-rich cultigens, densely settled population, and close contact with domesticated animals may have made them one of the most unhealthy of all the early farming populations.

As compared to studies from other regions of Europe, data from Ukraine appears to provide the best evidence for deteriorating health following the transition to agriculture. Specifically, following the adoption of agriculture in Ukraine, dental caries
and enamel hypoplasias were found to significantly increase, while stature significantly decreased. Studies from other regions of Europe seem to yield more variable results. In the Netherlands, no differences were found between foragers and farmers in terms of enamel hypoplasias, dental caries, or stature (Smits and van der Placht, 2009). Likewise, in Scandinavia no significant changes were found when foragers and farmers were compared in terms of enamel hypoplasias or stature, although agriculturalists were observed to have significantly more dental caries. In Portugal, the transition to agriculture seems to have affected oral health in complex ways. While some Neolithic farmers display higher rates of dental caries than earlier foragers, others do not. However, Portugal seems to be the only European location studied to date where periostitis increased with the adoption of farming. Data from the Czech Republic points to increased enamel hypoplasias and dental caries following the transition to agriculture in that region in a manner similar to that observed in Ukraine. Other European studies, such as those from the British Isles and Greece, quantified the health of early agriculturalists, but lacked comparative forager samples. These studies did find moderate to high rates of pathology among the early farmers, suggesting they suffered from suboptimal health. Overall, the evidence from Europe paints a picture of complex changes in health with agriculture. While most studies have some skeletal indicator that suggests deteriorating health, they also typically have other markers that suggest no change. In this regard, the data from Ukraine most clearly support the hypothesis that the transition to agriculture was detrimental to human health.

The rates of skeletal pathologies observed among the Tripolye appear to fall at the middle to upper end of published values for early European farming populations.
Likewise, the average Tripolye long bone lengths are among the shorter reported values. This suggests that as compared to other early European farming groups, the Tripolye’s specific cultural adaptation may have been especially detrimental to health. The combination of their heavy reliance on nutritionally poor cereals, high population density, and stabling of animals inside houses led the Tripolye to suffer from some of the worse health on the continent for that time period.

Conclusion

Based on his interpretation of bioarchaeological studies, Larsen (1995; 2006) has described the transition to agriculture as a catastrophe for the health of humankind. Using similar data, Diamond (1997) believes that the development and adoption agriculture was the biggest mistake humans ever made. The results of this study are in line with their interpretations. Bioarchaeological data presented here demonstrate that the transition to agriculture in prehistoric Ukraine led to increased levels of systemic stress and oral pathology. Specifically, the Tripolye agriculturalists were found to have significantly higher rates of enamel hypoplasias and dental caries, as well as significantly shorter average long bone lengths as compared to earlier Mesolithic and Neolithic period foragers. Furthermore, the Tripolye were found to have suffered from an extremely high rate of periodontal disease and a moderately high rate of porotic hyperostosis/cribriform orbitalia. When taken together, this information suggests that the arrival of the Tripolye’s specific farming cultural adaptation in Ukraine resulted in deteriorating health for populations in that region of Europe.
While the skeletal sample employed in this study is relatively small, it represents the largest collection of Tripolye burials currently available. As such, this study provides the first investigation of the biological consequences of the transition to agriculture for this portion of Eastern Europe, and increases our understanding of how this important period of prehistory has affected the human condition.
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