INVESTIGATION OF MIDDLE WOODLAND POPULATION MOVEMENT IN THE MIDWESTERN UNITED STATES USING STRONTIUM ISOTOPES

BY

DANA ELIZABETH BEEHR

DISSERTATION

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Anthropology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2011

Urbana, Illinois

Doctoral Committee:

Professor R. Barry Lewis, Chair
Professor Stanley H. Ambrose
Professor Thomas E. Emerson
Dr. Kristin Hedman, Physical Anthropologist

ABSTRACT

This research sought to compare levels of population movement in the Illinois and Ohio regions during the Middle Woodland period in Eastern North America. This was accomplished by subjecting 81 human remains at two Illinois sites (Utica Mounds and Albany Mounds) and one Ohio site (the Hopewell Mound Group) to strontium isotopic analysis in order to detect potential immigrants to the site, along with 38 faunal specimens to provide a baseline for comparison. Building on Bolnick and Smith's (2007) mtDNA research, it was hypothesized that the Illinois sites would demonstrate higher levels of population movement than the Hopewell site. The results of the study did not support the hypothesis. Three potential immigrants were detected in Illinois, all from Albany Mounds, while seven potential immigrants were detected at the Hopewell Mound Group. No potential immigrants were detected at Utica Mounds. Selected samples were also subjected to light isotope analysis ($\delta^{13}C$ and $\delta^{18}O$). $\delta^{13}C$ analysis confirmed that the staple diet at all sites involved primarily C_3 food sources, while the $\delta^{18}O$ analysis failed to support the strontium data with regards to potential immigrants. This may suggest that $\delta^{18}O$ analysis is not an appropriate technique to detect immigration in this region.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the help of the following individuals and institutions: the University of Illinois at Urbana-Champaign's Anthropology Department and its former chair Dr. Steve Leigh; Eve Hargrave and Dr. Kris Hedman at the Illinois State Archaeological Survey; Dr. Terry Martin and Dawn Cobb at the Illinois State Museum; Christina Kastell at the Putnam Museum of Natural Science; Dr. Brad Lepper, Linda Pansing and Bill Pickard at the Ohio State Historical Society; Dr. Kathy Brady at the Hopewell Culture National Historical Park; Dr. Michelle Birnbaum at the University of Wisconsin-Milwaukee; Dr. Robert Martin and Dr. Jamie Kelly at the Chicago Field Museum, as well as Dr. Paul Fullagar at the University of North Carolina-Chapel Hill. Especial thanks go to Dr. Craig Lundstrom and Dr. Tom Johnson at the University of Illinois at Urbana-Champaign's Geology Department for their assistance with performing the analysis of the samples. Thanks also to Dr. Barry Lewis and Dr. Stanley Ambrose, as well as the other members of my committee, for their invaluable guidance and assistance. And finally, deepest thanks to my husband Steven Pheley and my father Terry Beehr, without whose support and love I could not have finished this dissertation.

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CHAPTER 1

INTRODUCTION

The goals of this dissertation were to examine two hypotheses: first, that Illinois demonstrated higher levels of migration than Ohio during the Middle Woodland time period (150 BC to AD 400), and second, that migration was a significant demographic force during the Middle Woodland. This was accomplished through strontium isotopic analysis of human skeletal remains from three previously excavated sites: Utica Mounds and Albany Mounds in Illinois and the Hopewell Mound Group in Ohio. This research is important because these two regions have long been thought to be key players in the development of what has been known as the Hopewell Interaction Sphere, a widespread and significant cultural phenomenon involving trade and exchange during the Middle Woodland time period (Jeske 2006:288-9).

The Hopewell Interaction Sphere concept was established in the mid-twentieth century (Caldwell 1964), as a means of conceptualizing the nature and origins of Middle Woodland regional interaction. The exact nature of the Hopewell Interaction Sphere was a source of controversy for some time, with some researchers arguing it was primarily an ideological network and others claiming it was a network for exchange of status items (Caldwell 1964; Struever and Houart 1972). Items thought to have been exchanged within the Hopewell Interaction Sphere included primarily status and ritual goods such as catlinite pipes, figurines, ear spools, and rocker-stamped pottery (Griffin 1952:360; Seeman 1979), as well as exotic raw materials such as galena, obsidian, copper, and mica (Griffin 1952:360; Otto 1979; Seeman 1979). It is now recognized that the Hopewell Interaction Sphere was not a unified phenomenon, that interaction was probably carried out at the personal rather than the regional level, and that different classes of goods probably moved by a variety of small-scale processes (Carr 2005).

These research questions necessarily involve changing theoretical interpretations of migration as it pertains to North American archaeology. During the early twentieth century, migration was often employed to explain Native American archaeological assemblages. Research tended to treat indigenous cultural groups as static, homogenous and unchanging entities in which much of the variation could ultimately be explained by the effects of migration (Snow 1995:60). This uncritical and simplistic application, along with dissatisfaction with a lack of emphasis on human actors, led to a rejection of migration theory with the development of New Archaeology, which attempted to bring greater scientific rigor to archaeological inquiries (Burmeister 2000:540). The weak methodological and theoretical underpinnings of much earlier thinking on migration were recognized (Anthony 1990:896). Migration was rejected as an important factor and attention was focused on in-situ explanations of cultural development. The rejection of migration as a causal mechanism was so strong that Snow (1995:60) claimed migration had been effectively "outlawed" as a demographic process, and Burmeister (2000:540) asserted that it had been "banish[ed] from archaeology's field of vision."

Over the past two decades, migration has emerged once again as an important possible factor in explanations of social and demographic change. New theoretical approaches for identifying migration draw on research in fields such as demography and sociology (Anthony 1990, 1992; Burmeister 2000). Significantly, these theoretical approaches have refined previous understandings of migration as a single "mass" event. It is now recognized that most migrations are more accurately modeled as a process. Current theories recognize that long-distance migration may occur both in the presence of "push" factors in the home region and "pull" factors in the region to which migration is taking place, along with acceptable transportation costs along the route of travel (Anthony 1990; Burmeister 2000). Anthony (1990:901-905) examined archaeological correlates of long-distance migration, including leapfrogging, migration streams and return streams, and the age-sex structure of migratory populations. Burmeister (2000) further expanded on this by examining migration’s effect on material culture of both the sending region and the receiving region. He also explored methods of establishing archaeological proof of migration, with emphasis on signatures of migration unshared by other processes of cultural interaction.

Along with more rigorous theoretical approaches, recently developed research techniques, including isotopic and molecular analysis of artifacts and skeletal material, also allow new levels of insight into processes of population movement (Price et al. 2002). Armed with new methods for determining area of origin of individuals, archaeologists are increasingly examining the importance of migration as one of many forces that drive cultural change and regional dynamics.

Migration is relevant to studies of the Middle Woodland for two reasons. First, migration is a fundamental demographic process, and as such must be considered when attempting to construct a picture of Middle Woodland societies. Second, regional interaction is a key component of the concept of the Hopewell Interaction Sphere, and migration is a significant form of potential regional interaction.

Research such as that of Farnsworth and Asch (1986), Ruby et al. (2005), and Charles (1992, 1995) has demonstrated that intra-regional migration took place during this time period. Farnsworth and Asch (1986) see evidence for discontinuities in their analysis of the Lower Illinois River Valley. They argue that there is a drastic difference between the Havana Hopewell tradition and the Black Sand tradition that precedes it, and a gap of about 150 years as defined by radiocarbon dates between the earliest Havana sites and the latest sites of the preceding tradition (Farnsworth and Asch 1986:445). Based on this, they argue that the advent of the Havana Hopewell cultural tradition can be explained by an influx of settlers to the most-likely empty Lower Illinois River Valley, probably from the Central Illinois River Valley (Farnsworth and Asch 1986:446). Ruby et al. (2005) and Charles (1992, 1995) also see evidence for immigration in their analysis of Lower Illinois River Valley mortuary customs, consistent with recently developed migration models (Anthony 1990; Burmeister 2000). Charles (1992, 1995) and Ruby et al. (2005) discuss "two tracks" of the Lower Illinois River Valley Middle Woodland mortuary program. In one track, certain lineages received preferential treatment including temporary entombment in a ramped log tomb, followed by reburial in the ramp surrounding the central tomb, while in a second track, members are simply buried on the margins of the ramp. They argue that this represents differential treatment of founding lineages versus latecomers to the community, and that founding lineages gained status by a process of "levitation" as new immigrants filtered into the valley. This interpretation is consistent with Anthony's (1990) observations that very often in migrant groups, the initial immigrant families in a new region will gain status through their establishment of themselves as "apex families" (Anthony 1990:904), providing advice and assistance to newcomers. Studies such as these demonstrate that migration studies and theory are relevant both to the general understanding of the Middle Woodland, and to the understanding of the nature of Hopewell interactions across the midcontinent.

Recent mitochondrial DNA studies of Middle Woodland skeletal remains suggest that in addition to intraregional population movement, there were significant inter-regional contacts as well (Bolnick and Smith 2007). Bolnick and Smith's (2007) study suggested contact and genetic exchange between Ohio and Illinois in particular, the two regions under study in this dissertation. The Bolnick and Smith (2007) study examined mtDNA from 39 individuals from the Pete Klunk Mound Group, a group of Middle Woodland burial grounds in Illinois. These DNA sequences were compared with those for 34 individuals from Mound 25 of the Hopewell mound group in Ohio—a site located at the "epicenter of the Hopewell phenomenon" (Bolnick and Smith 2007:33). The researchers inferred not only that the Illinois population was most likely matrilocal, but also that gene flow was taking place between the Illinois and Ohio populations. The research results suggested that the direction of genetic transfer was from Ohio to Illinois, which was unexpected because previous research on Illinois/Ohio Hopewell contacts indicated the opposite—that population movement was unidirectional from Illinois to Ohio (Bolnick and Smith 2007:35). Bolnick and Smith (2007) suggest that such genetic flow was likely small in scale, comprising limited numbers of individuals from each successive generation, perhaps on pilgrimages, vision quests, or quests to gather exotic and culturally significant materials. This accords with Carr's (2005) suggestion that "small-scale" personal trips were an important mechanism of regional contact and exchange for this time period.

Bolnick and Smith's (2007) study was somewhat unusual in that most studies of mtDNA variation in North America have been concentrated in the west or along the northwest coast (e.g. Malhi et al. 2003; Malhi et al. 2004; Lorenz and Smith 1996) in an attempt to answer questions relating to the peopling of the New World (Bandelt et al. 2003; Fix 2005). However, as the focus of mtDNA research has begun to shift from continent-wide studies to investigating questions of regional gene flow and settlement patterns (Malhi 2004:33; Shook and Smith 2008:14), some researchers have begun to concentrate on eastern or northeastern North America

(Shook and Smith 2008; Stone and Stoneking 1998; Stone and Stoneking 1993). Bolnick and Smith's (2007) study adds to these.

Bolnick and Smith (2007) compared individuals that she and her researchers sampled from the Pete Klunk mound group against samples previously collected from the Hopewell Mound Group's Mound 25 by Lisa Mills (2003). As mentioned previously, her total sample set consisted of 39 individuals from Pete Klunk, along with 34 previously-analyzed individuals from Lisa Mills's (2003) data set. Although typical data sets taken from living populations often number in the hundreds (cf. Lorenz and Smith (1994) with a dataset of 497 individuals, Stoneking et al (1991) with 525, Helgason et al. (2006) with a dataset of 395, or Malhi et al. (2003) with a sample of 117), those taken from archaeological material are often smaller (e.g. Stone and Stoneking (1993) with a dataset of 50, or Shook and Smith (2008) with a dataset of 44, or Mills's own (2003) dataset of 49 individuals). Bolnick and Smith's (2007) sample set is thus comparable to those of other studies done on archaeological material. Her initial sample set from Pete Klunk consisted of 55 individuals; however, DNA extraction was only successful on 39 of these individuals, giving an extraction rate of 71%. This is similar to results reported by Shook and Smith (2008) in their study of prehistoric mtDNA from northeastern North America (75%) and slightly better than the 69% success rate obtained by Mills (2003). Materials sampled from living individuals have included blood or hair (Lorenz and Smith 1994), or cells taken from buccal swabs (Helgason 2006); however, Bolnick and Smith (2007) performed their analysis on material taken from rib bones. This is in contrast to Mills (2003:55-6), who chose to perform her analysis on teeth because teeth are more resistant to diagenetic contamination. Despite this, however, bones have been used in other studies of archaeological mtDNA. Ribs were also chosen for analysis by Stone and Stoneking (1998) in their work on the Norris Farms Oneota population, and bone samples were included in Shook and Smith's (2008) research. mtDNA analysis performed on the famous Qilakitsoq Inuit mummies even included samples of archaeological hair and fingernails (Gilbert et al. 2007). This demonstrates that teeth are not used exclusively in analyzing archaeological mtDNA, and that Bolnick and Smith's (2007) use of rib bones was not without precedent.

Bolnick and Smith (2007) list standard precautions taken to avoid contamination, including use of a special room dedicated to ancient DNA research, protective clothing, the use of disposable labware, and irradiation. Bolnick and Smith (2007) also included blank, "negative" controls at every step of the process to help identify possible contamination, though she did not include or did not mention positive controls. Yang et al. (2003) have called for the inclusion of positive controls as well as negative ones (control samples with very small amounts of modern mtDNA); however, this has not become common practice (e.g. Shook and Smith (2008), Gilbert et al. (2007), Izagirre (2005) all did not list positive controls as part of their anti-contamination measures). Bolnick and Smith (2007) also employed four separate methods to estimate gene flow between Illinois and Ohio, citing disagreement about which method was most acceptable. Though there was variation in the amount of migration, the methods agreed that the bulk of the gene flow was proceeding from Ohio to Illinois. Overall, Bolnick and Smith's (2007) research procedures are very similar to those of other researchers in the field.

Bolnick and Smith's (2007) findings as to haplogroup frequencies were somewhat unexpected in that haplogroup C was the most prominently represented (19 out of 39), followed by haplogroup A with nine out of 39. This is in contrast to Lorenz and Smith's (1996) study, which indicated that haplogroup A was the dominant haplogroup throughout most of North America, including the Midwest/Great Plains. Lisa Mills's (2003) research also demonstrated haplogroup A as the dominant haplogroup at the Hopewell Mound Group with 14 out of 34 individuals in her sample showing this haplogroup. However, haplogroup C was the next most prominent with 10 out of 34 individuals having this haplogroup. It is possible that high levels of haplogroup C are specific to the Pete Klunk site.

Considerable archaeological evidence of exchange items found in both regions support the inference of sustained contacts between Illinois and Ohio during the Middle Woodland period, but the nature of these contacts and the direction in which items were moving remain open research questions. Recent investigations such as the Emerson et al. (2004) study of pipestone pipes from the Tremper Mound site in Ohio offer a case in point. This large mortuary center contained a large quantity of apparently ritually destroyed status goods, including a cache of broken effigy and plain bowl pipes (Penny 2004:50). Such pipes had long been viewed as ideologically significant artifacts that were manufactured in Ohio from local pipestone source (Feurt Hill) and traded throughout Eastern North America (Struever and Houart 1972:71). The Emerson et al. (2004) analysis demonstrated that most of these pipes were in fact made of Illinois Sterling pipestone (Farnsworth and Asch 2004; Hughes et al. 1998) and Minnesota catlinite (Emerson et al. 2002, Emerson et al. 2005, Emerson et al. 2005a). When considered together with evidence of pipe manufacture found at Illinois sites, and the fact that Tremper pipe styles are very similar to those of pipes found in Illinois, Emerson et al. (2004) argue that the pipes were manufactured in Illinois and carried to Ohio, as opposed to being made of raw stone that had been carried to Ohio from Illinois. Thus, the Emerson et al. (2004) study reached quite a different conclusion than that of Bolnick and Smith (2007), who suggested that Middle Woodland population movement flowed from Ohio to Illinois, as well as calling into question traditional interpretations of the nature of Illinois and Ohio regional interaction during the

Middle Woodland period, most of which views goods and information as flowing from Ohio to Illinois.

As mentioned previously, the primary goals of this research were to examine two hypotheses through strontium isotopic analysis: first, that levels of population movement were higher in Illinois than Ohio during the Middle Woodland, and second, that population movement was itself a powerful demographic force during this time period. An additional goal of this research was to evaluate the potential of strontium isotopic analysis as a tool to determine population movement in eastern North America.

Investigation of the first hypothesis is important because it offers the possibility of resolving the discrepancy between the Bolnick and Smith (2007) mtDNA study and that of Emerson et al.'s (2004) pipestone study. Research involving strontium isotopic analysis in this case offered an excellent complement to Bolnick and Smith's (2007) mtDNA work in particular because this technique allows for an examination of an individual's lifetime migration history. Whereas Bolnick and Smith's (2007) mtDNA analysis could detect overall patterns of gene flow, strontium analysis can not only detect actual, individual immigrants to the area, but also potentially identify their area of origin, in effect offering almost a "real time" look at Middle Woodland population movement. This also related to the second hypothesis as demonstrating migration at work as a factor in demographic change.

The second hypothesis is important as part of the overall reappraisal of the role of migration as a demographic force in North American cultural development and during the Middle Woodland in particular. While research had previously been done on the question of population movement during this time period before (e.g. Bolnick and Smith's (2007) research, Farnsworth and Asch's (1986) studies of the Lower Illinois River Valley, as well as the research of Charles (1992; 1995) and Ruby (2006)), most of this research focused on intraregional rather than inter-regional population movement, and large-scale strontium isotopic analysis had not yet been employed in this region prior to this study. Indeed, Carr (2008b:621) has specifically called for the use of strontium isotopic analysis, among other techniques, to address such issues. Therefore, this research was able to contribute a fresh approach to this appraisal.

This research was also intended to serve as a pilot study for future Middle Woodland researchers. While strontium analysis had been used previously in other regions such as the American Southwest (Ezzo et al. 1997; Price et al. 1994), Chile (Knudson and Torress-Rouff 2009), Midwestern North America during the Mississippian period (Price et al. 2007), Mesoamerica (Price et al. 2000; Wright 2005), Scotland (Montgomery et al. 2007), England (Evans 2006), Jordan (Perry et al. 2008), and Neolithic Europe (Bentley et al. 2004; Bentley et al. 2003), it had not been employed on a large scale in Eastern North America before. As the first relatively large-scale application of this technique, this study explored the strengths and weaknesses of strontium analysis in this geographic region and attempted to establish groundwork to assist further uses of this form of analysis in future.

The next chapter will describe the technique of strontium isotopic analysis, including the theory behind the technique and a brief description of previous work involving this form of analysis, as well as examining its suitability for use in Eastern North America. The sites and collections chosen for inclusion in this study, and the procedures used to prepare the samples for analysis will be detailed in Chapter 3, the Materials and Methods section. Chapter 4 presents the resulting data for the sites included in this study. Analysis of the data and its implications is contained in Chapter 5, and final thoughts on the study as well as directions for future research will be offered in Chapter 6.

CHAPTER 2

STRONTIUM ISOTOPIC ANALYSIS

The concept behind the use of strontium isotopic analysis to determine individual migration history relies on the fact that strontium-87 is a radiogenic isotope formed by radioactive decay of rubidium-87, naturally occurring in rocks in the earth's crust (Price et al. 1994:320). Because ^{87}Sr is radiogenic and forms over time, levels of ^{87}Sr differ throughout the crust with the age of the underlying bedrock: specifically, older rock formations will contain more ^{87}Sr (Bentley 2006; Price et al. 1994). Strontium also occurs in three isotopes that are not radiogenic: ^{86}Sr, ^{84}Sr, and ^{88}Sr. The amount of ^{87}Sr in a given area is expressed as a ratio of ^{87}Sr/^{86}Sr (Bentley 2006; Price et al. 1994) and is usually reported to at least five digits (Bentley 2006). Strontium enters the local food chain through the natural processes of weathering; as the rocks in a region are worn away, the strontium they contain becomes part of the soil, where it is absorbed by local plants. Strontium isotope ratios in a region do not necessarily reflect only the underlying bedrock of that region; soils can incorporate strontium from other geological sources such as river silt and wind-blown sediments, rainwater, and sea spray in coastal areas. In addition, modern pollution such as fertilizers can alter ^{87}Sr/^{86}Sr ratios in a given area, which can have an effect on the Sr isotope ratios of modern (though not archaeological) flora and fauna (Bentley 2006).

Strontium isotopic analysis has many potential applications in archaeological research. Strontium can substitute for calcium in skeletal tissues, and in this way the ^{87}Sr/^{86}Sr ratio of a given region is recorded in the skeletal remains of the animals that live there (Bentley 2006; Price et al. 2002). Because bone is remodeled throughout one's lifetime, if human bone from an archaeological context demonstrates an $^{87}Sr/^{86}Sr$ ratio that differs from the strontium isotope profile common to the region, it suggests that the individual was a recent immigrant to the region. Given a strontium isotope database for adjacent regions, the isotopic ratio for a sample can be used to help identify the individual's place of origin. $^{87}Sr/^{86}Sr$ analysis also offers the possibility of being able to determine an individual's migration history over the course of their lifespan (Budd et al. 2000:688; Price et al. 1994:316). Unlike bone, tooth enamel is laid down in childhood and is not subsequently remodeled. Therefore, a mismatch between strontium isotopic signatures of bone and tooth enamel indicate that the individual's childhood was spent in a different region from their adulthood (Bentley 2006; Budd et al. 2000; Ezzo et al. 1997; Hodell et al. 2004; Price and Gestsdottir 2006:132).

Enamel can also be used by itself to determine migration history, and is generally considered to be a better choice given that enamel is more resistant to diagenetic contamination (Bentley 2006). Generally speaking, a mismatch between an individual's enamel and the Sr isotope ratios of the local fauna also suggests the individual migrated to the region during adulthood (Bentley 2006; Bentley et al. 2004; Price et al. 2002, 2006:132, but see Wright 2005), although as previously mentioned, due to modern pollution, it is best to use archaeological faunal material for such a baseline (Bentley 2006).

The provenance principle, which states that raw material sources demonstrate differing geochemical signatures, enabling artifacts to be traced back to the sources from which they were made through analysis of chemical composition (Oregon State University Archaeometry Lab 2011), underlies much isotopic research today. Strontium isotopic analysis can be considered a variant of this in so far as the raw material source is the home region and the "artifact" in question is the human body. The provenance principle is ideally applied in cases where there is a single, “point” source for raw materials, where variability is discrete, and where the source in question is homogenous rather than heterogenous (Oregon State University Archaeometry Lab 2011). Some or all of these conditions may be lacking in strontium isotopic analysis (for example, strontium analysis almost always deals with regional rather than point sources) which can add additional challenges to this form of analysis.

Strontium analysis is a very versatile technique in that it can be used on a variety of substances, including cortical and trabecular bone, dentine, enamel, and bulk samples of soil, plant life and water (Bentley 2006; Price et al. 2002). This technique also offers a number of different ways to detect immigrants. With single individuals, bone can be compared against teeth and if the ratios of the two substances differ, then it indicates that the individual died in a different land from his or her birth. If there are a large number of human remains to be evaluated, a 2*s* deviation cut-off can be used; individuals that fall outside this range are potential immigrants. Human remains can also be compared against a 2*s* range of faunal samples, or against bulk soil and plant samples, although a great number of bulk soil samples may be needed from a variety of geological contexts to capture the full range of regional variation (Price et al. 2002:120)). Plants will be less variable than soil, and faunal bone varies less than plants, demonstrating an “averaging” effect; therefore these may be better choices to establish baseline regional $^{87}Sr/^{86}Sr$ ratios (Price et al. 2002:125). It is possible to compare different skeletal elements against each other, as skeletal elements fully remodel at different times (Sealy 1995). Bentley (2006) has also argued that with fine control over the foods a population ate and where those foods came from (their “menu”), it may be possible to calculate a baseline $^{87}Sr/^{86}Sr$ signature based on their food sources.

Unlike other methods for tracing population migration, such as gene flow analysis, strontium analysis allows researchers to determine life history of individuals. In large ungulates such as bison, multiple horizontal samplings of the same tooth have been used to develop a fine-grained picture of movement over time, which has enabled reconstruction of yearly migration patterns for these animals (Bentley 2006:176; Widga et al. 2010). There is some doubt over whether this same technique is applicable to humans; however, sampling teeth that calcify at different times during childhood and infancy, such as first molars and third molars, may accomplish the same effect (Bentley 2006). Alternatively, if Gulson et al.'s (1997, 1998, 1999, 2003) research on lead isotopic signatures and lactation applies to strontium, it may be possible to use teeth that formed during lactation to determine maternal strontium signature as well. With good control over regional and extra-regional strontium signatures, it may be possible to identify prior areas of residence for potential immigrants (see for example Hoogewerff and Papesch's (2001) analysis of the "iceman" Ötzi). In addition, strontium isotopic analysis can offer clues to settlement patterns such as patrilocality versus matrilocality: e.g. if one gender demonstrates greater variance in $^{87}Sr/^{86}Sr$ ratios is likely to be the gender that moves upon marriage (Bentley 2006:175).

At the same time however, $^{87}Sr/^{86}Sr$ analysis demonstrates several limitations. Diagenetic contamination is a potentially serious issue for research involving bone or dentine (though not enamel). Procedures exist to remove diagenetic contamination of bone (for example, cleansing in mixtures of weak acetic acid), although it is unclear how successful these procedures are (Bentley 2006; Budd et al. 2000). There are also ways to determine whether and how much diagenetic contamination has taken place. Price et al. (2002) has suggested measurement of uranium levels in bone. Budd et al. (2000) suggests measurement of dentine

$^{87}Sr/^{86}Sr$ abundance as a means of estimating potential contamination, assuming that contamination is additive in nature. With a large enough sample size, the spread of values can also be measured; a large spread of values makes it unlikely that much contamination has occurred, as bone that has been susceptible to diagenesis is likely to converge on the local $^{87}Sr/^{86}Sr$ ratio (Price et al. 2007:121). Also, Price et al. (2000) suggests that samples that show as strong outliers may be assumed to be relatively free from diagenetic contamination.

If faunal material is used to establish a baseline, care must be taken with faunal selection. Modern fauna are often undesirable as use of modern industrial fertilizers can alter the strontium profile of the modern foodweb. Therefore it is often best to use archaeological fauna (Bentley 2006; Price et al. 2002, though some researchers have used a combination of modern and archaeological fauna, e.g. Price et al. 2007). Large animals have large home ranges and may engage in seasonal migration that does not approximate the human dietary catchment area, whereas small animals such as snails and rodents are more likely to feed locally but also may not reflect the full range of strontium available in the area; Price et al. (2002) recommends the use of a mix of small and large fauna where possible. Fauna that serve as prey species for humans may be traded or hunted at great range from the region under study, and so may not reflect the regional strontium profile.

Determination of nonlocal $^{87}Sr/^{86}Sr$ signatures may also be affected by differing dietary practices. Because this technique relies on strontium ingested with food, individuals who consume high levels of imported foods may demonstrate strontium signatures differing from local ratios (e.g. Wright’s (2005) Tikal study). It may be difficult to determine the migration history of individuals who moved multiple times during childhood, or who traveled from place to place; a single $^{87}Sr/^{86}Sr$ ratio may reflect the average of the places they visited, and multiple sampling may be necessary to determine their full migration history (Bentley 2006, although as mentioned above, he suggests that sampling multiple teeth from the same individual may avoid this problem). Furthermore, without good control over regional and extra-regional strontium profiles, it will often not be possible to assign a definitive homeland to individuals with non-local strontium signatures. Often the most that can be said is that certain regions are not ruled out, as the possibility exists of other, unknown areas with similar regional strontium profiles that could also be the sending regions for immigrants (Price et al. 2007). If more than two populations are included in a study, and those populations demonstrate overlapping strontium profiles, then without very fine control over the regional strontium profiles it can be difficult to distinguish among the two sites (Montgomery et al. 2007).

Despite these limitations, $^{87}Sr/^{86}Sr$ isotopic analysis has been used with success to determine migration patterns in regions as diverse as the American Southwest, Mesoamerica, Iceland, the Middle East, South America, North Africa and Europe (Bentley et al. 2003; Evans et al. 2006; Ezzo et al. 1997; Knudson and Torres-Rouff 2009; Montgomery et al. 2007; Perry et al. 2008; Price et al. 1994, 2000, 2006, 2006a; Sykes et al. 2006; Tafuri et al. 2006; Wright 2005). Price et al. (1994) and Ezzo et al.'s (1997) research at Grasshopper Pueblo in Arizona demonstrated significant levels of immigration at that site from regions to the southwest and northeast. Price et al. (2000) have also analyzed skeletons from Teotihuacan and found high levels of immigration there, which suggests that Teotihuacan relied on immigration to maintain its population. Price et al. (2000) analyzed bone and dental samples from the Oaxaca barrio at Teotihuacan, and compared them with similar samples from Monte Alban in Oaxaca. It was found that the samples from the Oaxaca Barrio demonstrated a greater range of ratios than the Monte Alban samples, indicating that those inhabitants from the barrio probably came from a range of areas, instead of being drawn exclusively from Oaxaca. Tafuri et al. (2006) used this technique to examine the origins of pastoralism in the North African Sahara. Price et al. (2006) investigated the settlement history of Iceland using this technique, and detected between nine and thirteen possible immigrants to the region. $^{87}Sr/^{86}Sr$ analyses on both human and animal teeth from a Neolithic village in Germany demonstrated differences that led Bentley et al. (2003) to suggest that the site may have been inhabited by two different groups which may have practiced different subsistence strategies, while Sykes et al. (2006) were able to use strontium isotopes to determine information about the introduction of fallow deer into England.

Perry et al. (2008) did research in northwest Jordan, investigating whether a religious enclave known as Khirbet edh-Dharih was local in origin or founded by immigrants. In addition, they tested whether very small numbers of faunal samples (1 to 2 per site) would serve to adequately capture the range of bioavailable strontium in a given region. This was important because Jordanian archaeology does not generally focus on collecting large numbers of small faunal remains, meaning that there is a dearth of local archaeological faunal samples to provide baselines for Sr analysis (Perry et al. 2008:534). Their study included 20 faunal samples from 13 sites throughout western Jordan as well as 12 adult human samples from the single site of the Khirbet edh-Dharih cemetery. Two possible outliers were detected among the human material. However, Perry et al. (2008) concluded, based on cluster analysis of the faunal data, that these small numbers of fauna were not enough to demonstrate the full range of bioavailable strontium in Western Jordan.

Working with two vastly different sites in two different time periods (in Yorkshire and in the Outer Hebrides in Scotland), Montgomery et al. (2007) attempted to identify groupings in relatively homogenous Sr data sets. Through use of direct soil, seawater and rainwater samples, as well as careful consideration and analysis of dietary strategies, including the interplay of land-based and maritime-based diets, Montgomery et al. (2007) identified groupings in her data sets that she interpreted as different communities with different subsistence strategies. However, she acknowledged her methods might not transfer to other geological regions with less control over the regional strontium profile.

Wright's (2005) study illustrates some of ways in which $^{87}Sr/^{86}Sr$ analyses can be used to deduce information about dietary practices. Working with material from Tikal in Guatemala, Wright (2005) detected eight easily identifiable immigrants to the city out of a sample of 83 individuals. In this study, Wright (2005) evaluated two methods for detecting non-local strontium isotope ratios: she defined immigrants as those who fell outside two standard deviations of her normal distribution (as suggested by Price (1994)) and also attempted to compare human skeletal ratios with those obtained from local fauna. Through comparison with local faunal ratios, she demonstrated that the human ratios were higher than would be expected on the basis of chance alone. Wright (2005) suggested that this difference might be due to dietary practices, such as lime processing of maize or heavy consumption of sea salt.

Perhaps one of the most interesting studies involving Sr analysis was performed by Price et al. (2006a), involving human remains excavated in Mexico that showed some traces of traditional West African dental modification practices. Enamel from these remains revealed extremely high Sr isotope ratios that point back to a West African childhood for these individuals (Price et al. 2006a). Price et al. (2006a) inferred that these individuals were slaves that had spent their childhood in Africa, where they had been captured, and transported to Mesoamerica.

$^{87}Sr/^{86}Sr$ isotopic analysis has sometimes been used in combination with other forms of isotopic analysis to give a more complete picture of past human lifeways. Evans et al. (2006, 2006a) combined $^{87}Sr/^{86}Sr$ isotopic analysis with $\delta^{18}O$ analysis to detect immigrants at a Late Roman burial site in southern England, and to investigate Bronze Age burials around Stonehenge, while Knudson and Price (2007) conducted a similar study with Tiwanaku sites in the Andes. Another such example is that of Knudson and Torres-Rouff (2009), which combined $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ analysis with analysis of burial and cranial modification practices to determine whether the cultural distinctiveness of the Upper Loa River Valley in the Chilean Atacama Desert represents an immigrant population or *in situ* development. Knudson and Torres-Rouff (2009) detected only one outlier from their human samples, clearly suggesting that the unusual cultural practices at this site were developed locally.

Strontium isotopic analysis has also been used to determine matrilocality vs. patrilocality in nonhuman hominids**.** Copeland et al. (2011) performed strontium isotopic analysis on eight *Australopithecus africanus* and 11 *Paranthropus robustus* specimens to determine geological home range. Their research found that there was no significant difference in numbers of potential immigrants as defined by $^{87}Sr/^{86}Sr$ isotopic analysis *between* the two taxa, but that *within* the two taxa, females (identified as those with smaller tooth size, based on the high levels of sexual dimorphism in these species) were significantly more likely to display nonlocal $^{87}Sr/^{86}Sr$ signatures than males. For those individuals at the most extreme ends of the size continuum (and thus most securely identified as male or female), 75% of the smaller individuals demonstrated nonlocal signatures, as compared to 17% of larger ones. Copeland et al. (2011) interpreted these data as indicating female dispersal from their native groups, in contrast to the "*Gorilla*-like social structure" (Copeland et al. 2011:5) of conventional wisdom, in which dominant males monopolize females and force younger males out. Copeland et al. (2011:5) suggested that there was "no appropriate modern analogue" for australopithecine social structure.

Strontium isotope analysis has not been widely applied in Eastern North America because of concerns that the underlying geology of the region is too homogenous to allow it to be effective. The provenance principle indicates that geological sourcing works best with point sources that are homogenous, with discrete variations (Oregon State University Archaeometry Lab 2011), which may not apply to the relatively uniform geology of Eastern North America. However, research done by Sillen et al. (1998) at Swartkrans suggested that soil strontium isotopic ratios may differ from that of substrate rock, and that attempts to reconstruct regional ^{87}Sr /^{86}Sr ratios should begin with biologically available strontium, rather than that detectable in underlying geology. While the Swartkrans area offers much more geological variation over a much smaller area than the subtle variations in the region included in this study, the principle that biologically available ^{87}Sr/^{86}Sr may differ from bedrock ^{87}Sr/^{86}Sr remains the same. This suggests that despite the homogenous underlying bedrock, bioavailable strontium may differ across this region, making strontium analysis a viable technique for investigation of population movements in Eastern North America.

This possibility is strengthened by recent studies including those of Hedman et al. (2008) and Price et al. (2007). Hedman et al. (2008) demonstrated that there are measurable differences in isotope ratios in different regions of Illinois, which suggests that strontium isotope analysis might be successful in detecting differences in ^{87}Sr /^{86}Sr ratios between Illinois and Ohio. Hedman et al. (2008) further suggest that the Midwest region has enough ^{87}Sr/^{86}Sr variability to make strontium isotopic analysis a valid and reliable instrument with which to estimate regional interactions, despite the relatively homogenous geology. Hedman et al. (2008) performed their analysis on bone and tooth enamel of faunal remains from Midwestern sites. Their sample focused primarily on Illinois, including sites from the American Bottom and the Great Lakes region, but also included sites from Iowa, Indiana, and Missouri. One to six samples were taken primarily from white-tailed deer remains available at each site. A total of 47 enamel and 28 bone samples were included in the study. The results indicated that, while some sites did have similar ratios, there were significant differences in ratios recovered throughout the regions they sampled, and differences between sites were greater than differences within them, as well as greater than the range of uncertainty of the instrumentation used in the project (Hedman et al. 2009). This suggests that differing regions of the American Midwest do in fact have detectable differences in $^{87}Sr/^{86}Sr$ ratios, meaning that the technique of strontium isotopic analysis is appropriate for determining migration patterns in Eastern North America.

Further evidence of the interpretive value of strontium isotopic research in Midwest archaeology can be found in Price et al.'s (2007) work on the Mississippian site of Cahokia, in Illinois. Price et al. (2007) investigated $^{87}Sr/^{86}Sr$ isotope ratios from this site and from the Wisconsin site of Aztalan. Based on artifactual evidence, Aztalan is a site thought to be related to Cahokia in some way, possibly even founded by Cahokians. Price et al. (2007) collected bone and enamel samples of faunal remains from both sites to use as baseline comparisons (including squirrel and deer teeth from Cahokia and deer and other teeth from Aztalan), and found distinct differences between the two regions. Using the baseline comparison and analyzing a sample of 20 human individuals, Price et al. (2007) were able to identify five clearly non-local $^{87}Sr/^{86}Sr$ ratios and one possible non-local $^{87}Sr/^{86}Sr$ ratio from human remains at Aztalan, including three individuals who demonstrated $^{87}Sr/^{86}Sr$ isotope ratios within the Cahokian range. Price et al. (2007:536) stated that they were quite cautious in making the distinction between local and nonlocal signatures, and it is possible that a higher number of individuals in their study originated outside Aztalan. However, even with their conservative approach, they were still able to identify immigrants to the site of Aztalan and suggest a possible connection with Cahokia.

The above studies suggest despite homogenous bedrock geology, there are in fact subtle regional differences that affect bioavailable strontium and make strontium isotopic analysis a potentially useful tool for detecting population movement in the North American Midwest. The underlying geology of the two regions under study, Illinois and Ohio, along with other factors that may affect the signatures of their bioavailable strontium, will be discussed below along with the implications for strontium analysis.

During the last ice age, glaciers covered most of northern and western Ohio, while the southern and eastern portions of the state were left unglaciated. The two most recent glaciations, the Illinoian and Wisconsinan, made the most prominent contributions to the geology of Ohio and Illinois (Grimley 2000; Hansen 1997; U.S. Geological Survey 1995).

On the western edge of Illinois, the location of one of the sites included in this study, Albany Mounds, glacial material is primarily from the Illinoian glaciation—the most extensive glaciation of the state. The Illinoian till contains material from the Illinois basin, primarily shales, siltstones, and other carbonates, as well as some material from northern Indiana Ohio, and Ontario, Canada (U.S. Geological Survey, 1995). Central Illinois, where Utica Mounds is located, was covered by the Lake Michigan lobe during the Wisconsin glaciation (Kempton and Gross 1971). The Lake Michigan lobe brought material from Wisconsin, and the west Michigan and northern Illinois basins, including sandstones and shales as well as carbonates. Its point of origin was Hudson Bay (U.S. Geological Survey 1995).

In Ohio, the Scioto lobe of the Wisconsinan glaciation covered Ross County, bringing material from Ontario including crystalline rocks such as quartzites as well as limestones

(Goldthwait 1959). The line of glacial advance passes through Ross County, leaving part of the county covered by glacial sediments. As a result, Ross County can be divided into several zones consisting largely of Devonian, Mississippian and Pennsylvanian bedrocks overlain by primarily Wisconsinan clay and loam till (Ohio Department of Natural Resources 2007, 2007a).

Debris brought by glaciers from the Ontario region could conceivably affect the $^{87}Sr/^{86}Sr$ average ratio in the areas under study. Groundwater $^{87}Sr/^{86}Sr$ studies suggest that $^{87}Sr/^{86}Sr$ ratios of the Illinois Basin, Michigan and Wisconsin are fairly close to those of Ohio and Illinois and that there should not be much of a difference between Ohio and Illinois soils (Bullen et al. 1996; Marcantonio et al. 1990; McNutt et al. 1989; Stueber et al. 1987). However, groundwater and other studies from Ontario and the Canadian Shield suggest $^{87}Sr/^{86}Sr$ ratios lower than the averages of both Illinois and Ohio. For example, Franklin et al.'s (1991) groundwater study found $^{87}Sr/^{86}Sr$ ratios of 0.7057-0.7070 in northwest Ontario, with an average of around 0.706. Average ratios of 0.704 ± 0.001 and 0.7054 ± 0.0004 were found by Marcantonio et al. (1990). This is much lower than the ratios found by Stueber et al. (1972) and Stueber et al. (1987) for Ohio and Illinois, which ranged from 0.7079 to 0.7130.

In addition to complex geology, the river systems of Illinois and Ohio may also contribute to regional $^{87}Sr/^{86}Sr$. Research by Douglas et al. (2002) on $^{87}Sr/^{86}Sr$ ratios recorded for the Connecticut River watershed suggest that rivers tend to reflect the $^{87}Sr/^{86}Sr$ ratios of the sources from which they originate. Given that the Illinois region is watered by the Mississippi river system, the Mississippi source rocks may influence $^{87}Sr/^{86}Sr$ isotope ratios in Illinois, which would explain Hedman et al.'s (2008) results demonstrating measurable differences in $^{87}Sr/^{86}Sr$ ratios in different regions in Illinois. Research by Stueber et al. (1972) on $^{87}Sr/^{86}Sr$ ratios of Ohio water sources has demonstrated a wide variation in $^{87}Sr/^{86}Sr$ ratios of Ohio waters, ranging from 0.7078 to 0.7130, with higher ratios in the south and east, perhaps due to a change in the geology from limestone to clastic sediments. The Ohio sites from this study are from the southern part of the state and may thus be expected to have ^{87}Sr/^{86}Sr isotopic ratios from the higher end of the scale. Such ratios would differ from those found in a preliminary study of Illinois strontium, which averaged 0.708967 ± 0.000635 for three deer from the American Bottom Dohack site 11S642 (though they would be similar to the ratio of 0.712149 ± 0.000998 for three deer from the Upper Mississippi Material Services Quarry) (Hedman, personal communication). These higher ratios would also differ from those found by Stueber et al. (1987) in his study of Illinois groundwater, which demonstrated ^{87}Sr/^{86}Sr isotopic ratios from 0.7079 to 0.7108. While the range of groundwater ^{87}Sr/^{86}Sr ratios for Illinois and Ohio are similar, these ranges are wide enough to expect interregional differences in foodweb ^{87}Sr/^{86}Sr isotopic ratios. Hedman et al.'s (2008) results reinforce that suggestion. Their ^{87}Sr/^{86}Sr ratios were recovered from deer tooth enamel, and therefore likely reflect the regional bioavailable Sr isotopic ratios. It will be necessary therefore to compare these ratios to Ohio Hopewell deer and other nonmigratory fauna, which will represent the bioavailable Sr isotopic ratio of the region.

The inclusion of archaeological nonhuman teeth allowed the reconstruction of the preindustrial biologically available Sr ratios for the regions under study. Based on Hedman et al.'s (2008) and Price et al.'s (2007) work in Illinois, initial expectations for the Illinois sites in this study were that the Albany site would have values broadly similar to those found in Price et al.'s (2007) Aztalan study, roughly 0.710 to 0.711. The Utica Mound Group is located in the same county as the Material Services Quarry included in Hedman et al.'s (2008) study, and was expected to have similar ratios to those found at that site (0.712). In Ohio, strontium ratios from the Hopewell Mound Group were expected to be similar to the high end of the range reported by Steuber et al. (1972), or roughly 0.7130.

Light isotopes

As an adjunct to the strontium study, selected samples were also subjected to light-isotope analysis, in particular $\delta^{13}C$ and $\delta^{18}O$ analysis. This portion of the study was restricted to individuals where samples over 10 µg were recovered, in order to ensure that enough of each sample remained for $^{87}Sr/^{86}Sr$ analysis; 10 µg of sample is generally required in order to allow for accurate recovery of $^{87}Sr/^{86}Sr$ analysis (Glessner, 2009, personal communication). As a result, light isotope data for the sites in the study is not as complete as the strontium data; however, where it exists, it provides useful additional information to the strontium data. These techniques will be briefly described below.

Carbon isotope analysis is used in reconstructions of paleodiet. This technique works by measuring the ratio of ^{13}C to ^{12}C in food residues and body tissues. It is most commonly used to determine the presence or absence of dietary maize, but can also be used to detect the presence of marine resources in the diet (Ambrose 1990, 1993). Because ^{13}C is heavier than ^{12}C, plants tend to discriminate preferentially in favor of $^{12}CO_2$ during photosynthesis. This discrimination is most pronounced in C_3 plants, which have average $\delta^{13}C$ values of about -26.5‰. C_4 plants such as maize discriminate less against $^{13}CO_2$ and have higher $\delta^{13}C$ values compared to C_3 plants, averaging -12.5‰ (Ambrose 1990, 1993). Because most plants in North America are C_3 plants, higher levels of ^{13}C are a reliable marker of maize consumption. $\delta^{13}C$ values vary across trophic levels, being enriched by as much as 11‰ in bone carbonates such as apatite (DeNiro and

Epstein 1978; Ambrose et al. 2003). $\delta^{13}C$ values can also be used to detect high dietary levels of marine resources in the diet, although this is difficult if the diet also contains large amounts of C_4 plants since the $\delta^{13}C$ ranges of marine foods and C_4 plants overlap (Schoeninger and DeNiro 1984).

The present study relies on apatite from tooth enamel, which reflects whole-dietary carbon (Ambrose and Norr 1993). Carbon isotope research on bone collagen from Middle Woodland sites in western Illinois found little evidence of maize consumption (Rose 2008). However, because collagen preferentially reflects $\delta^{13}C$ values of dietary protein, and maize is a low-protein source, collagen analysis may not be the optimum technique for detecting low levels of maize consumption (Ambrose and Norr 1993). This study may be considered a useful complement to Rose's (2008) study.

Oxygen isotope analysis is similar to $\delta^{13}C$ analysis in that it involves measuring the ratio of ^{16}O to ^{18}O in body tissues such as bone or enamel. It is also similar to $^{87}Sr/^{86}Sr$ analysis in that this technique can be used to determine lifetime migration history. However, instead of relying on the isotopic ratio of foods consumed, $\delta^{18}O$ analysis measures this ratio in water imbibed by the individual or population under study (White et al. 2004). The $\delta^{18}O$ value of water in a geographical region is influenced by various factors including distance from the Equator and from the nearest ocean, elevation above sea level, and climatic factors such as temperature and humidity (White et al. 2004). $\delta^{18}O$ values in regional water can vary with seasonal temperature changes. Because of this, $\delta^{18}O$ analysis can be used with multiple samplings of single teeth to reconstruct paleoclimate (Fricke et al. 1998).

$\delta^{18}O$ analysis has also been used to determine immigration history; see, for example, White et al.'s (2004) Oaxacan barrio study at Teotihuacan, Dupras et al.'s (2001) study of the

Dakhleh Oasis in Egypt, and Evans et al.'s (2006) research on a possible immigrant population at a Southern England cemetery. The regional $\delta^{18}O$ signature is reflected in an individual's body water, and as with $^{87}Sr/^{86}Sr$ analysis, becomes incorporated into that individual's tissues including teeth and bones (White et al. 2004). As with $^{87}Sr/^{86}Sr$, therefore, a mismatch between an individual's enamel or bone $\delta^{18}O$ signature and that of the surrounding region indicates that the individual is an immigrant to the area. In analyzing tooth enamel, there is the possibility of a trophic level effect when dealing with breastfeeding; teeth formed during breastfeeding tend to be offset about 0.7‰ higher from the regional signature (White et al. 2004:177). Therefore, care must be taken when selecting teeth and during interpretation of the results.

White et al.'s recent (2009) study involving use of $\delta^{18}O$ and $\delta^{13}C$ analysis to reconstruct the habitat of *Ardipithecus ramidus* makes it clear that skeletal $\delta^{18}O$ values are determined by an extremely complex set of factors including local climate, local rainfall levels, feeding preferences (e.g. browsing vs. grazing), habitats and microhabitats and even diurnal vs. nocturnal feeding strategies. Such complexity indicates that oxygen isotope analysis may be inappropriate for determining migration history absent pronounced regional differences in $\delta^{18}O$ values. It was decided to proceed with $\delta^{18}O$ analysis in this study, with the understanding that the presence of supporting oxygen data could strengthen the case for any potential immigrants identified by $^{87}Sr/^{86}Sr$ analysis, while the lack of such data would not necessarily refute the case for such immigrants. In this study, $\delta^{18}O$ values are expressed as parts per thousand (permil, ‰) difference relative to the V-SMOW (Vienna Standard Mean Oceanic Water) standard. Carbon isotopes are expressed as ‰ difference from the PDB standard.

The next chapter will deal with the methodology of the study, including brief descriptions of the three sites included in the study, the sampling procedure followed and the human and faunal samples taken from each site, and the methods by which the samples were processed for analysis.

CHAPTER 3

MATERIALS AND METHODS

This study drew upon collections of materials from sites already excavated in the Midwest. Sites chosen were large funerary mound sites with many burials, under the assumption that larger sites would be more cosmopolitan and tend to attract more immigrants, thus better reflecting levels of migration within the differing regions. Initially the plan was to focus on three sites—two from Illinois and one from Ohio—with an additional two sites to be sampled if initial results suggested that these two sites would be helpful. Sites sampled included Utica Mounds and Albany Mounds in Illinois, and the Hopewell Mound Group in Ohio. The additional sites included Ater Mounds in Ohio and Pinson Mounds, an extra-regional site in Tennessee. However, as the project evolved, it was decided that Pinson Mounds was extraneous to the project aims, and closer examination of the Ater Mounds human collections indicated that there was not enough human and faunal material there to provide adequate sampling. Thus Ater Mounds and Pinson Mounds were dropped from the project, and my research focused on the three "core" sites, increasing sampling size at the Hopewell Mound Group instead.

The research design called for premolar tooth enamel to be sampled from 25 individuals from each site. Because premolars calcify between two and seven years of age (Steele and Bramblett 1988:102), it was inferred that these teeth were more likely to record evidence of moves that happened early in life. The first molar was chosen as an alternative tooth, to be sampled if there were not enough premolars at a site to make up a full twenty-five teeth; however, interpretation of the data from this tooth must be done with caution. The first molar calcifies between 9 months and 4 years of age (Steele and Bramblett 1988:102). Research by Gulson et al. (1997), Gulson et al. (1998), Gulson et al. (1999) and Gulson et al. (2003) on immigrants to Australia indicates that during pregnancy and lactation, stores of lead from the mother's skeleton are mobilized and transmitted to the infant. This mobilization is greater during lactation than pregnancy and especially great if the maternal diet is deficient in calcium. If strontium is mobilized in the same fashion, then it is possible that the Sr ratios of teeth calcified during this time could reflect that of maternal origins, rather than the local signature. In a very few cases, where not enough premolars or first molars were present at a site to make a full sample, other teeth were taken for sampling. The full list of individuals included in this study, including the tooth chosen from each individual, can be found in Appendix 1.

The above-mentioned research by Gulson et al. (1997, 1998, 1999, 2003) suggests that data from the first molars included in this sample may complement Bolnick and Smith's (2007) mtDNA research, which suggested that the Illinois population was matrilocal. If first molars taken from Illinois individuals do not display anomalous $^{87}Sr/^{86}Sr$ ratios, then that may suggest that these individuals' mothers were local to the region, strengthening Bolnick and Smith's (2007) interpretation. If these first molars do display anomalous $^{87}Sr/^{86}Sr$ ratios, this might indicate that these individuals' mothers were immigrants, weakening Bolnick and Smith's (2007) case.

A total of 81 human samples were included in this study, comprising 18 males or probable males, 29 females or probable females, and 34 individuals of unknown or indeterminate sex. Six individuals were adolescents; the rest were adults. No children were included in this study. Age and sex determination were taken from curatorial records.

In addition to human material, 38 samples of faunal material from the study sites were analyzed to provide a baseline against which to compare the human material in order to identify outliers. Originally intentions were to confine faunal samples to white-tailed deer (*Odocoileus* *virginianus)* tooth enamel. White-tailed deer teeth are fairly common finds in habitation sites. Because they are a food item, it is likely that deer contributed to the $^{87}Sr/^{86}Sr$ ratios of the human inhabitants of these sites. White-tailed deer are a relatively localized species, meaning that they are likely to reflect $^{87}Sr/^{86}Sr$ ratios of the local catchment area, and have been used in previous studies of bioavailable Sr (Hedman et al. 2009). However, the sites in question had few faunal remains; in fact, obtaining fauna proved as difficult if not more difficult than obtaining the human material for this project. In order to obtain large enough numbers of faunal samples from each site, other animals than white-tailed deer were included. Faunal samples therefore consisted of 23 deer teeth, one fragment of deer bone, nine beaver teeth (*Castor canadensis*), one wapiti or elk tooth (*Cervus elaphus,* a species formerly identified as *Cervus canadensis* (Terry Martin, Illinois State Museum, personal communication, September 2011)), one raccoon tooth (*Procyon lotor*), one fragment of mussel shell (*Megalon nervosa*), one fragment of softshell turtle shell (*Apalone* sp. unknown), and one tooth from a freshwater drumfish (*Aplodinata grunniens*). Faunal samples including skeletal elements are listed in Appendix 2.

Two charcoal samples were taken from each site for radiocarbon analysis, in order to attempt to establish some measure of site contemporaneity. Establishing sites such as Albany and Utica as roughly contemporaneous with the Hopewell Mound Group increases the likelihood of communication directly between the sites, including population movement. This is especially interesting in light of Emerson et al.'s (2004) pipestone findings; Albany Mounds is near to a large pipestone deposit that might have been used for manufacturing ceremonial pipes such as those Emerson et al. (2004) included in their Tremper Mounds study. Unfortunately, little charcoal was available from the study sites, and little provenience information exists for the material that was available. Two samples—one from Utica and one from Albany—were suspected to be intrusive; the Utica sample may have come from a later, possibly historic fence post (Mary Simon, 2009, personal communication) while the Albany sample might possibly have been root material from a tree struck by lightning as opposed to being human in origin (Christina Kastell, 2010, personal communication). Nevertheless, since there was no other material available, it was decided to go ahead and submit the charcoal for analysis.

Radiocarbon data retrieved from the sites yielded the following uncalibrated dates (see Table 1): 400 RCBYP (radiocarbon years before present) ± 70 and 1060 RCYBP ± 70 for the samples taken from Utica Mounds; 1780 RCYBP ± 20 and 1725 RCYBP ± 20 for the samples taken from the Hopewell Mound Group, and 1810 RCYBP ± 25 and 220 RCYBP ± 15 for the samples taken from Albany Mounds. When calibrated, these yielded dates of AD 1530 ± 114 and AD 967 ± 187 for the Utica samples; AD 236 ± 96 and AD 318 ± 71 for the Hopewell samples, and AD 223 ± 93 and AD 1801 ± 153 for the Albany samples. The samples for Utica were dated conventionally, whereas due to small amounts of material, the samples from Hopewell and Albany were dated using AMS. No provenience information was available on samples from Utica Mounds, or for the second sample from Albany, and it was strongly suspected that these materials were intrusive. These samples, however, were submitted for processing because they represented the only accessible means by which chronometric age estimates could be obtained for the study sites. The single valid date from Albany Mounds and the dates from the Hopewell Mound Group establish some measure of contemporaneity between these two sites at least as well as confirming that the sites are Middle Woodland.

In the remaining portion of this chapter, each of the sites will be briefly described. Mounds from which samples were taken will be described in detail. Many of these mounds were excavated before the use of the metric system became standard in American archaeology, so measurements will be given in feet where metric measurements were unavailable. Next, the samples collected from each site will be described, and then the laboratory methods used to process the samples and prepare them to be run. Results will be described in the next chapter.

Site Descriptions

Utica Mounds

Utica Mounds is a multi-mound site located on bluffs overlooking the Illinois River Valley of Central Illinois (see Fig. 1). The site was originally dug in 1929, by Percy Hodges and A. R. Kelly working under W. K. Moorehead's direction (Henriksen 1965:1). In 1993 and 1994, a UIUC salvage excavation was carried out on a small "remnant portion" of Mound Group 3 (Walz and Hedman 1998). The field notes of the original 1929 excavation are extremely poor and disorganized and portions of them appear to be missing, a fact noted by H. C. Henriksen (1965) who attempted to organize them into some sort of usable format.

Henriksen (1965:62) summarized the original field notes thus: Utica Mounds consisted of 27 or 28 mounds divided into three groups, with 14 mounds included in Group 1, and seven each in Groups 2 and 3 (Henriksen 1965:62). These mound groups straddled the Illinois River, with Groups 1 and 2 raised on a bluff on the north bank of the river while Group 3 was on another ridge located on the south bank (Henriksen 1965:62). The mounds were circular or oval, between 2 and 5 feet in height with a base diameter of between 20 and 75 feet. Mounds were built over a prepared surface of sand and gravel, with rectangular or circular graves usually placed at the center. In Mound Group 2, these burials were occasionally paved with stone. Often these burial pits were filled with a blackish "gummy" type of soil that may have had some ritual significance. The mounds themselves were constructed of a yellowish-brown earth that often contained animal remains and other small artifacts. The base of several mounds contained fire pits or “fire areas” (Henriksen 1965:62). Burials were generally either extended or bundled; bundle burials were often placed in close physical proximity to extended burials. Flexed and skull burials were also present. Juveniles were often buried in what Henriksen terms “birth position” (1965:62), between the legs of adult burials with their heads oriented toward the adults’ feet. One mass grave consisting of 46 bundle burials was present, and some burials showed evidence of burning. Snake skeletons were found in association with some graves, and one grave may have been surrounded by a snake “effigy” figure constructed of cobbles. All of the artifacts associated with these burials were consistent with Hopewell material culture. Henriksen (1965) attempted to cross-date the site from the comparison of excavated artifacts, and concluded that the site was probably fairly early; he also indicated that it was consistent materially with a northern variant of the Illinois River Valley Hopewell phenomenon (Henriksen 1965:65-66). The 1993-1994 salvage excavation yielded a single uncalibrated radiocarbon date of 2010 ± 80 RCYBP which, when calibrated yielded a date of AD 10 (Walz and Hedman 1998). The date was taken from charred human bone recovered from 70 cm below the surface of Mound 6, Group 2 (Walz and Hedman 1998) and supports Henriksen’s placing of this site as fairly early.

Provenience information for materials from the 1929 excavation was poor to nonexistent. When present, typical proveniences for the materials were such remarks as: “Skull #14,” “Mound 11 Skull & Skeleton,” or “Skull 2, Pile 3.”

A total of 22 teeth were sampled from the available Utica Mounds human skeletal material, including 15 premolars and seven first molars. Given the incomplete analysis of the excavated remains from this site, several human skeletal remains sampled for inclusion in the present study lack age and sex information. 14 faunal samples were included in the study to provide a strontium baseline for the site. Four of these samples were provided by the Illinois State Archaeological Survey (ISAS, formerly the Illinois Transportation Archaeological Research Program, or ITARP). Additional faunal material was provided by the Illinois State Museum (ISM). While ISM did not have faunal material from Utica Mounds, they did have copious amounts of faunal material from French Canyon West. Because this site is located in the same county as Utica Mounds, it was thought that faunal material from this site would have participated in the same catchment area as those found at Utica Mounds. Thus it was thought that their strontium ratios should reflect the same levels of bioavailable strontium as faunal material from Utica Mounds. Ten faunal samples were taken from the French Canyon West site material curated by the ISM. Faunal material consisted of ten white-tailed deer teeth (*Odocoileus virginianus),* one beaver tooth (*Castor canadensis*), one wapiti or elk tooth (*Cervus elaphus,* formerly known as *Cervus canadensis* (Terry Martin, Illinois State Museum, personal communication, September 2011)) and one shell fragment (*Megalonaias nervosa*). Radiocarbon samples were drawn from ISAS's Utica Mounds collection. They consisted of pieces of charcoal. Both fragments lacked provenience information, and one was suspected to be of historical origin. When dated using conventional methods, the possibly-historical sample provided a date of 400 RCYBP ± 70, which when calibrated became AD 1530 ± 114 and the other provided a date of 1060 RYBP ± 70, which when calibrated became AD 967 ± 187. Neither of these dates was contemporaneous with the other sites in the study and they are probably invalid due to the lack of provenience information.

Albany Mounds:

Albany Mounds is a Middle Woodland-period, multi-mound group in Whiteside County in northwest Illinois (see Fig. 2). This mound group consists of 81 mounds located along the Mississippi River's eastern bank (Herold 1971). Excavation on this site began in 1873 and was carried out in a fairly haphazard fashion until the work of William Baker Nickerson in 1908. A man with many years' background in archaeology, he excavated systematically and took detailed notes on what he found (Herold 1971). A review of the excavations was published in 1971 by Elaine Herold.

Twenty-five burial mounds were excavated at this site in total. Some of these mounds were constructed over a prepared surface. Burial tombs were from 1 to 3 feet below the natural ground level, and walls of timber or stone were often built up around them. Tombs included both extended and bundle burials, and burials appear to have been defleshed through exposure prior to interment. Burial tombs included individuals of both sexes and there is little evidence of preferential treatment by sex. Some, but not all, mounds contained grave offerings (Herold 1971).

Individuals sampled from Albany Mounds were taken from Mounds 9 (n=7), Mound 20 (n=6), Mound 17 (n=3), Mound 15 (n=2), Mound 12 (n=1), and Mound 65 (n=1). The sample of remains included one individual from Mound 80 at the request of ISM curator Dawn Cobb. The individual was extremely robust with almost "neandertaloid" characteristics and the skull bore evidence of cutmarks, both features that were unusual amid the Albany assemblage (Cobb, personal communication, 2009). These mounds will be briefly described below.

Mound 9, which contributed the largest number of individuals to this study, was perhaps the most structurally complex mound on the site. Compared to the other mounds, this mound was elongated, being some eighty feet long and eight feet high, and oriented on a northeast/southwest axis. Mound fill was largely red clay (Herold 1971:12). When sectioned by archaeologists along its long axis, each third of the mound was found to contain a separate burial tomb, and were designated 9a, 9b, and 9c respectively (Herold 1971:12). In addition, the mound itself appears to have been built over an older cemetery that archaeologists designated the "Old Burial Ground," part of which had been disturbed by the creation of Mound 9b. A total of 99 burials were recovered from this mound, including 14 from Mound 9a, 25 from Mound 9b, 11 from Mound 9c, and 44 from the Old Burial Ground. Three burials were located in the mound fill and may have been intrusive. (Herold 1971).

Mound 9a contained a pit dug two feet into the base of the mound and capped with eight feet of fill. The sides of the pit had then been built up with logs and sealed with a blackish soil that the excavators compared to "bogland muck" (Herold 1971:15). The pit contained two complete adult burials and five fragmentary burials, four of which were juveniles. In the fill covering the pit were six more fragmentary burials, arranged above and below an oval lens of baked earth. Four of these six burials may have been bundle burials (Herold 1971:15). The Mound 9a pit was linked to the Mound 9b pit with a layer of "trampled" earth which was interpreted as indicating traffic back and forth between the two pits and suggests that they were contemporary (Herold 1971:15).

Mound 9b covered a square yet "saucer-shaped" (Herold 1971:15) pit dug two or three feet into the natural surface and roofed with black oak (*Quercus velutina*) timbers interpolated with rows of stone. The pit itself contained three extended adult burials with two juveniles at their feet, as well as a “heap” (Herold 1971:16) of two more adults and two children nearby. Two more burials were on the northwest side of the tomb, another juvenile extended burial was on the east side, and three more individuals, two adults and one child were in the southeast corner. The tomb also contained seven other burials with location not specified (Herold 1971:16). Covering the remains was a mass of “hopelessly” (Herold 1971:16) commingled individuals. In addition to human remains, the pit also contained two projectile points, one of white flint (Herold 1971:16).

Five additional burials were located outside the tomb proper. These may have been part of the Old Burial Ground. Slightly to the east of the pit was another burial, a grave with a single skeleton, deeper than the log tomb yet undisturbed by it. This burial (Bur. 23) may have been the earliest burial at the site (Herold 1971:14).

Mound 9c consisted of a stone-covered pit dubbed the “Great Stone Grave” by Nickerson (Herold 1971:16). Originally there may have been a mound over this grave. Five individuals including four adults and one juvenile were interred here, all of which rested on a layer of pink ochre. Two more graves were located outside of the pit and to the southeast. One of these contained another juvenile in more pink ochre and with 35 shell beads in association, while the other contained an extended adult burial with several other possible adult and juvenile bundle burials. Two of these were below and covered by the Great Stone Grave, suggesting that the stone-covered grave was later in origin. Two additional adult burials were located above the stone-covered grave, one of which was associated with several artifacts including one skull of an unidentified carnivorous mammal and artifacts of red quartzite and flint (Herold 1971).

The Old Burial Ground, as demarcated by “great quantities of bones” (Herold 1971:17) was located under the southern half of Mound 9. Based on his analysis of the site stratigraphy, Nickerson concluded that this cemetery predated the building of the tombs. The construction of the Mound 9b tomb showed evidence of having disturbed some of the Old Burial Ground graves. Bones from these graves were apparently piled up and tossed or thrown out of the tomb along with the dirt during the original Mound 9b construction. Some of the Old Burial Ground skeletal remains showed evidence of partial burning, and the southeastern part of the cemetery produced clusters of skulls without mandibles. Various stone and flint artifacts were recovered, not in direct association with the Old Burial Ground skeletal remains but from a small area slightly to the east (Herold 1971:18).

Of the seven individuals sampled from Mound 9, two came from Mound 9a, one from Mound 9b, and four from Mound 9c. None were taken from the Old Burial Ground. Sample selection was primarily weighted toward obtaining available and appropriate teeth of a preservation caliber robust enough to withstand the sampling procedure, with equal distribution of samples over the site a secondary concern.

In contrast to Mound 9, Mound 20 was located at the base of a bluff, on what was probably a former village site (Herold 1971). This mound was unique in that it had been constructed around an artificial clay “nucleus” (Herold 1971:32) about three feet high, which contained the central burial pit. The pit itself had sloping sides and was closed with logs and stones. Other large piles of stones were found throughout the mound, as were probable fireplaces. Most of these fireplaces were probably associated with the former village, but one was located on the clay nucleus itself and may have had something to do with its construction (Herold 1971). The mound had been built on a surface prepared with a layer of sand. A cache of galena was discovered on the original ground surface slightly to the east of the pit (Herold 1971).

There was a grave with burned or calcined bone at the very bottom of the clay pit, which may have predated the building of the pit and the nucleus (Herold 1971:32). According to Herold (1971), Nickerson's interpretation was that the burial had been placed first, then the nucleus constructed and the pit dug down to it. The cremains represented the remains of two persons. Ten more individuals, five adults and five juveniles, comprised eight other burials in the pit. Five of these burials were bundle burials, and two crania showed evidence of cutmarks, unusual at this site (Herold 1971:33).

One bundle burial was associated with a few grave goods including a platform pipe and two flint artifacts. Eight other individuals comprising six discrete burials were resting against the tomb's north wall (Herold 1971:33). Twenty more bundle burials containing 23 individuals had been placed above the tomb's roof, and there were six other fragmentary burials in the clay "nucleus" itself (Herold 1971).

Mound 17 was located near Mound 20, also at the base of a bluff. This mound had been constructed over a two-foot-deep rectangular pit enclosed with logs that had been plastered with red clay. A row of stones also lined the long sides of the pit. The tomb may have been covered at some point, but any covering had decayed by the time of excavation (Herold 1971). The mound contained the remains of eight adults and six juveniles in 12 burials. Four adults and one child were interred in the tomb as extended burials oriented toward the northeast. Three juveniles were interred on the crossed hands of one of these adult burials (Herold 1971:28). Two more individuals, one bundled and one extended, had been interred at the tomb's north end, and another adult burial was interred above tomb (Herold 1971).

Mound 14 was part of the same grouping as Mounds 17 and 20. This mound was a small elliptical mound only 28 inches high that had been built on a natural gravel surface. An area of large stones was at the mound's center. The central tomb itself had been dug to a depth of nine inches below ground level and contained seven adults and two children. Two of the adults were extended with their heads to the northeast and the rest of the burials were commingled. Scattered woodchuck bones (*Marmota monax*) were found near the commingled burials. To the northwest of the tomb in the mound's fill were a few human long bones, designated "Burial 9" (Herold, 1971:26).

Mound 12 was located on the side of a bluff, to the north-northeast of Mound 17. The mound was an elliptical dome, about five feet high (Herold, 1971:22). The burial pit itself had been dug through several clay and gravel layers, and the mound fill was a clayey loam (Herold, 1971). The pit was rectangular and oriented on the northeast/southwest axis. It may originally have been roofed with stones. As was seen with Mound 17, the long sides of the pit each had a row of stones, with the western stone row being five feet longer than the pit dimensions. The pit contained four extended adults and one juvenile that had been placed between the legs of one of the adult burials. The position of this juvenile is similar to that of infant burials found at Utica Mounds in what Henriksen (1965:72) termed "birth position," except in those cases the juvenile's head was oriented toward the adult's feet. Here, all burials were oriented with their heads toward the northeast (Herold, 1971).

Mound 65 was located in a cultivated field (Herold 1971:49). Nickerson did not dig this mound, and the original notes for the mound have been lost. Apparently the mound originally had been eight feet in height and 75 feet across at the base. Mound fill was a sandy loam. This mound contained a rectangular "burial area" (Herold 1971:49) surrounded on three sides by a border or wall of piled stones. Two extended adult burials with heads toward the south were found within this border, while a third extended adult burial was found under the eastern wall of the border, oriented transversely with the head toward the east. The burials were covered with a "greasy" layer of black soil which the original excavators interpreted as the remains of an original hide covering (Herold 1971:54) but which may have been similar to the black "gummy" soil described by Henriksen (1965:72) at Utica Mounds, as well as the "bogland muck" (Herold 1971:15) found over the burials in Mound 9a. Other fragmentary burials were apparently found in the fill over the burial area, but there is little information about these interments and the remains may not have been preserved (Herold 1971:54). The burials within the burial area were associated with grave goods. One individual was interred with shell bead strings and rolled tubes of sheet copper and silver, while chert artifacts, sheets of mica, a copper-hafted tool, a worked bear jaw and chunks of meteoric iron were found between the two burials. The sheet copper and silver tubes contained plant remains which may have been maize (Herold 1971:54). The meteoric iron artifacts were badly rusted but resembled knife blades (Herold 1971:54).

Mound 80 was the first mound to be dug at Albany Mounds, by excavators from the Davenport Academy of Sciences in 1873 (Herold 1971:63). There is little information about this mound. Its fill apparently consisted largely of sand. Six feet below the surface of the mound, the excavators reported finding the skeletons of seven adults and one child, interred face up with heads to the south. The whereabouts of only three of these remains are known today (Herold 1971:63).

Human material from Albany Mounds came from collections held by the Illinois State Museum. Human samples consisted of 21 teeth, including 14 premolars, 7 first molars, and one third molar. The third molar was included in the study by special request from the head curator, Dawn Cobb. The ISM collections contained neither faunal material nor charcoal from Albany Mounds. Faunal material came from the collections at the University of Wisconsin-Milwaukee.

It consisted of 14 faunal specimens, including one raccoon tooth, five deer teeth, and eight beaver teeth. Charcoal for radiocarbon analysis was provided by the Peabody Museum in Indiana. Samples consisted of charred wood – maple in one case, unidentifiable in the other. No provenience information was associated with this material, and one specimen was strongly suspected to be a modern lightning-struck tree. However, since no other charcoal was available, both of these samples were submitted for analysis. The first sample returned a date of 1810 RCYBP ± 25, which when calibrated became AD 223 ± 93. This date falls within the range for the Middle Woodland period in Eastern North America. The second sample, suspected to be the tree struck by lightning, gave a date of 220 RCYBP ± 15, which when calibrated became AD 1801 ± 153. This marks the sample as intrusive.

Hopewell Mound Group:

The Hopewell earthwork site can be found in Ohio's Ross County, along the North Fork of the Paint Creek River Valley in the Central Scioto Drainage system (Case and Carr 2008:362). It sits on a terrace above the river and consists of a large, roughly rectangular earthen enclosure with a smaller, square enclosure attached to the east end. A number of mounds are located in and around the two enclosures (n=38) (see Fig. 3). The large enclosure also contains two smaller earthen enclosures, one "D"-shaped and the other circular. These enclosures most likely served as ceremonial centers for ritual purposes (Greber and Ruhl 1989). Carr (2008) argues that rituals performed at Ohio sites such as these helped to develop and maintain sociological complexity and served as a means of binding together the population of the central Scioto region.

Three major excavations were conducted at the Hopewell Mound Group during the 19th and early 20th centuries. The first excavations were those of E. G. Squire and E. H. Davis in

1845. W. K. Moorehead next dug the site in 1891-1892, followed by H. C. Shetrone in 1922-25 (Greber and Ruhl 1989). Squire and Davis's work was fairly rigorous for its day and formed the foundation for much later Ohio research and writing. Moorehead's excavations relied rather substantially on their research. Unfortunately Moorehead's erratic record-keeping, as well as publication errors, created difficulties in correlating these two sets of research. Shetrone's excavations added to the confusion after he "renumbered" several of the mounds that had been excavated earlier. Greber and Ruhl (1989) examined the notes of these previous excavations and were able to codify and cross-reference them into a usable form.

The individuals sampled in this study include remains from both the Ohio Historical Society, which houses material recovered during Shetrone's excavations, and the Chicago Field Museum, which houses material from Moorehead's excavations. Provenience information for the Field Museum remains is of uneven quality, possibly reflecting Moorehead's note-taking practices (Greber and Ruhl 1989). Provenience information for these samples was taken from Chase and Carr's (2008a) efforts correlating and cross-referencing the provenience of the skeletons at the Field Museum. Remains included in this study include 22 teeth from Mound 25, with four additional remains from Mound 2, three from Mound 23, and one each from Mound 20, Mound 18 and Mound 3. Six individuals lack within-mound provenience information, three from the OHS and three from the Field Museum.

Mound 25 is the largest and most complex mound excavated at the Hopewell site. It is located within the D-shaped earthwork inside the larger of the two enclosures. This mound is an oval or elliptical mound lying along a northeast to southwest axis and is 550 ft in length. The mound itself is a composite mound that can be divided into three parts. Elevations taken at the eastern, central and western mounds measure 21 ft 2 inches, 19 ft 5 inches, and 16 ft 6 inches respectively. Basal width likewise varies; the width of the eastern mound is 150 ft, that of the central mound is 189 ft at the base, and the base of the western mound is 96 ft wide (Greber and Ruhl 1989). The mound may originally have had some sort of “effigy” shape, perhaps feline, which was subsequently destroyed by cultivation (Greber and Ruhl 1989:39). The eastern and western mounds were similar and relatively simple in structure. Each was constructed on a surface or “plaza” (Greber and Ruhl 1989:42) that had been prepared by removing the topsoil. There was a base stratum of heavy stones, directly on the plaza surface for the western mound and over a layer of yellowish gravel for the eastern mound. These surfaces were then covered with fill, and finally capped with another layer of gravel (Greber and Ruhl 1989).

The central mound was much more complex, showing reuse over a long time period. The floor of this mound had been covered with a plaster or “concrete” (Greber and Ruhl 1989:43) composed of a mixture of clay and water. Portions of this surface at the eastern end of the central mound were also covered with yellow gravels similar to those found over the plaza area for the eastern mound. This clay floor demonstrated evidence of various kinds of activities, including a number of wooden structures as indicated by postholes, basins of fired clay, pits, areas of burning, stone “pavements,” many graves and tombs, and large artifact depositions (Greber and Ruhl 1989:42). The wooden structures had been burned down, and their remains had been buried individually under three to six feet of earth. These mounds themselves had then been joined together with two fill layers, each covered with gravel. An additional mound of strata, containing burials located unusually above the “floor” level, was attached to the mounds over the burned structures by several “capping strata” (Greber and Ruhl 1989:45) consisting of loam, and at last the whole mound was surrounded by a retaining wall of large, heavy stones (Greber and Ruhl 1989).

Greber et al. (1989) divided the Mound 25 burials into distinct groups, which they argued represented more or less contemporaneous social components. Group A1 consisted of calcined bone interred on a raised surface and covered by a small inner mound (Greber and Ruhl 1989:51), while Group A2 comprised two individuals laid to rest in a small grave within some sort of enclosure (Greber and Ruhl 1989:51). Both groups were located in the south portion of the Central Mound. Six burials laid within a small internal mound in the southeastern portion of the Central Mound formed Group B (Greber and Ruhl 1989:51). This group consisted entirely of re-interred cremains placed separately on layers of bark, possibly bark mats, and separated from each other by single logs. One of these burials had been placed in a shallow grave. Groups C, D and E (Greber and Ruhl 1989:52) had been combined in a single mound fairly early in the process of building the Central Mound. These burial groups were each associated with large wooden enclosures, as indicated by post molds. Group C was in the northeastern portion of the Central Mound, while groups D and E were centrally located. Both of the latter burial groups were associated with altars. All three groups contained both extended burials and reinterred charred remains, and these burials alone were associated with log tombs (Greber and Ruhl 1989:51-2). Group F consisted of four burials to the west of the internal mound combining Groups C, D, and E (Greber and Ruhl 1989:52). These burials were both cremated burials as well as extended. One of the cremated individuals had been laid to rest on a platform; the others lay on bark mats. All four of them had been covered with a layer of clay that had been surrounded by a wooden enclosure of some sort. In addition, there were four additional burials in the Central Mound’s upper fill, interred on the west side and laying on gravel beds one to two meters above the level of the surface. These were designated by Greber et al. (1989:46) as “Group I.”

Mound 23 was located in the southeastern portion of the great enclosure. It was an oblong mound in shape, about 10 feet high in the center and measuring 100 feet by 150 feet in width and length. Mound fill consisted of soil, gravel layers, ashes and earth and burned clay (Greber and Ruhl 1989:22). Nine skeletons were recovered from the eastern portion of the mound, three to four feet below the surface, one of which was associated with a number of stone artifacts. An additional 33 remains were discovered at the mound's "baseline," arranged "without order" (Greber and Ruhl 1989:25). Some of these remains were associated with areas of burning, and there was some charring of the remains (Greber and Ruhl 1989). A few skeletons had accompanying grave goods, including copper and textile artifacts, strings of pearl and shell beads, and worked canine teeth including a necklace comprised of over 120 teeth (Greber and Ruhl 1989:25), and pipes (Greber and Ruhl 1989).

Mound 2 is in the center of the large enclosure, 80 ft wide and between 6 and 7 feet high. Its most notable feature was its large quantities of disk-shaped chert bifaces, deposited in a cache measuring perhaps 20 feet in diameter in the center of the mound (Greber and Ruhl 1989). The mound also contained five burials with a number of grave goods. Two burials, one of which was headless, were laid on a platform covered with a layer of black muck, interred with several copper artifacts. One individual was interred in a large stone grave with stone walls and floor, the only example of its kind at the Hopewell site, along with copper artifacts and an ocean shell. To the north of this stone grave was another burial, also with shell and pearl beads, a marine shell, and a copper artifact. These two individuals were oriented with their heads to the southeast. Still further north was located another burial with shell and copper artifacts and a possible trophy skull in close association (Case and Carr 2008).

Mound 20 contained a central altar with charcoal around which nine skeletons had been placed "without order" (Greber and Ruhl 1989:19). Three of these nine were juveniles. Another juvenile was found north of this altar at a two-foot depth, associated with copper artifacts and two shell cups and some shell beads. East of this was another skeleton with a fractured skull and two carved wooden figures of bear canine teeth. Ear spools were also found with two skeletons (Greber and Ruhl 1989).

Mound 18 was in the northeast area of the enclosure. It was almost four feet high, 75 feet on length on the north-south axis and 55 feet in length on the east-west axis. This mound contained an altar at its center. One skeleton was recovered to the northwest and another to the southeast of this altar. The southeastern skeleton was associated with a sandstone pipe and a fossil shark tooth (Greber and Ruhl 1989:19).

Mound 3 is to the northwest of the "D"-shaped enclosure. This mound contained two altars of unequal sizes. A burial was found to the west of the first altar containing one skeleton and part of a second one associated with artifacts including a copper axe, mica fragments, a pottery vessel, and a worked human mandible (Greber and Ruhl 1989:21).

Originally, samples from Ater Mounds, another multimound burial group, were to be included in the Ohio samples for this study. However, on examination, the material from Ater Mounds was found to be unsuitable for inclusion. Too few potential samples were present and no supporting faunal material was available for this site. Therefore Ater Mounds was dropped from the study and samples from the Hopewell Mound Group were expanded. 38 teeth in total were sampled from Hopewell Mounds. 13 samples were taken from the Chicago Field Museum's collections and 25 were taken from materials at the Ohio Historical Society. Samples included 27 premolars, seven molars (six third molars and one second molar), three incisors and one canine. A wider variety of teeth were sampled from this site than from other sites because of the necessity of finding enough teeth at the Chicago Field Museum. Samples included fifteen females or probable females, eight males or probable males, and 15 individuals of unknown gender. 16 individuals were classified simply as “adult.” By age, the sample included nine individuals classified as M. Adult, five as Y. Adult, one as “adult (20-25 yrs),” one as “adult 20+”, and one as “adult 25+”. Age status was not given for three individuals.

The Hopewell National Park Service provided faunal material. Six samples were initially provided from Hopewell Mound Group, and an additional four samples came from a Late Woodland pit dug in the Hopeton Triangle, a site in the same county. While it would have been preferable to sample faunal material that was contemporaneous with the sites in question, the paucity of faunal remains available from the Hopewell site made that impossible. Faunal material from the Hopewell Mound Group itself consisted of three deer teeth and one deer bone fragment (*Odocoileus virginianus*), one fragment of a softshell turtle shell (*Apalone*), and one tooth from a freshwater drumfish (*Aplodinatus grunniens*). The four faunal samples from the Hopeton Triangle consisted of deer teeth *(O. virginianus,* as above). Radiocarbon samples were provided by the Hopewell Culture Historical National Park: one from the Hopewell Mound Group itself and one from the Hopeton Triangle. They consisted of one locust wood fragment and one red oak fragment.

Methods:

Initial processing of all samples was done at the UIUC Environmental Isotope Paleobiogeochemistry Lab. Processing procedure followed Ambrose et al. (1997:352) and

Balasse and Ambrose (2002:920), modified for use on tooth enamel rather than bone. Teeth were selected for sampling on the basis of completeness. Isolated teeth were selected almost exclusively; only in a very few cases were teeth chosen that were still embedded in bone. One such exception was DBA 50, included on special request by Physical Anthropologist and Archaeological Research Associate Dawn Cobb at the Illinois State Museum. The lingual face of the tooth was chosen for drilling preferentially. If the lingual surface was cracked, broken or otherwise unsuitable, the buccal surface was chosen. The tooth surface to be drilled was first abraded to remove surface contaminants and/or possible preservatives. The surface was then examined microscopically to detect cracks or soft "white" spots of decay that might contaminate the sample. Such areas were drilled as well and the powder discarded so that contaminants could be removed. The tooth was then ultrasonicated for five to ten minutes to shake loose remaining dirt that might contaminate the sample. Teeth were dried under heat lamps. Prior to drilling, the roots of the teeth were wrapped in parafilm, to further reduce potential contamination. About fifteen milligrams of enamel were removed via drilling and stored in 1.5 mL microcentrifuge tubes.

Flakes were processed in some cases. If a tooth flaked during drilling, drilling was halted for that tooth in order to avoid damaging it further. The flakes were then crushed to powder in an agate mortar and pestle. After that, the treatment of enamel proceeded along the same lines as those that had been drilled.

Once the sample had been obtained, it was then placed in a microcentrifuge tube. Microcentrifuge tubes were filled with 1.5 mL of 50% Clorox, and left to stand open for roughly 24 hours. At the end of this time, the tubes were closed, vortexed, and the Clorox decanted. The remaining sample was rinsed four times with distilled water. Tubes were then filled with 0.1 M acetic acid and left to stand for four hours exactly. After four hours had passed, the tubes were again rinsed four times with distilled water, and the sample tubes were placed, open, in a freezer for one hour. The tubes were then dried for 12 to 15 hours in a vacuum freeze-dryer. At this time, the tubes were closed and weighed and the percent yield calculated. Average apatite yield was 67.3 percent.

Most samples were processed and analyzed for strontium at the UIUC Geology Department. Due to the large number of samples, the Hopewell samples from the Ohio State Historical Society were sent to the strontium lab at the University of North Carolina-Chapel Hill. The same apatite purification process was used for both the samples processed on-site and those sent to UNC-Chapel Hill. Those processed for strontium at UIUC were treated in the following method: The samples were dissolved in 500 µL 3M $HNO_{3.}$ A Teflon column that had been precleaned by soaking in 8M HNO_3 was loaded with cleaned Sr-spec resin (Eichrom 50-100µm). The column was washed with one full reservoir (~ 2 mL) of 0.05 M $HNO_{3,}$ to remove any contaminants. After this had drained all the way through, the resin was rinsed with one full reservoir of nanopure water. Again, this was left to drain all the way through. The column was then preconditioned with 1 mL 3M HNO_3. This was done in order to prepare the resin to catch the sample and hold in the Sr when it was loaded. After this had drained through, 300 µL of sample was loaded on the column, leaving a 200 µL reserve. Once this had drained completely, transferring the Sr content of the sample into the resin, 3 x 2 mL 3M HNO_3 was added to the column reservoir and permitted to drain through in order to “knock out” contaminants such as rubidium and krypton. After this, 2 x 2 mL 0.05 HNO_3 was added as an elution rinse to remove the strontium. This elution rinse was caught in specially cleaned Teflon beakers. The beakers were placed, unlidded, on a hotplate overnight until the acid had evaporated off and the sample was left. Then a small amount ("two drops") of concentrated nitric acid was added to the sample and left on the hotplate to "blast off" any organic contaminants that might still remain. When this was dried down, the sample was prepared for running by dissolving it in 40 µL concentrated nitric; after it had fully dissolved, 1960 µL nanopure was added to bring it up to a full 2 mL sample. This was then loaded onto the UIUC Geology Department's ICP-MS and run with standards of South China Sea coral.

Larger samples (those greater than 9 mg after apatite purification) were also run for light isotopes ($\delta^{18}O$ and $\delta^{13}C$). This was done at the Illinois State Geological Survey (ISGS). No additional processing beyond the apatite purification was necessary for this. Prior to dissolving the sample in the 500 µL 3 M HNO_3, roughly 600 µg of it were extracted and loaded into reaction vessels, which were then run on the ISGS's Kiel carbonate analyzer. Only larger samples were used in order to ensure that there would be enough sample remaining for the Sr analysis.

Results for strontium isotopic analysis and for carbon and oxygen analysis will be presented in the next chapter.

CHAPTER 4

RESULTS

$^{87}Sr/^{86}Sr$ results:

Table 2 and Figure 4 illustrate the mean, standard deviation, and 2*s* range for each site. As mentioned in the Methods section, all human samples were of tooth enamel. Most were taken from the third or fourth premolar or first molar of each individual, although in some cases other teeth were included. Faunal samples were taken from deer or beaver teeth except for faunal from the Hopewell Mound Group, which included one fragment of deer bone, one tooth of a freshwater drumfish, and a piece of turtle shell. (A listing of human and faunal remains sampled, including skeletal elements, can be found in Appendices 1 and 2.) Following the methods suggested by Price et al. (1994, 2002), potential immigrants were initially defined as those $^{87}Sr/^{86}Sr$ ratios that fell beyond two standard deviations of mean $^{87}Sr/^{86}Sr$ faunal ratios for each site. Samples with ratios that fell outside this range were then compared against the 2*s* range for human material from the site. It is possible that the humans at any given site had unusual dietary practices that may have offset their ratios slightly from those of the local fauna (cf. Wright 2005). Thus, testing potential outliers against the human range would offer a possible corrective. For good measure, potential immigrants would also then be tested against the 2*s* range for the mean of the combined human and faunal material, on the assumption that samples with $^{87}Sr/^{86}Sr$ ratios that lay beyond this combined range would be very strong and robust candidates for immigrant status. In addition, the combined $^{87}Sr/^{86}Sr$ ratio for all material, human and fauna, from each site, provides a means of comparing the sites against each other and determining whether it is possible to distinguish between them on the basis of $^{87}Sr/^{86}Sr$ ratios. Medians were also calculated for each site.

In the case of Utica faunal, and Hopewell human and faunal material, the sample set was made up of material from two different sources. The Utica faunal material consisted of four samples from the site of Utica Mounds itself and ten samples from the French Canyon West site, a site located in the same county as Utica Mounds. In the case of the Hopewell Mound Group, the Hopewell human material was drawn from two separate collections, that of the Chicago Field Museum and that of the Ohio State Historical Society; the faunal material consisted of six samples from the Hopewell Mound Group itself and four samples from the Hopeton Triangle. In these cases, mean $^{87}Sr/^{86}Sr$ ratios were calculated for the groups as a whole, and then also for each group separately, to determine if there were any major differences between these separate groups.

Initial analysis revealed no human samples with $^{87}Sr/^{86}Sr$ ratios that lay beyond two standard deviations of the mean faunal ratio from Utica Mounds, Albany Mounds, or the Hopewell Mound Group. Strontium ratios—faunal, human and combined—for each site were as follows:

For Utica Mounds, total faunal mean is 0.710281 ± 0.000778, with a 2*s* range of 0.708725 to 0.711837. Total faunal median is 0.710073. As mentioned above, the total Utica faunal dataset can be separated into two groups: faunal material from Utica Mounds proper and material from French Canyon West. The mean $^{87}Sr/^{86}Sr$ ratio for Utica faunal material is 0.709647 ± 0.000597, giving a 2*s* range of 0.708453 to 0.710841, with a median of 0.709849, while that for faunal material from French Canyon West is 0.710534 ± 0.000711 with a 2*s* range of 0.709112 to 0.711956 and a median of 0.710662. The 2*s* ranges are slightly offset from each other, suggesting some difference between groups. However, given the small size of the groups in question, any difference is likely to be no more than a statistical artifact. The mean human $^{87}Sr/^{86}Sr$ ratio is 0.710718 ± 0.000339, with a 2*s* range of 0.709920 to 0.711516 and a median of 0.710732. This range is narrower than but comparable to that for all Utica faunal material and suggests no large differences in dietary $^{87}Sr/^{86}Sr$ ratios between these two groups. The average $^{87}Sr/^{86}Sr$ ratio for the entire Utica Mounds data set is 0.710548 ± 0.000606 with a 2*s* range of 0.709336 to 0.711760 and a median of 0.710073.

For Albany Mounds, the average $^{87}Sr/^{86}Sr$ ratio for faunal material is 0.709848 ± 0.000862. This gives a 2*s* range of 0.708122 to 0.711570. The median for Albany faunal material is 0.709510. The mean $^{87}Sr/^{86}Sr$ ratio for Albany human material is 0.710249 ± 0.000480, with a 2*s* range of 0.709289 to 0.711209 and a median of 0.710194. As with Utica Mounds, the human 2*s* range falls entirely within the 2*s* range for faunal material, suggesting that the dietary $^{87}Sr/^{86}Sr$ ratios of human and faunal are similar. The mean $^{87}Sr/^{86}Sr$ ratio for the entire Albany Mounds dataset is 0.710088 ± 0.000678, giving a 2*s* range of 0.708732 to 0.711444, while the median for the entire dataset is 0.710146. This range largely overlaps with that from Utica Mounds, suggesting an essential similarity in bioavailable strontium in their catchment areas and further suggesting that the two sites may not be distinguishable on the basis of their $^{87}Sr/^{86}Sr$ ratios.

The average $^{87}Sr/^{86}Sr$ ratio for the Hopewell faunal dataset is 0.710800 ± 0.001419, with a 2*s* range of 0.707962 to 0.713638 and a median of 0.710631. The average $^{87}Sr/^{86}Sr$ ratio for the Hopewell human dataset is 0.710616 ± 0.001072, giving a 2*s* range of 0.708472 to 0.712760. The median for the entire Hopewell human dataset is 0.710276. For the entire Hopewell dataset, human and faunal, the average $^{87}Sr/^{86}Sr$ ratio is 0.710655 ± 0.001139, with a 2*s* range of

0.708377 to 0.712933 and a median of 0.710380. The 2*s* range for the entire Hopewell dataset is larger than and contains the ranges for both Utica Mounds and Albany Mounds, suggesting that its catchment area has a wider range of bioavailable strontium ratios than either of the Illinois sites. It also indicates that the Hopewell Mound Group may not be distinguishable from either Albany or Utica on the basis of its $^{87}Sr/^{86}Sr$ ratios.

Both the Hopewell human dataset and the Hopewell faunal dataset can be further broken down into two groups. The Hopewell human dataset is composed of material from the Chicago Field Museum collections and material from the Ohio Historical Society collections. The average $^{87}Sr/^{86}Sr$ ratio for the Field Museum material is 0.710533 ± 0.001094 with a 2*s* range of 0.708345 to 0.712721 and a median of 0.710184, while the $^{87}Sr/^{86}Sr$ ratio for the Ohio Historical Society material is 0.710659 ± 0.001081, giving a 2*s* range of 0.708497 to 0.712821, and the median is 0.710348. These two ranges are very close to each other and both averages lie well within both ranges, suggesting that there is no meaningful difference in $^{87}Sr/^{86}Sr$ ratios between the material curated in the Chicago Field Museum and that curated at the Ohio Historical Society. The Hopewell faunal dataset is composed of material from the Hopewell Mound Group itself, and material from the Hopeton Triangle, a site within the same county as the Hopewell Mound Group. The average $^{87}Sr/^{86}Sr$ ratio for the material from the Hopewell Mound Group proper is 0.710308 ± 0.000928, with a 2*s* range of 0.708452 to 0.712164 and a median of 0.710031. The average $^{87}Sr/^{86}Sr$ ratio for the Hopeton Triangle material is 0.711540 ± 0.001843, giving a 2*s* range of 0.707854 to 0.715226 and a median of 0.711527. While the average $^{87}Sr/^{86}Sr$ ratios of both groups of faunal material lie within each other's 2*s* range, the 2*s* range for the four teeth from the Hopeton Triangle is exceptionally large, suggesting a very variant data set. This will be discussed below.

While initial analysis detected no potential human immigrants, as defined by $^{87}Sr/^{86}Sr$ ratios that lie outside of the 2*s* range for their sites, there were several faunal samples that did meet this definition. DBA1 (*Odocoileus virginianus*) from Utica Mounds with an $^{87}Sr/^{86}Sr$ ratio of 0.708807 lies beyond the 2*s* range for the entire Utica dataset (though not for the Utica faunal dataset exclusively). DBA 64 (*Castor canadensis*) from Albany Mounds with an $^{87}Sr/^{86}Sr$ ratio of 0.712020 lies beyond both the 2*s* range for the Albany faunal dataset and the 2*s* range for the entire Albany dataset. DBA 120 and DBA 121, both *Odocoileus virginianus* remains from the Hopeton Triangle, with $^{87}Sr/^{86}Sr$ ratios of 0.713070 and 0.713199 respectively, lie beyond the 2*s* range for the entire Hopewell dataset. DBA 120 and DBA 121 also lie beyond the 2*s* range for the Hopewell Mound Group fauna exclusively. The four Hopeton Triangle teeth show a very strong bimodal distribution, with the other two teeth, DBA 119 and DBA 122, having $^{87}Sr/^{86}Sr$ ratios of 0.709906 and 0.709983 respectively.

It is possible that these faunal outliers represent members of species who originated outside of the region of study, perhaps being traded into the region via human activity, and thus they may not reflect regional bioavailable $^{87}Sr/^{86}Sr$ ratios. Therefore, it was decided to recalculate the $^{87}Sr/^{86}Sr$ average ratios for each site while excluding these faunal outliers. When this is done, several potential human outliers appear at each site.

With DBA 1 excluded, the new average $^{87}Sr/^{86}Sr$ range for the Utica faunal dataset becomes 0.710394 ± 0.000678, with a 2*s* range of 0.709038 to 0.711750. The new range for the entire Utica Mounds dataset becomes 0.710598 ± 0.000535, giving a 2*s* range of 0.709528 to 0.711668. There still remain no human outliers beyond this range, suggesting that there are no immigrants among the sample material taken from Utica Mounds.

With DBA 64 excluded from the Albany material, the new average $^{87}Sr/^{86}Sr$ ratio for the Albany faunal dataset becomes 0.709679 ± 0.000617 with a 2*s* range of 0.708445 to 0.710913, while the average $^{87}Sr/^{86}Sr$ ratio for the entire Albany dataset becomes 0.710031 ± 0.000598, giving a 2*s* range of 0.708835 to 0.711227. Three $^{87}Sr/^{86}Sr$ ratios fall outside the new 2*s* range of the faunal material, suggesting that they may be potential immigrants: DBA 37 (0.711052), DBA 41 (0.711106), and DBA 49 (0.711426).

DBA 37 is Burial 93 from Albany's Mound 20, the mound with the clay "nucleus." Burial 93 was a cremated burial that the excavator argued was likely to have immediately preceded the construction of the "nucleus" (Herold 1971:32). This individual was an adolescent possible female, aged 12 to 20 years (14-18 years if female and 16-20 years if male). The sampled tooth was the right fourth lower premolar (RPM_4). All third molars were present and showed signs of slight wear; however, all visible cranial sutures were open. Evidence of healed porotic hyperostosis was present on the occipital bone. There was no evidence as to cause of death.

DBA 41 was a member of Mound 20's Burial 51, a bundle burial of two individuals interred in the mound fill above the central tomb. DBA 41 was a young adult of unknown sex, aged 20 to 35 years of age, buried with a young male also aged 20 to 35 years. DBA 41 is represented solely by a lower mandible and two large fragments of maxilla. The tooth sample from this individual came from the upper first molar (LM^1). The young male companion burial was not included in this study.

DBA 49 was recovered from Mound 17, as an extended burial (Burial 3). This individual is an adolescent probable male, aged 16 - 20 years as determined by dental development and postcranial analysis. The sample taken from this individual was a left lower premolar (LPM_4).

There is some evidence of disease, including healed lesions on both femoral diaphyses and both tibial diaphyses, as well as active lesions on the left tibia. A healed porotic hyperostosis was demonstrated on his occipital bone. There is no evidence as to cause of death.

Of the three possible outliers (DBA 37, DBA 41, and DBA 49), DBA 49 presents the most robust case to be determined a potential migrant. In addition to falling outside the 2*s* faunal range, DBA 49 also falls outside both the 2*s* range for the Albany human dataset exclusively, and the new 2*s* range of the entire Albany dataset. DBA 49 is thus the strongest potential immigrant in the Albany dataset.

With DBA 120 and DBA 121 excluded, the new average $^{87}Sr/^{86}Sr$ ratio for the Hopewell faunal dataset becomes 0.710217 ± 0.000802, with a 2*s* range of 0.708613 to 0.711821. For the entire Hopewell dataset, human and faunal, the new average $^{87}Sr/^{86}Sr$ ratio becomes 0.710547 ± 0.001034, giving a 2*s* range of 0.708479 to 0.712615. Seven human samples now fall outside the 2*s* range of the Hopewell faunal dataset: DBA 65 (0.712480), DBA 67 (0.712320), DBA 97 (0.712177), DBA 98a (0.712861), DBA 104 (0.712257), DBA 107 (0.712142), and DBA 111a (0.712304), suggesting that they may represent potential immigrants.

DBA 65 (Individual 41593.Z) was an adult female (age 18 years). Her cranium was gracile and there were very few teeth present. The sample taken from this individual was an incisor, I^1. As the adult incisor is one of the earliest teeth to begin mineralization at age 9 months (Steele and Bramblett 1988:102), it is possible that the $^{87}Sr/^{86}Sr$ ratio for this individual reflects maternal contribution. There is no postcranial material available from this individual. Though this individual was included in the Hopewell collections, provenience information was lacking and her light isotope data, discussed below, suggests that she might be intrusive from a later period.

DBA 67, a potential outlier, was one of seven commingled individuals representing one female, one male, and five of indeterminate sex. Two samples were taken from this material, DBA 67 and DBA 68. Both samples consisted of an LPM_4 to ensure that the same individual was not sampled twice. While these individuals were included in the Hopewell collection, no detailed provenience was available for them; however these individuals may have been retrieved from Hopewell Mound 25 and may have been accompanied by copper artifacts such as a copper plate and beads (Case and Carr 2008a). Six of these individuals were full adults, based on fused proximal femurs; one of them, sex indeterminate, was a late adolescent (16 to 19 yrs old) based on an open distal femur suture.

DBA 97 was a member of Burial 41 in Mound 25. This burial consisted of three extended burials, along with a trophy skull and several worked mandibles (Case and Carr 2008a). DBA 97 was represented solely by an unworked mandible, which Case and Carr (2008a) argued belongs to the remains described as Skeleton 1 by Shetrone. Some cutmarks were present on the mandible. Several teeth had been lost antemortem, and the right rear molar was impacted. OHS records describe this individual as of unknown sex, but Case and Carr (2008a) suggests that the individual was a female “middle adult” (aged 36-49). The tooth sampled from this individual was the fourth right lower premolar (RPM_4).

Though included in the Hopewell collection, DBA 98a is lacking in provenience information and as with DBA 65, the light isotope data from this sample (discussed below), suggests this may be an intrusive burial. This individual is represented only by a mandible. Age is given as “Adult” (estimated at between 21 and 25 years) and sex is unknown. The tooth sampled for this individual was the third right lower premolar (RPM_3). No pathologies were observable on this individual. One tooth (the right lower third molar) exhibited decay.

DBA 104 is Individual 71 from Burial 4 in Mound 2. This was a single extended burial on the mound floor, oriented toward the southeast and associated with several copper artifacts (Case and Carr 2008a). This individual was judged to be a probable young adult female, aged between 21 and 25 years. Most of the skull and large parts of the postcrania are present, including clavicles, right humerus and part of the left, both radii and ulnae, parts of the scapulae, most of the spinal column and almost all of the pelvis and both legs. An upper third right molar (RM^3) was sampled from this individual.

DBA 107 comes from "Lot 82," Burial 16 of Mound 25. This was another single burial, extended and oriented with head to the northeast (Case and Carr 2008a). The sample for this individual was taken from RPM_3. This individual is an adult probable female, represented only by a skull. There was some occipital flattening, and a cut mark on the left zygomatic arch. No pathology was observable on this individual.

The final possible outlier from the Hopewell Mound Group dataset is DBA 111a. This individual was recovered from Burial 15 in Mound 25, and is designated Individual/Lot 96. There is some confusion about whether these remains or another set of remains actually represent Burial 15 (Case and Carr 2008a). The sample for this individual came from the first right lower premolar (RPM_3). This individual was comparatively well represented skeletally. Large chunks of the cranium, the long bones, and the pelvis were all present. The age of this individual was given as young adult (26-30 years) and the sex as a probable female. Markings of strong development for the attachment of the soleus muscle for the tibia were present. No pathologies were identified.

Of these seven, DBA 98a presents the most robust case for a potential immigrant. DBA 98a's $^{87}Sr/^{86}Sr$ ratio lies not only beyond the *2s* range for the Hopewell faunal dataset exclusively, but also beyond the revised range for the full Hopewell dataset (combining human and faunal material. However, DBA 98a does not fall beyond the 2*s* range of human strontium ratios from the Hopewell Mound Group, meaning that the case for DBA 98a as an immigrant is weaker than that for the Albany Mounds individual represented by DBA 49.

Carbon and oxygen isotopes:

Selected samples were also subjected to light isotope analysis, specifically $\delta^{13}C$ and $\delta^{18}O$. Samples were chosen for analysis based on sample size. Teeth that, after apatite preparation, yielded less than 9 mg of sample were not chosen for light isotope analysis. The optimum size for $^{87}Sr/^{86}Sr$ analysis is generally considered to be 10 to 15 mg of sample (Justin Glessner, personal communication, 2009). While sample sizes needed for light isotope analysis were not large (~600 µg), it was still deemed best to be conservative when selecting samples for light isotope analysis.

Fifteen human teeth and ten faunal teeth were sampled from the Utica Mounds dataset. The ten faunal teeth all came from the French Canyon West material. Data from one human sample (DBA 29) and two faunal samples (DBA 86 and DBA 93) were lost due to a mechanical error, yielding a total sample of 14 human teeth and eight faunal teeth. The faunal teeth for which data were recovered consisted of six white-tailed deer, one beaver and one elk tooth.

Twenty-two teeth total were sampled from Albany Mounds, including eight human teeth and 14 faunal teeth. The 14 faunal teeth comprised all of the available faunal material from Albany Mounds. They consisted of one raccoon tooth, eight beaver teeth and five deer teeth.

Samples chosen for light isotope analysis from the Hopewell Mound Group included 12 teeth from the human collection drawn from the Chicago Field Museum (all except DBA 74), and the 25 teeth drawn from the collections at the Ohio Historical society, for a total of 37 human teeth. Only the faunal material from the Hopewell Mounds National Park service was included in this portion of the study, yielding six faunal samples in all for the Hopewell Mound Group. These faunal samples included three white-tailed deer teeth, one long-bone fragment, also from a white-tailed deer; one turtle shell fragment, and one tooth from a freshwater drumfish.

Light isotope data for all samples is presented in Appendix 3, and means and standard deviations are presented in Table 3. Since the samples tested for light isotopes are a subset of those tested for ^{87}Sr/^{86}Sr, the light isotope data is not as comprehensive as that for ^{87}Sr/^{86}Sr. Still, the additional data helps to enhance and enrich the picture of human population movement and diet at the three sites in the Middle Woodland by providing a complementary source of data to the ^{87}Sr/^{86}Sr data and by providing more direct evidence of levels of maize consumption than Rose's (2008) study.

δ^{13}C results:

For all three sites in this study, average δ^{13}C values of the human datasets were consistent with a diet composed primarily of C_3 plants. The average δ^{13}C value for Utica Mounds human dataset was -14.07‰ ± 2.41‰. Average δ^{13}C value for Albany Mounds human dataset was -15.06‰ ± 0.41‰. DBA 50, the individual sampled on special request from the Illinois State Museum, has a δ^{13}C value of -14.92‰, not significantly different from the Albany average. The average δ^{13}C value for the Hopewell Mound Group human dataset was -13.06‰ ± 3.38‰, which breaks down into -13.84‰ ± 2.40‰ from the Chicago Field Museum material and – 12.69‰ ± 3.72‰ from the Ohio Historical Society material.

The $\delta^{13}C$ values for the Hopewell Mound Group human dataset are higher than that for either Albany or Utica and suggest that the population represented by this dataset relied on a maize-based diet to a greater degree than individuals at the other two sites. The Hopewell human dataset included four individuals with anomalous $\delta^{13}C$ values: DBA 65 with a $\delta^{13}C$ value of -6.29‰, DBA 98a with a $\delta^{13}C$ value of -2.01‰, DBA 99 with a $\delta^{13}C$ value of -2.62‰, and DBA 100 with a $\delta^{13}C$ value of -3.99‰. DBA 65 is from the Chicago Field Museum collections, while the remaining three individuals come from the collections at the Ohio Historical Society. In addition, one individual from Utica Mounds, DBA 15, also had an anomalous $\delta^{13}C$ value of -6.11‰. Analysis properties for these five individuals were normal, indicating that the $\delta^{13}C$ values were valid. These $\delta^{13}C$ values are all consistent with diets containing extremely large amounts of maize, which would be unusual for Middle Woodland sites (Smith 1992) and would contradict Rose's (2008) results. It is possible that these individuals are intrusive. Radiocarbon dating of the skeletal remains would confirm this. The minimal provenience information for Utica Mounds has been discussed previously, and the four Hopewell Mound Group individuals were also lacking provenience information, though they were included in the collections with the remains of individuals of known provenience. When the $\delta^{13}C$ values of these five individuals are excluded, the average $\delta^{13}C$ value for the Hopewell Mound Group human dataset becomes -14.19 ‰ ± 0.56‰, which breaks down into -14.53‰ ± 2.32‰ for the Chicago Field Museum material and -14.03‰ ± 0.59‰ for the Ohio Historical Society material. That for the Utica Mounds human dataset becomes -14.69‰ ± 0.78‰. These values indicate a diet based on C_3 plants and support Rose's (2008) collagen research indicating little maize consumption during this time period.

The faunal samples from the sites also showed a primarily C_3-based diet. The average $\delta^{13}C$ value from Utica Mounds was -14.62‰ ± 1.21‰, while that for Albany Mounds was -14.42‰ ± 1.20‰. The Hopewell Mound Group initially demonstrated an average $\delta^{13}C$ value of -11.01‰ ± 5.52‰. However, one of the faunal samples in this dataset, DBA 78, had a $\delta^{13}C$ value of -0.78‰. This value is so abnormal compared to the rest of the $\delta^{13}C$ values in this study that this sample is likely to have been contaminated in some way. Alternatively, it could be misidentified, perhaps the remains of a modern cow. When DBA 78 is excluded, the average $\delta^{13}C$ value for the Hopewell faunal dataset becomes -13.06‰ ± 2.58‰. The average $\delta^{13}C$ ratios for the two largest groups of fauna in the entire faunal dataset, the deer and the beaver, were -14.59‰ ± 1.24‰, and -14.23‰ ± 1.09‰ respectively. These low $\delta^{13}C$ values show they did not consume C_4 plants such as maize.

$\delta^{18}O$ results:

$\delta^{18}O$ results were compared with the $^{87}Sr/^{86}Sr$ results for each site to determine whether individuals identified as potential immigrants by $^{87}Sr/^{86}Sr$ ratios would also appear as immigrants with regards to their $\delta^{18}O$ values. As with the $^{87}Sr/^{86}Sr$ results, potential immigrants were here defined as individuals whose $\delta^{18}O$ values lay beyond two standard deviations of the regional faunal mean at each site. Such outliers were to be compared against the 2*s* range of the human dataset for their site, in order to compensate for any potentially unusual dietary practice that might affect $\delta^{18}O$ values, and then further tested against the combined human and faunal means for each site. The combined site means were also compared with each other, to determine whether it was possible to distinguish among the populations of the three sites on the basis of $\delta^{18}O$ values. As with the $^{87}Sr/^{86}Sr$ results, datasets that were composed of samples from different collections were further broken down into these subgroups, and then the means and 2*s* ranges of the different subgroups were evaluated against each other to check for differences between the groups.

White et al.'s (2009) extensive discussion of $\delta^{18}O$ analysis indicates that determinants of skeletal $\delta^{18}O$ values are extremely complex, involving multiple factors such as local humidity and feeding environments, and suggests that this technique is best used to determine migration history in areas with large differences in $\delta^{18}O$ values between regions. Taking this into account, interpretation proceeded with the understanding that if the $\delta^{18}O$ data showed the same outliers as the $^{87}Sr/^{86}Sr$ data, it would strengthen the case for these outliers to be regarded as immigrants; whereas if the $\delta^{18}O$ data did not demonstrate the same outliers as the $^{87}Sr/^{86}Sr$ data, it might weaken, but would not necessarily invalidate the interpretation of these outliers as immigrants.

The $\delta^{18}O$ data from Utica Mounds supported the $^{87}Sr/^{86}Sr$ results in that no human samples demonstrated a $\delta^{18}O$ value beyond 2*s* of the faunal range. The average $\delta^{18}O$ value for the entire Utica faunal dataset, including six deer and one beaver (DBA 88a) was 24.49‰ ± 1.98‰, yielding a 2*s* range of 20.54‰ to 28.45‰ and with a median of 24.04‰. When the $\delta^{18}O$ value from the beaver was excluded (to account for any possible specific differences in feeding patterns between it and the deer), the remaining deer specimens gave an average $\delta^{18}O$ value of 24.91 ± 2.06, with a 2*s* range of 20.79‰ to 29.03‰. In comparison the $\delta^{18}O$ mean for the Utica human dataset was 26.14‰ ± 0.82‰, with a 2*s* range of 24.50‰ to 27.79‰ and a median of 25.84‰. This range lies within the 2*s* faunal range, whether calculated with the beaver specimen or without, indicating similar dietary $\delta^{18}O$ values for both human and faunal samples from Utica

Mounds. One human sample has a $\delta^{18}O$ value that falls beyond the 2*s* range of the human dataset: DBA 14, with a $\delta^{18}O$ value of 27.82‰. However, this $\delta^{18}O$ value still lies well within the 2*s* range of the Utica faunal dataset. In addition, DBA 14's $^{87}Sr/^{86}Sr$ ratio was within the 2*s* range of the Utica mounds faunal strontium ratios as well. Thus, DBA 14 is most likely not an immigrant.

The average $\delta^{18}O$ value for the complete Utica Mounds dataset, combining both human and faunal material, is 25.54‰ ± 1.54‰, giving a 2*s* range of 22.45‰ to 28.63‰ with a median of 25.55‰. There are no outliers, either human or faunal, from this range.

For the Albany Mounds material, three potential human immigrants were identified by $^{87}Sr/^{86}Sr$ analysis: DBA 37, DBA 41, and DBA 49. One anomalous faunal sample was detected as well: DBA 64. Of these, neither DBA 41 or DBA 49 were included in the light isotope portion of this study due to small sample size, and of the remaining two samples, the $\delta^{18}O$ data does not support the case for either of them to be immigrants. The average $\delta^{18}O$ value for Albany Mounds faunal material was 23.81‰ ± 1.93‰, giving a 2*s* range of 19.95‰ to 27.67‰ and a median of 23.62‰. This was then broken down into separate calculations for both deer and beaver, because of the different feeding patterns and environments of the two species. For Albany Mounds deer, the average $\delta^{18}O$ value was 24.96‰ ± 1.86‰, giving a 2*s* range of 21.24‰ to 28.69‰, while for Albany Mounds beaver, the average $\delta^{18}O$ value was 22.65‰ ± 1.07‰, with a 2*s* range of 20.55‰ to 24.84‰. Both DBA 37, with a $\delta^{18}O$ value of 25.49 ‰, and DBA 64, with a $\delta^{18}O$ value of 21.77‰, lie within the 2*s* range of the deer faunal material.

The 2*s* range of the Albany beaver material excludes not only DBA 37, but in fact most of the Albany Mounds human sample; in fact, only DBA 32 and DBA 36 actually lie within the 2*s* range for the beaver material. This suggests that, due to species differences, beavers may not be a valid faunal proxy for human $\delta^{18}O$ values at a given site. With the beaver data thus excluded, the $\delta^{18}O$ values for the Albany Mounds faunal dataset do not reveal any immigrants at this site.

The mean $\delta^{18}O$ value for the Albany Mounds human dataset is 25.41‰ ± 0.58‰, giving a 2*s* range of 24.24 ‰ to 26.57‰ and a median of 25.54‰. As was seen at Utica Mounds, this 2*s* range fits within the 2*s* range of Albany Mounds deer specimens (though not Albany Mounds beaver), indicating that the humans at this site most likely shared dietary $\delta^{18}O$ values with the deer in this region. For the combined Albany Mounds dataset, including both human and faunal material, the average $\delta^{18}O$ value is 24.39‰ ± 1.74‰ with a median of 24.57‰. This gives a 2*s* range of 20.91‰ to 27.87‰. This range overlaps substantially with that for the Utica Mounds combined dataset, indicating that the populations of these two sites cannot be distinguished from each other on the basis of $\delta^{18}O$ values.

The Hopewell Mound Group $^{87}Sr/^{86}Sr$ data revealed six individuals who were potential immigrants to the region: DBA 65, DBA 67, DBA 97, DBA 98a, DBA 107, and DBA 111a. However, as with Albany Mounds, the results of $\delta^{18}O$ analysis for this site do not support the interpretation of these individuals as immigrants. Excluding DBA 78 from the faunal analysis on the basis of its possible contamination as revealed by its abnormal $\delta^{13}C$ value (as discussed previously), the average $\delta^{18}O$ value for the Hopewell Mound Group faunal dataset is 25.23‰ ± 2.59‰, giving a 2*s* range of 20.05‰ to 30.42‰ and a median of 24.81‰. DBA 65 (with a $\delta^{18}O$ value of 27.62‰), DBA 67 (25.84‰), DBA 97 (24.66‰), DBA 98a (26.81‰), DBA 107 (27.79‰), and DBA 111a (24.90‰) all lie within this range.

This faunal data set can be further refined by excluding DBA 82 (softshell turtle specimen) and DBA 83a (a freshwater drumfish) as well as DBA 78 and concentrating on the remaining three samples: DBA 79, DBA 80, and DBA 81 (all deer). The average $\delta^{18}O$ value for these three individuals is 26.52‰ ± 2.24‰ with a 2*s* range of 22.04‰ to 30.99‰. Again, the potential human immigrants as determined by $^{87}Sr/^{86}Sr$ analysis all lie within this range, and no other human sample has a $\delta^{18}O$ value outside it. This indicates that $\delta^{18}O$ analysis does not detect any human immigrants in the Hopewell Mound Group dataset.

The average $\delta^{18}O$ value for the Hopewell Mound Group human dataset is 26.25‰ ± 0.85‰, with a 2*s* range of 24.50‰ to 28.00‰ and a median of 26.19‰. There is one human sample that lies outside the 2*s* range of the human dataset: DBA 94 with a $\delta^{18}O$ value of 28.70‰. However, this is well within the 2*s* range of the faunal material, and so DBA 94 is most likely not an immigrant. As with the other two sites, the human 2*s* range for the Hopewell Mound Group dataset is contained within the 2*s* range of the faunal dataset at this site, indicating no meaningful difference in dietary practice with regards to $\delta^{18}O$ values. The Hopewell Mounds human dataset can be separated into samples taken from the Chicago Field Museum and those taken from the Ohio Historical Society material. When this is done, the mean $\delta^{18}O$ value for the Field Museum material is revealed to be 26.35‰ ± 0.95‰ with a 2*s* range of 24.45‰ to 28.25‰ and a median of 26.41‰, while that for the Ohio Historical Society material is 26.21‰ ± 0.85‰, giving a 2*s* range of 24.50‰ – 27.92‰ and a median of 26.14‰. These ranges are almost identical and indicate no substantial differences between these two groups, suggesting that they represent the same population of Hopewell Mound Group inhabitants.

For the entire Hopewell dataset, combining both human and faunal material, the average $\delta^{18}O$ value is 26.05 ‰ ± 1.30‰. This gives a 2*s* range of 23.45‰ – 28.65‰ and a mean of 26.16‰. This mean and 2*s* range overlaps extensively with the mean $\delta^{18}O$ values and 2*s* ranges from Albany and Utica Mounds, suggesting that the populations at these three sites cannot be distinguished from one another by means of $\delta^{18}O$ analysis.

The faunal material included in the light-isotope portion of the study was dominated by members of two species: deer and beaver. The average $\delta^{18}O$ values and 2*s* ranges were calculated for these groups to determine whether they differed. The average $\delta^{18}O$ value for deer was 25.27‰ ± 1.98‰, with a 2*s* range of 21.31‰ to 29.24 ‰ and a median of 24.54‰, while the average $\delta^{18}O$ value for beaver was 22.65‰ ± 1.01‰, giving a 2*s* range of 20.62‰ to 24.67‰ and a mean of 22.18‰. These ranges largely overlap; however the range for beaver is narrower and lower than that for deer, which may reflect different feeding environments.

Plotting $\delta^{18}O$ and $\delta^{13}C$ data for faunal specimens at each site and across sites (Figs. 12-15) revealed a clustering effect among the Albany Mounds beaver material (the only site with more than one beaver specimen). Albany mounds beaver data fell into a group comprised of five individuals demonstrating $\delta^{13}C$ values of around -15.00‰ and $\delta^{18}O$ values between 21.00‰ and 23.00‰, with three outliers. The outliers from this group had higher $\delta^{13}C$ values (between -13.00‰ and -12.00‰) and higher $\delta^{18}O$ values as well, between 23.00‰ and 24‰. These groupings may reflect seasonal variation in diet. Stuart-Williams and Schwarcz (1997) have found that $\delta^{18}O$ values in beaver incisors vary with the seasons by about 4‰ and tend to be highest in late summer and early fall. It is therefore possible that the three outlying beaver specimens were consuming a fall diet at the time this enamel was forming.

Deer at all sites fell into two discontinuous groups based on the $\delta^{18}O$ data: one with $\delta^{18}O$ values between 22.00‰ and 25.00‰, and the other with $\delta^{18}O$ values ranging between roughly 26.50‰ to 28.00‰. These differences may reflect differences in dietary strategies. Luz et al. (1990) in their research on deer bone $\delta^{18}O$ values indicated that such values derived from three sources: drinking water, oxygen in the atmosphere, and oxygen values of water in food substances. Leaves in particular may contain water enriched in ^{18}O (Luz et al. 1990). Deer specimens with high δ^{18}O values may have gained a larger amount of their water in the form of leaf water, while those with lower δ^{18}O values may have had more opportunity to drink from running water such as streams and rivers.

In general, the δ^{18}O data neither supported the case for potential immigrants that had already been identified by ^{87}Sr/^{86}Sr analysis, nor identified potential immigrants that ^{87}Sr/^{86}Sr analysis had failed to catch. No potential immigrants at any of the three sites were detected by this method. When taken together with the inability to distinguish the populations of Albany Mounds, Utica Mounds and the Hopewell Mound Group from each other on the basis of their mean δ^{18}O values and 2*s* ranges, this suggests that δ^{18}O analysis may be inappropriate for detecting population movement in this region of Eastern North America, in line with White et al.'s (2009) discussion of the potential uses of δ^{18}O analysis.

CHAPTER 5

DISCUSSION

Excluding two individuals of uncertain provenience who were likely intrusive burials, this study determined eight potential migrants as defined by those who demonstrated strontium signatures falling outside two standard deviations of faunal mean. Three of these potential migrants were found in Illinois, all at the Albany Mounds site, and the remaining five were found at the Hopewell Mound Group in Ohio. Not only were larger absolute numbers of potential immigrants found at the Hopewell Mound Group, but they also formed a larger percentage of the whole (13% in Ohio compared to 7% for Illinois). This does not support the genetic work of Bolnick and Smith (2007), which suggested that migration and population movement was flowing from Ohio to Illinois.

Of course, given that all three potential Illinois immigrants were found at Albany Mounds, it is possible that the Illinois data reflects different regional patterns of population movement. Indeed, taken on its own, the number of potential migrants in the Albany Mounds sample is 14%, almost identical to that found at the Hopewell Mound Group. It may be that there were very few migrants or immigrants to central Illinois while Albany Mounds experienced significantly higher levels of immigration. Different regional patterns of population movement fit Anthony's (1990) model of long-distance migration, which suggests that migration tends to proceed to specific, known destinations and can bypass large tracts of land on the way. Given that PIMA evidence suggests a possible pipestone connection between Illinois and Ohio sites like Tremper (Emerson et al. 2004), and that Albany Mounds is near a pipestone workshop, connections between Albany and Ohio may be one explanation. Alternately, taking into account

Carr's (2006) envisioning of Middle Woodland population movement as a series of small-scale, idiosyncratic processes such as pilgrimages and healing quests, it may be that Albany Mounds with its pipestone workshop simply possessed more drawing power of this kind than Utica Mounds.

All of the potential outliers from Albany Mounds lie within the 2*s* range of both the Hopewell Mound Group and Utica Mounds. This does not prove that either of these two areas originated the Albany Mounds outliers, but at least it does not rule out the possibility of these sites as potential points of origin.

The five potential outliers from the Hopewell Mound Group, on the other hand, all lie outside the 2*s* deviation for either of the Illinois sites. This strongly suggests that these individuals, if immigrants, did not originate at either Albany Mounds or Utica Mounds. This is perhaps not surprising in view of Carr's (2008) envisioning of the purpose of the Hopewell Mound Group. Carr (2008) makes a powerful, densely supported argument that Ohio earthworks such as the Hopewell Mound Group were constructed by and served as drawing points from multiple symbolic communities dispersed over a large region. The Hopewell earthwork is seen by Carr (2008a) as one part of a "tripartite alliance" helping to bond together symbolic communities represented by six different earthworks scattered throughout Ross County. Furthermore, Carr (2008) has also argued that Ohio Hopewell individuals were very tightly interconnected through a dense, overlapping and interwoven network of clans, sodalities and ceremonial societies. If the Ohio Hopewell were indeed unusually closely connected, it may be that there was greater population mobility in Ohio in general and that burials especially at these earthworks were more likely to reflect any extra-regional immigrants.

Charles (1992, 1995) argues similarly in his analysis of Middle Woodland burial mounds in the Lower Illinois River Valley, which experienced a dramatic population increase over the course of the Middle Woodland after having been virtually depopulated during the preceding Early Woodland period. Charles (1995) argues that Middle Woodland burial mounds and their associated mortuary practices served the function of integrating and attracting newcomers to the communities while at the same time helping elites to maintain their privileged status. Following Brown (1981), Charles (1992) describes a "two-track" burial program in which dominant lineages are given central tomb burial (at least initially) in burial mounds, while burials of other lineages are located outside the central tomb on the mound's edges. He then goes on to argue that the dominant or central lineages may have been those who arrived in the region first, and that they gained in status through a process of "levitation" (1992:191) as further immigrants continued to arrive, these immigrant lineages then being accorded secondary status as illustrated in their peripheral burials. This analysis is consonant with Anthony's (1990:901) observation that the initial migrants to a community may use their longer familiarity with the new region to assist later arrivals in adapting, while accruing status and influence to themselves in the process. However, given the relative dearth of potential immigrants detected at Albany Mounds and Utica Mounds, this model appears to be inappropriate for these sites.

The strontium data for this study supports Carr's (2008) argument for the Hopewell Mound Group (and especially Mound 25) as one of six sites that served as focal points for three "symbolic communities" along the Paint Creek, North Fork and Scioto River, helping to weld them into a sustainable community. The most potential immigrants at any single site in this study were found at the Hopewell Mound Group, 13 percent of total individuals sampled, suggesting that immigration was a non-trivial demographic force at that site. Carr (2008) interprets the

Hopewell site as having an especial significance among the six sites he mentions in his analysis, stating that it contained the remains of "a select group of important persons who filled key social roles of responsibility in each of the three local symbolic communities" (Carr 2008:134). The high levels of non-local strontium signatures found in this study support that interpretation, as does the fact that the Hopewell material demonstrated more variability in $^{87}Sr/^{86}Sr$ ratios than the Illinois sites. Carr's (2008) assertion that the population represented by the Hopewell Mound Group was patrilineal is also supported by this data as all the potential immigrants identified by this study at Hopewell Mounds were females, probable females, or unknown gender.

Charles's (1992) proposed two-track mortuary program and settlement model for the Lower Illinois River Valley appears to be inapplicable to Utica Mounds at least, as no potential immigrants were detected at that site in this study. In contrast, Albany Mounds, when taken alone, demonstrated a percentage of potential immigrants comparable to that at the Hopewell Mound Group (three out of 21 human immigrants or 13%). Charles's (1992) model thus may be more applicable to Albany Mounds than to Utica Mounds. However, the number of potential immigrants detected at Albany Mounds still remains a clear minority. Furthermore, of the three potential immigrants, two of them came from the same mound (Mound 20, a mound with an unusual and distinct clay "nucleus" not found in any of the other excavated mounds at this site) and one of them came from Mound 17, located near Mound 2. These individuals may have been part of a distinct sub-population with higher immigration levels, one that was not present in other mounds on the site. (It is perhaps noteworthy that Mound 9, the largest and most elaborate of the mounds involved in this study and the one from which the most samples were taken, did not show any potential immigrants.) This suggests that Charles's (1992) model may not be a good fit for Albany Mounds either.

The clear distinctions between Charles's (1992) model and the two sites in this sample, as well as the distinctions between the sites themselves, what with Albany and Utica demonstrating drastically different levels of immigration, suggest that that Illinois is less integrated than Carr's (2008) powerful vision of Ohio. The burial mounds of Albany and Utica do not appear to be playing the same roles as Charles (1992, 1995) has demonstrated for the Lower Illinois River Valley, and in fact they may have different meanings at each separate site. Ruby et al. (2005) attempted to evaluate the Hopewell manifestation in the Lower Illinois River Valley and the Scioto-Paint Creek drainage area (as well as the Wabash-Ohio confluence in Indiana) against Smith's (1992) "bullseye" model of Hopewell settlement: that Hopewell earthworks served as a single gathering center for a single community of individuals living in dispersed hamlets around that center. Ruby et al. (2005) determined that the model was too simplistic for the areas involved in their study. However, the data from this current study does not contradict the Smith (1992) model for Utica Mounds at least. Given that Utica Mounds has lower amounts of exotic material than Albany (Emerson, 2011, personal communication), it may be that Utica Mounds was a fairly isolated "backwater" and more localized community than Albany Mounds. On the other hand, Albany Mounds, which displayed similar levels of immigration to the Hopewell Mound Group when taken on its own, may have been a more cosmopolitan site. The three immigrants at Albany Mounds fall within the 2*s* range for the Hopewell Mound Group, which certainly does not prove that they came from that site, but does not rule it out either. In addition, given the levels of overlap between the two sites, it cannot be ruled out (though again, it is not proved) that more immigration was not occurring between them.

Further evidence that Illinois was fragmented, with different regions following different patterns, may come from contrasting this data with Bolnick and Smith's (2007) DNA study.

Bolnick and Smith’s (2007) study focused on the Pete Klunk mound group in Illinois along with the Hopewell Mound Group in Ohio. In addition to determining that gene flow was occurring from Ohio to Illinois, Bolnick determined also that the population at the Illinois site practiced matrilocality. If this were the case for the sites included in this study, we would expect to see males demonstrating immigrant signatures at the Illinois sites. However, no potential immigrants were found by this study at Utica Mounds, and at Albany Mounds, between one-third and two-thirds (depending on the gender of the potential immigrant of unknown sex) of the immigrants were female. This does not support the inference of matrilocality for either of these sites. It is possible that the sites in this study practiced different post-marital residence patterns than the population represented by the burials at Pete Klunk. It would be interesting to perform $^{87}Sr/^{86}Sr$ analysis on the Pete Klunk population, to see if the strontium data supported Bolnick and Smith’s (2007) inference of matrilocality for that site.

A recent study by Hill et al. (2011) examining residence patterns among 32 modern-day foragers suggests that in practice the most common pattern for postmarital residence among human hunter-gatherers is neolocality. This is in contrast to conventional interpretations of the ancestral residence pattern for hunter-gatherers as patrilocal postmarital residence (a supposition supported by Copeland et al.’s (2011) research on early hominin taxa, which suggested female dispersal on reaching sexual maturity). Hill et al. (2011) found that individuals tended to live in bands accompanied by adult siblings and/or siblings-in-law of either sex, and that a majority of band members in Hill et al.’s (2011) study were un-related to each other genetically. Hill et al. (2011:1288) asserted that “bands are mainly composed of individuals either distantly related by kinship and/or marriage or unrelated altogether.”

Of the three sites in this study, Albany Mounds demonstrates the best case for postmarital neolocality, as this site features nearly equal numbers of male and female immigrants. When Bentley's (2006) observation that postmarital residence pattern may be indicated by observing a greater spread of ^{87}Sr /^{86}Sr ratios in one sex than the other is considered, the case strengthens. Broken down by gender, Albany Mounds males and females demonstrate very similar 2*s* ranges (see Table 4). For Albany females, the mean ^{87}Sr/^{86}Sr ratio was 0.710143 ± 0.000484 with a 2*s* range of 0.709175 - 0.71111, whereas for Albany males, the mean ^{87}Sr/^{86}Sr ratio was 0.710401 ± 0.000473, with 2*s* range 0.709455-0.711348. The standard deviation in each case is similar, though the means themselves are slightly offset.

When Utica Mounds is broken down by gender, Utica Mounds males show an ^{87}Sr/^{86}Sr ratio of 0.710556 ± 0.000288 with a 2*s* range of 0.709980 - 0.711132; Utica Mounds females, in contrast, have an ^{87}Sr/^{86}Sr ratio of 0.710947 ± 0.000340 with a 2*s* range of 0.710266-0.711628. (DBA 15, the potentially intrusive individual, was of unknown gender and so was not included in either category.) In this case, the females show a slightly larger 2*s* range than the males (and in fact, one male, DBA 13, falls outside of the Utica females' 2*s* range with an ^{87}Sr/^{86}Sr ratio of 0.710225). This may suggest that the population at Utica Mounds practiced patrilocality as a postmarital residence pattern, but given that the demographic data including sex data for the Utica Mound specimens are incomplete (with only 3 identified males or probable males and 5 identified females or probable females), any observed differences between the sexes are likely to be statistical artifact.

As mentioned previously, the ^{87}Sr/^{86}Sr data from the Hopewell Mound Group clearly supports Carr's (2008) inference of patrilocality. Not only are all of the immigrants whose gender is known female, but females demonstrate more ^{87}Sr/^{86}Sr variance than males do.

Exclusive of the probably-intrusive DBA 65, the mean $^{87}Sr/^{86}Sr$ ratio for Hopewell Mound Group females is 0.710792 ± 0.000902 with 2*s* range of 0.708987 - 0.712597. In contrast, Hopewell Mound Group males demonstrate a mean $^{87}Sr/^{86}Sr$ ratio of 0.710273 ± 0.000860 with 2*s* range of 0.708554 - 0.711993. The mean for HMG males, interestingly enough, is very close to the Hopewell Mound Group faunal mean exclusive of DBA 120 and DBA 121, which is 0.710217 ± 0.000802. This further strengthens the inference that the human population of the Hopewell Mound Group is patrilineal.

Hopes for this research were that the three sites in the study would demonstrate strontium regional signatures and 2*s* ranges that were clearly distinct from each other. According to the provenance principle, sourcing works best with discrete rather than clinal variations between the areas under study (Oregon State University Archaeometry Lab 2011), so distinct mean $^{87}Sr/^{86}Sr$ ratios at each site would be ideal for identifying potential immigrants and determining possible interactions between the sites. Unfortunately, the means for each site lay well within the 2*s* ranges of the other two sites, meaning that the sites did not display discrete variations and the populations at each site could not be distinguished from one another on the basis of strontium signatures. This complicates interpretations of possible population movement patterns among these sites. It is possible that more migration was occurring at these sites than was found in this study, but that this migration was undetectable because the immigrants had strontium signatures that fell within the 2*s* ranges of each site. In addition, it is possible that migration was occurring to these sites from other areas outside of this study, but, again, was undetectable because the sending areas had similar regional strontium signatures to the sites in the study. Therefore more population movement may have been occurring than was detected by this present research. Better control of the regional strontium profiles, including increased faunal sampling from each of the three sites in question and faunal and soil sampling from surrounding regions, may enable future researchers to better account for total regional population movement.

Widga et al.'s (2010) bison study provides strontium data from regions outside the area covered by this study, including three sites in Iowa (Simonsen, Cherokee Sewer, and Hill), one in Minnesota (Itasca), and one in Nebraska (Logan Creek). Baseline strontium profiles for those regions were compiled through soil and floral analyses from a variety of geological contexts. Widga et al.'s (2010) baseline results ranged from a low of 0.7088 ± 0.0002 in the Missouri Valley to highs of 0.7118 ± 0.0003 and 0.7107 ± 0.0001 for northeastern Minnesota (the Superior and Wadena Lobes of the Wisconsinan Glaciation respectively) and 0.7101 ± 0.0006 (the Des Moines Lobe of the Wisconsinan Glaciation) for Iowa. The $^{87}Sr/^{86}Sr$ ratios for DBA 37 and DBA 41, two of the three potential immigrants from Albany Mounds and both from Mound 20, fit within the 2*s* range for Iowa, while that for DBA 49, a Mound 17 burial and the strongest potential immigrant at Albany, fits within the 2*s* range of the Superior Lobe of the Wisconsinan Glaciation in northeastern Minnesota. Of course this does not prove that these regions were the homelands of the three Albany potential immigrants, but these regions cannot be ruled out as potential homelands for the Albany immigrants on the basis of this data either. The five legitimate potential immigrants in the Hopewell Mound Group dataset (DBA 67, DBA 97, DBA 104, DBA 107, and DBA 111a) also all demonstrate $^{87}Sr/^{86}Sr$ ratios that fit within the 2*s* range for northeastern Minnesota as well, although Carr's (2008) analysis suggests that these individuals' areas of origin are more likely to be elsewhere in Ohio.

Unfortunately this study was not able to shed much light on the question of pipe movement as raised by Emerson et al.'s (2004) study. Because of the overlap in 2*s* ranges between Albany Mounds and the Hopewell Mound Group, it is not possible to determine from this study whether population movement was taking place between Ohio and Illinois, much less in which direction it was occurring (and therefore, to gain some insight into who was taking the pipes from Illinois to Ohio; whether they were being brought by individuals from Ohio, or taken by individuals from Albany). The three potential immigrants found at Albany Mounds fit within the range of both the Hopewell Mound Group and Utica Mounds, which does not establish that they come from either of those sites, but at least does not rule them out as a possibility. However, the five non-intrusive Hopewell Mound Group potential immigrants do not fit within the 2*s* range of either of the Illinois sites, ruling these sites out as possible points of origin. Again, because of the overlap in 2*s* strontium signature ranges, it is possible that these sites also experienced population movement between them that is not detectable in the current study (i.e. immigrants from the Hopewell Mound Group with strontium signatures that fit within the 2*s* range for Albany Mounds, or vice versa).

It is possible that the Tremper Mound pipes did not come directly from Illinois to Ohio. Polly Wiessner's (2002) writings on the hxaro exchange among the !Kung (Ju/'hoansi) bushmen suggest an alternate possibility. Hxaro is a network of multiple exchange partnerships along which items other than food (such as tools or beads) move (Wiessner 2002:421). Hxaro partnerships can last a lifetime, and can be inherited by descendants on the death of one of the members of the original partnership (Wiessner 2002:422). While serving as a source of material possessions, hxaro also provides participants with alternate sources of support which could be utilized in times of stress as a means of managing risk. As such, these hxaro trading networks can extend over distances up to 200 km. (A similar network of trade may be the Kula ring of the Trobriand Islands, involving ritualized and continuous exchange of armshells and shell necklaces, although the kula ring was primarily among elite individuals and was used as a means of increasing status (Hage et al. 1986)). If the pipes found at Tremper Mounds moved via a similar process, they may have traveled vast distances through other regions before ending up in Ohio. In that case, we would not expect strontium signatures to reveal any direct contact between Illinois and Ohio because Illinois would only be the starting point of a long, roundabout chain of exchange, of which Ohio would be the last link. This possibility also cannot be ruled out on the basis of the strontium data in this study.

Most of those identified as potential immigrants by this study are female, which as mentioned previously, contradicts the prescriptions of migration theory (Anthony 1990; Burmeister 2000). However, this may support Carr's (2008) assertion that the Scioto Hopewell populations were patrilineal. His assertion is based on statistical analyses of mortuary goods showing that a greater number of males than females held status positions in Hopewell society and that the positions of highest status and prestige were restricted to males (Carr 2008). It also accords with Mills's (2003) mtDNA work, which failed to find support for matrilineal kinship practices at the Hopewell Mound Group. If Carr's (2008) analysis is correct, it may be that more females than males were outsiders to the community represented by the Hopewell Mound Group because they were likely to marry into the community from different regions.

At each site, faunal means were slightly lower than human means and also displayed a larger standard deviation. One explanation for this may be statistical artifact given that fewer faunal remains than human remains were sampled at each site. It may also be that the human population at each site engaged in dietary practices that affected their $^{87}Sr/^{86}Sr$ ratio, perhaps consuming resources transported from elsewhere, such as food gathered on hunting trips. (Wright (2005) has an example of this in her Tikal research: her study found that the human $^{87}Sr/^{86}Sr$ ratios were offset slightly from faunal $^{87}Sr/^{86}Sr$ ratios, which she attributed to the use of imported sea salt by the human population.) Another reason might be that the faunal samples for each site incorporated multiple species, some of which might have been less appropriate proxies for human feeding ranges than others. At Albany Mounds, for example, the beavers have a mean ^{87}Sr/^{86}Sr ratio of 0.709921 with a 2*s* range of 0.708880 - 0.710963. For deer, the mean Sr ratio was 0.709140 with a 2*s* range of 0.708851 - 0.709429. The mean for beaver thus lies outside the 2*s* range for deer, and is closer to (though still below) the human mean. This indicates that the two species had feeding practices at this site that resulted in differing ^{87}Sr/^{86}Sr ratios, and also that the feeding practices of the deer at this site resulted in ratios that differed more greatly from the human ratios than that of the beavers. If this is true at all sites, then this study's heavy reliance on deer for the faunal dataset may explain the differences in ^{87}Sr/^{86}Sr ratios between faunal and humans. Bentley (2006) discusses the need for care in species selection when choosing faunal material for a baseline, as fauna with too large a home range may incorporate sources of strontium unavailable to the human population, while those with too small a home range may not include the whole range of strontium available in an area. Unfortunately, supporting faunal material was so limited that a wide range of choices was not available.

The human/faunal gap may have differing causes at different sites. It is worthy of note that, if the human dataset for the Hopewell Mound Group is broken down by gender, then the mean male ^{87}Sr/^{86}Sr ratio becomes 0.710273 with a 2*s* range of 0.708554 - 0.711993, while the female ^{87}Sr/^{86}Sr ratio (excluding DBA 65, the probably-intrusive burial) becomes 0.710792 ± 0.000902 with 2*s* range of 0.708987 - 0.712597. As mentioned previously, the male strontium mean is very close to the faunal mean for the Hopewell Mound Group (exclusive of DBA 120 and DBA 121) of 0.710217 ± 0.000802, strengthening the inference that the population of the Hopewell Mound Group was patrilocal. This is a pattern that was not observed at the other two sites in this study, which may indicate a differing cause for the faunal / human gap at the other two sites.

Several of the potential immigrants detected by this study are represented solely by skulls or mandibles. Such individuals include DBA 41 from Albany, and DBA 97, and DBA 107 from the Hopewell Mound Group. (DBA 65 and DBA 98a were also solely represented by cranial elements; however as discussed previously these individuals are likely intrusive.) Seeman (1988) discusses the phenomenon of worked or preserved skulls in Hopewell culture as well the debate over whether such skulls represented honored ancestors or "trophies" of enemies vanquished in battle. After examining collections of such individuals, Seeman (1988) concluded that worked skulls or mandibles were disproportionately from young or younger males and that they were therefore likely to be victory trophies. The fact that the "cranial burials" DBA 41, DBA 97 and DBA 107 all demonstrate potentially non-local ^{87}Sr/^{86}Sr signatures would seemingly strengthen the inference that these individuals represented victory trophies. However, these burials include one individual of indeterminate gender (DBA 41), and two females (DBA 97 and DBA 107), which does not accord with Seeman's (1988) interpretation that victory trophies are disproportionately young males. DBA 97 may be the most likely "victory trophy" as this individual was represented by an unworked mandible included in a burial with a trophy skull and several worked mandibles.

In general, the oxygen isotope data did not strengthen the case for any of these potential outliers as immigrants. δ^{18}O values for all the individuals identified as possible outliers on the basis of their ^{87}Sr/^{86}Sr data lay within the 2*s* range of δ^{18}O values for the sites as determined by faunal data. Taking into account White's (2009) detailed examination of oxygen isotopic analysis, and the assertion that this technique may not be appropriate except in areas with drastic differences in $\delta^{18}O$ values across regions, it is likely that $\delta^{18}O$ analysis is not appropriate as a method for determining mobility in Midwestern North America. In any case, the lack of supporting $\delta^{18}O$ data weakens, but does not necessarily refute the case for individuals identified as possible outliers by means of their $^{87}Sr/^{86}Sr$ data.

With the exception of five probably intrusive individuals of unknown provenience, the $\delta^{13}C$ values of the entire human sample at all sites are consistent with a C_3 diet including little to no maize. This confirms and complements the work of Rose (2008), who investigated maize usage patterns over time in the Midwest through use of bone collagen. The $\delta^{13}C$ means of each site all lay within two standard deviations of each other. This indicates no essential difference between sites in C_4 plant consumption and, by inference, dietary practices.

The hypotheses of this study were as follows: <u>first, that regional interaction during the Middle Woodland was largely one-way and may have involved population movements from Ohio to Illinois; second, that population movement in and of itself was a significant force in Middle Woodland development.</u> As previously mentioned, larger numbers of nonlocal $^{87}Sr/^{86}Sr$ ratios found at the Illinois sites would support the first hypothesis, whereas equal numbers between the two sites or larger numbers found at the Ohio sites would refute it; the second hypothesis would be supported by large numbers of nonlocal signatures found at any site.

The first hypothesis is not supported by this data. Both numerically and percentage-wise, the largest number of nonlocal signatures in this study was recovered from the Hopewell Mound Group, suggesting that Ohio, or at least the Ohio community represented by the Hopewell Mound Group, was the focus of more immigration than the Illinois sites. Therefore, the data in this study refutes the first hypothesis.

The results of this study tentatively support the second hypothesis. Eleven total potential immigrants were detected according to the $^{87}Sr/^{86}Sr$ analysis. However, while lying beyond the 2*s* range for faunal material, nine of these individuals did not lie beyond the combined $^{87}Sr/^{86}Sr$ range for their sites (two individuals at Albany Mounds and seven at the Hopewell Mound Group). In addition, for those samples where there were $\delta^{18}O$ values, the $\delta^{18}O$ data did not accord with the $^{87}Sr/^{86}Sr$ data. This weakens (though does not necessarily invalidate the $^{87}Sr/^{86}Sr$ data for these individuals. Therefore, the identification of these outliers can only be seen as tentative.

In addition to examining levels of population movement during the Middle Woodland, this study also examined whether strontium isotopic analysis was an appropriate technique for determining immigration histories in the Midwest, as had been indicated by several small pilot studies (Hedman et al. 2009; Price et al. 2007). The results of this study would seem to indicate that it is of limited usefulness. The $^{87}Sr/^{86}Sr$ mean for each of the sites included in this study lies well within the two-sigma range for the other sites. This indicates that it is not possible to distinguish among the populations of these three sites through use of strontium isotopic analysis. However, it is possible to determine outliers from the regional averages through use of this technique, as demonstrated for Hopewell Mounds and Albany Mounds. This suggests that strontium isotopic analysis, while limited in its applicability, does have value as a technique for determining migration history in eastern North America.

CHAPTER 6

CONCLUSION

The purpose of this dissertation was to build on the work of Bolnick and Smith (2007) by examining numbers of potential immigrants at three Middle Woodland sites: Albany and Utica Mounds in Illinois and the Hopewell Mound Group in Ohio. Two hypotheses were tested. First, Illinois experienced greater rates of Middle Woodland population movement than Ohio. This hypothesis was tested by comparing nonlocal $^{87}Sr/^{86}Sr$ ratios for human teeth at the Albany and Utica sites in Illinois with samples from the Hopewell Mound Group in Ohio. Second, migration was a significant demographic force in Midwestern North America during the Middle Woodland period. This was tested by comparing the frequency of non-local signatures found at Illinois and Ohio sites.

The second hypothesis was tentatively borne out by this study, while the first was not supported. Larger numbers of potential nonlocal $^{87}Sr/^{86}Sr$ ratios were recovered from the Hopewell Mound Group, both absolutely and in terms of percentage, than from the Illinois sites. This suggests, contrary to Bolnick and Smith (2007), that the Hopewell Mound Group was experiencing higher levels of immigration than the two Illinois sites in this study.

Patterns of migration also differed between the two Illinois sites in this study, with Albany Mounds demonstrating three potential nonlocal $^{87}Sr/^{86}Sr$ ratios and Utica Mounds displaying none. This suggests an essential difference between the two sites in the amounts of extraregional contact they experienced, and may further indicate that Illinois was less well integrated than Carr (2008) has argued was true for Ohio at this time. The data from Illinois's Utica Mounds, in conjunction with the relative lack of exotic goods found at that site (Emerson

2011, personal communication), may support Smith's (1992) "bullseye" interpretation of Middle Woodland mound group settlement patterns. Two of the three potential immigrants at Albany Mounds were recovered from the same mound (Mound 20), and the third potential immigrant was recovered from a mound very nearby (Mound 17), which may indicate that immigrants at Albany Mounds formed a subgroup of the site's population. The two Mound 20 immigrants fit within the 2*s* range of $^{87}Sr/^{86}Sr$ ratios for Iowa, while the Mound 17 potential immigrant fit within the 2*s* strontium range for Minnesota as determined by Widga's (2010) bison study. This does not prove that these individuals came from these regions, but does not rule them out either. The five potential immigrants detected at the Hopewell Mound Group also fit within the 2*s* strontium range for Minnesota; however, Carr's (2008) analysis makes a potential Minnesota homeland for these individuals unlikely.

At all sites there was a slight difference in mean $^{87}Sr/^{86}Sr$ ratios between the human and faunal data. This gap may have different causes at different sites; at the Hopewell Mound Group, for example, the male human mean $^{87}Sr/^{86}Sr$ ratio was almost identical to the faunal ratio, while the female strontium mean was offset, consistent with a patrilocal interpretation of Ohio Hopewell postmarital residence. However, this pattern did not exist at the Illinois sites. The gap at the Illinois sites might instead be explained by differing human and faunal catchment areas, or perhaps human reliance on extra-regional food sources.

Along with the $^{87}Sr/^{86}Sr$ isotopic data, light isotope data was taken from certain individuals at the three study sites. Light isotopes collected included $\delta^{18}O$ and $\delta^{13}C$ values. The data sets for the light isotope data are incomplete for the Illinois sites, but nearly complete for the Hopewell Mound Group. In general, the $\delta^{18}O$ values do not track with the strontium data: no outliers were found at any site in regards to the oxygen data. Individuals who were potential outliers at Albany, however, were unfortunately not included in the study, due to the samples recovered from them being too small.

Where age and sex could be identified, the potential outliers were in the majority female and in early adulthood. Of the three potential immigrants at Albany Mounds, one was unknown sex; one was probable male, and one was probable female. Of the potential immigrants at the Hopewell Mound Group, four were probable females and the rest were of unknown sex. It is possible that migration patterns for Middle Woodland populations differed by gender. Perhaps females tended to migrate more than males, possibly as brides. This would accord with Carr's (2008) assertion that the population represented by the Hopewell Mound Group practiced patrilineal systems of descent, as well as Mill's (2003) mtDNA study, which found no evidence of matrilineal burial at the Hopewell Mound Group's Mound 25. Possibly, population movement patterns differed by region. Ohio females may have been more mobile than females in Illinois.

The data for Albany Mounds, the only Illinois site to demonstrate immigration, does not support Bolnick and Smith's (2007) inference of matrilocality, as the numbers of male and female immigrants were equal. However, Bolnick and Smith (2007) did their study on Pete Klunk, a different mound group in Illinois. Thus, the lack of evidence for matrilocality at Albany Mounds may strengthen the conclusion that Illinois was not closely integrated during the Middle Woodland.

The Hopewell Mound Group data supports Carr's (2008) interpretation of the Hopewell Mound Group as a site that played a powerful integrative role for communities in the Scioto / Paint Creek River drainage. This site had the largest number of potential immigrants of the three sites in this study, as well as the most variability in $^{87}Sr/^{86}Sr$ ratios, suggesting that its population came from a wider variety of potential homelands than the other sites. This increased diversity makes sense for a site with region-wide influence.

Three of the potential immigrants--one at Albany Mounds and two at the Hopewell Mound Group were represented solely by skulls or mandibles, which may indicate that these individuals were “trophy skulls” (Seeman 1988). However, this inference is weakened by the fact that these individuals are all female or of undetermined gender and older, contra Seeman’s (1988) identification of trophy skulls as those of predominantly young “draft-age” males. Therefore, it may be unlikely that these individuals represent victory trophies.

The means of the $^{87}Sr/^{86}Sr$ ratios recovered from all sites lie within two standard deviations of each other. According to this dataset, the populations of these sites cannot be distinguished from one another through the use of $^{87}Sr/^{86}Sr$ analysis. $^{87}Sr/^{86}Sr$ analysis can be used to identify potential outliers at each site, but this technique cannot be used to trace migration from one site to another of the sites included in this study, if such migration was occurring. Migration may also have been occurring into the sites from external regions with similar $^{87}Sr/^{86}Sr$ ratios to the sites in this study. Because of this, it is possible that higher levels of migration were occurring at these sites than this study was able to detect.

The overlapping $^{87}Sr/^{86}Sr$ ratios meant that this study could not do much to clarify the nature of the movement of the Tremper Mound pipes. Because the 2*s* strontium ranges overlapped to such a degree, it was not possible to determine the level and direction of migration, if any, between Illinois and Ohio based on these data. The possibility that the Tremper Mound pipes were journeying to Ohio from Illinois via a round-about exchange network such as the hxaro network of the !Kung San (Wiessner 2002) also cannot be ruled out by this study.

The overlap between the sites' 2*s* $^{87}Sr/^{86}Sr$ ratios suggests that strontium isotopic analysis may not be an appropriate technique for determining migration history in Midwestern North America. However, other studies such as that of Hedman et al. (2009) and Price et al. (2007) were able to detect measurable differences in $^{87}Sr/^{86}Sr$ ratios among Midwestern North American archaeological sites. Data from other sites, or from other regions in the Midwest, might enhance this picture. A very advantageous direction for future research would be to expand the sampling of faunal material from both Illinois and Ohio, and to include soil and groundwater analysis. This would give a much better picture of what the various background $^{87}Sr/^{86}Sr$ ratios are for different parts of the North American Midwest.

This study focused on only three sites, two in Illinois and one in Ohio. Expanding analysis to other sites in these regions would yield a better picture of overall population movement. Further studies could target other large sites such as Tremper Mounds in Ohio or Pete Klunk in Illinois, or could expand sampling strategy to include smaller sites as well. The second strategy would provide a fuller picture of whether population movement rates were evenly reflected across site types.

While carbon and oxygen isotope analyses were conducted on a portion of the samples involved in this study, use of these techniques was hindered by the need to preserve enough of the samples for strontium analysis. Therefore, though near-complete light isotope data exists for Hopewell Mound Group dataset, the other two sites do not have such comprehensive data. Expanding light isotope analysis at the sites of Utica and Albany could yield useful information. In the case of $\delta^{18}O$ analysis, further extensive sampling of the kind suggested for strontium analysis, could help to clarify whether this technique can play a role in Midwestern North American archaeology and if so, what that role might be. Carbon isotope analysis remains useful for identifying potentially younger intrusive burials of Late Woodland farmers that ate maize. This was demonstrated with five individuals who lacked provenience information, one at Utica Mounds and four at the Hopewell Mound Group. All of these individuals, and no others, demonstrated $\delta^{13}C$ values that were consistent with a majority C_4 diet, strongly suggesting that they were intrusive to the sites.

In conclusion, the results of this analysis did not support the research done by Bolnick and Smith (2007). Greater numbers of potential non-local signatures were found at the Hopewell Mound Group than at either of the two Illinois sites, suggesting that the Hopewell Mound Group was the focus and destination for a greater amount of population movement. Though avenues still exist for further investigation, this study is a valuable addition to the knowledge of migration patterns during the Middle Woodland time period in Midwestern North America.

Table 1. ^{14}C Dates from Utica, Albany and Hopewell.

ISGS #	Sample	Site	Provenience	Cat. #	Material	Method	Date in RCYBP	Calibrated Date
6588	CI-460	Utica	None	None	Charcoal unidentified	Conv.	400 ±70	AD 1530 ± 114
6587	CI-461	Utica	None	None	Charcoal unidentified	Conv.	1060 ± 70	AD 967 ± 187
A1487	CI-466	Hopewell Mound Group	Fea. 1 S ½, 79-84 cmbd	HOCU Cat# 35676	Wood - locust	AMS	1780 ± 20	AD 236 ± 96
A1488	CI-467	Hopewell Mound Group	Fea. 167-3, 49-64 cmbd	HOCU Cat# 23625	Wood – red oak	AMS	1725± 20	AD 318 ± 71
A1489	CI-468	Albany Mounds	None	None	Wood – maple	AMS	1810 ± 25	AD 223 ± 93
A1514	CI-472	Albany Mounds	None	None	Wood – unidentified	AMS	220 ± 15	AD 1801 ± 153

Table 2. Means, Standard Deviations, and 2*s* Ranges of $^{87}Sr/^{86}Sr$ ratios from Utica, Albany and Hopewell

Site	Mean $^{87/86}Sr$ ratio	Standard Deviation	2*s* range
All Utica	0.710548	0.000606	0.709336-0.711760
Utica Human	0.710718	0.000339	0.709920-0.711516
All Utica Faunal	0.710281	0.000778	0.708725-0.711837
Utica Faunal Alone	0.709647	0.000597	0.708453-0.710841
FCW Faunal Alone	0.710534	0.000711	0.709112-0.711956
All Albany	0.710088	0.000678	0.708732-0.711444
Albany Human	0.710249	0.000480	0.709289-0.711209
Albany Faunal	0.709848	0.000862	0.708122-0.711570
All Hopewell	0.710655	0.001139	0.708377-0.712933
Hopewell Human	0.710616	0.001072	0.708472-0.712760
Hopewell Field Human	0.710533	0.001094	0.708345-0.712721
Hopewell OHS Human	0.710659	0.001081	0.708497-0.712821
All Hopewell Faunal	0.710800	0.001419	0.707962-0.713638
HMG Faunal Material	0.710308	0.000928	0.708452-0.712164
Hopeton Triangle Faunal	0.711540	0.001843	0.707854-0.715226

Table 3. $\delta^{13}C$ and $\delta^{18}O$ Means, Standard Deviations, and 2*s* Ranges from Utica, Albany and Hopewell.

Site	Mean $\delta^{13}C$‰	Standard Deviation	2*s* Range	Mean $\delta^{18}O$‰	Standard Deviation	2*s* Range
All Utica	-14.27	2.04	-10.19 - -18.35	25.54	1.54	22.45 – 28.63
Utica Human	-14.07	2.41	-9.25 – -18.90	26.14	0.82	24.50 – 27.79
FCW Faunal	-14.62	1.21	-12.20 – -17.04	24.49	1.98	20.54 – 28.45
All Albany	-14.65	1.02	-12.61 – -16.70	24.39	1.74	20.91 – 27.87
Albany Human	-15.06	0.41	-14.25 – -15.88	25.41	0.58	24.24 – 26.57
Albany Faunal	-14.42	1.20	-12.02 – -16.81	23.81	1.93	19.95 – 27.67
All Hopewell (minus DBA 78)	-13.06	3.27	-6.52 – -19.60	26.13	1.20	23.73 – 28.53
Hopewell Human	-13.06	3.38	-6.30 – -19.82	26.25	0.85	24.50 – 27.00
Hopewell Field Human	-13.84	2.40	-9.05 – -18.64	26.35	0.95	24.45 – 28.25
Hopewell OHS Human	-12.69	3.75	-5.19 – -20.19	26.21	0.85	24.50 – 27.92
HMG Faunal Material (minus DBA 78)	-13.06	2.58	-7.90 – -18.21	25.23	2.59	20.05 – 30.42

Table 4. $^{87}Sr/^{86}Sr$ Ratios by Site and Gender

Site by Gender	**Mean $^{87}Sr/^{86}Sr$ ratio**	**Standard Deviation**	**2*s* Range**
Utica females	0.710947	0.000340	0.710266 - 0.711628
Utica males	0.710556	0.000288	0.709980 - 0.711132
Albany females	0.710143	0.000484	0.709175 - 0.711110
Albany males	0.710401	0.000473	0.709455 - 0.711348
HMG females	0.710792	0.000902	0.708987 - 0.712597
HMG males	0.710273	0.000860	0.708554 - 0.711993

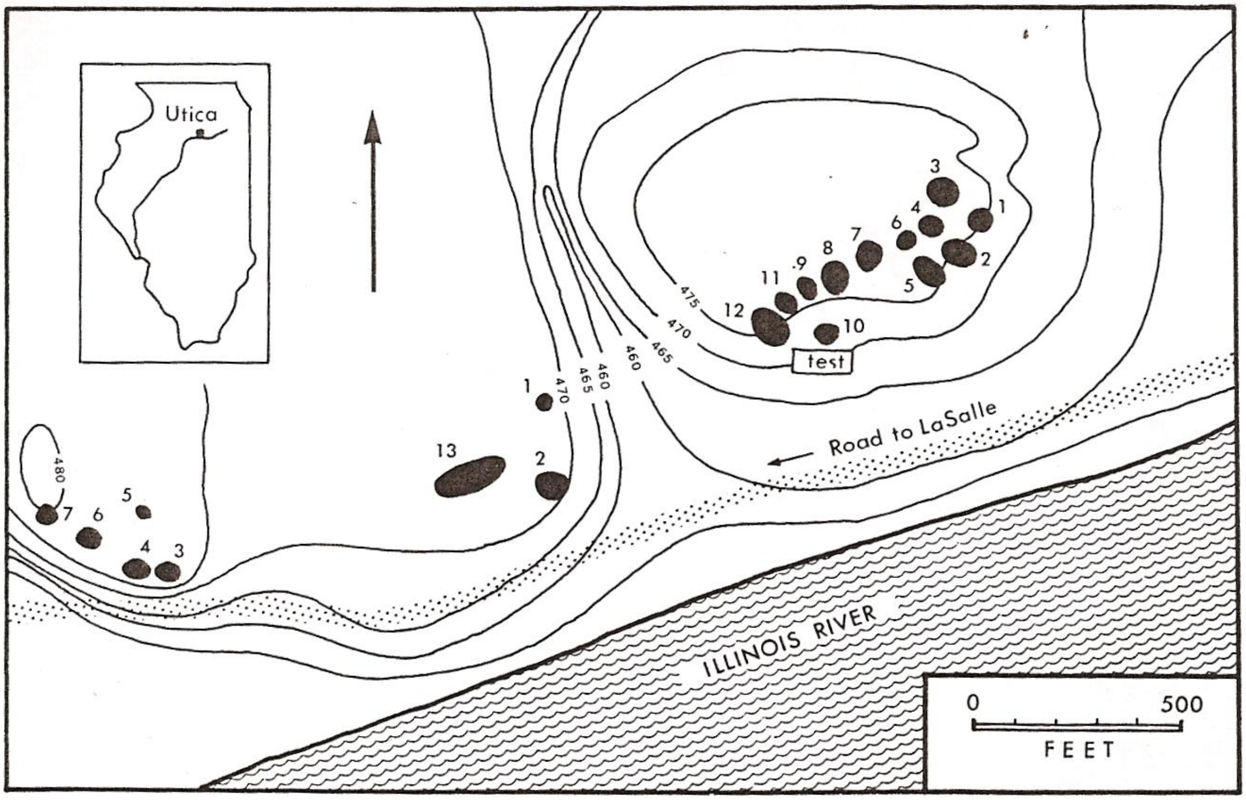

Figure 1. Utica Mounds Site (Henriksen 1969:3)

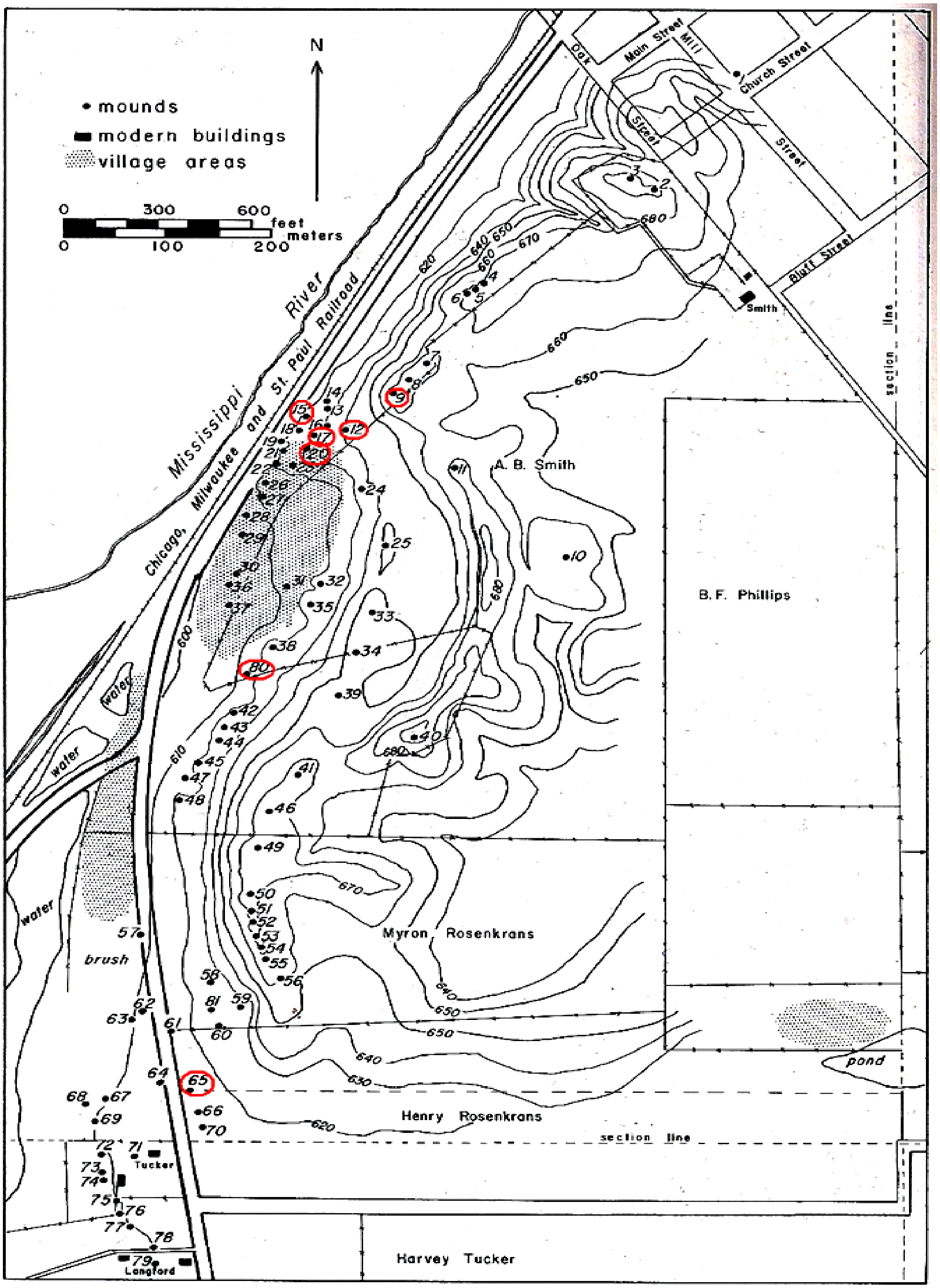

Figure 2. Albany Mounds showing Mounds 9, 12, 15, 17, 20, 65, and 80 (Herold 1971:x). Mounds marked in red.

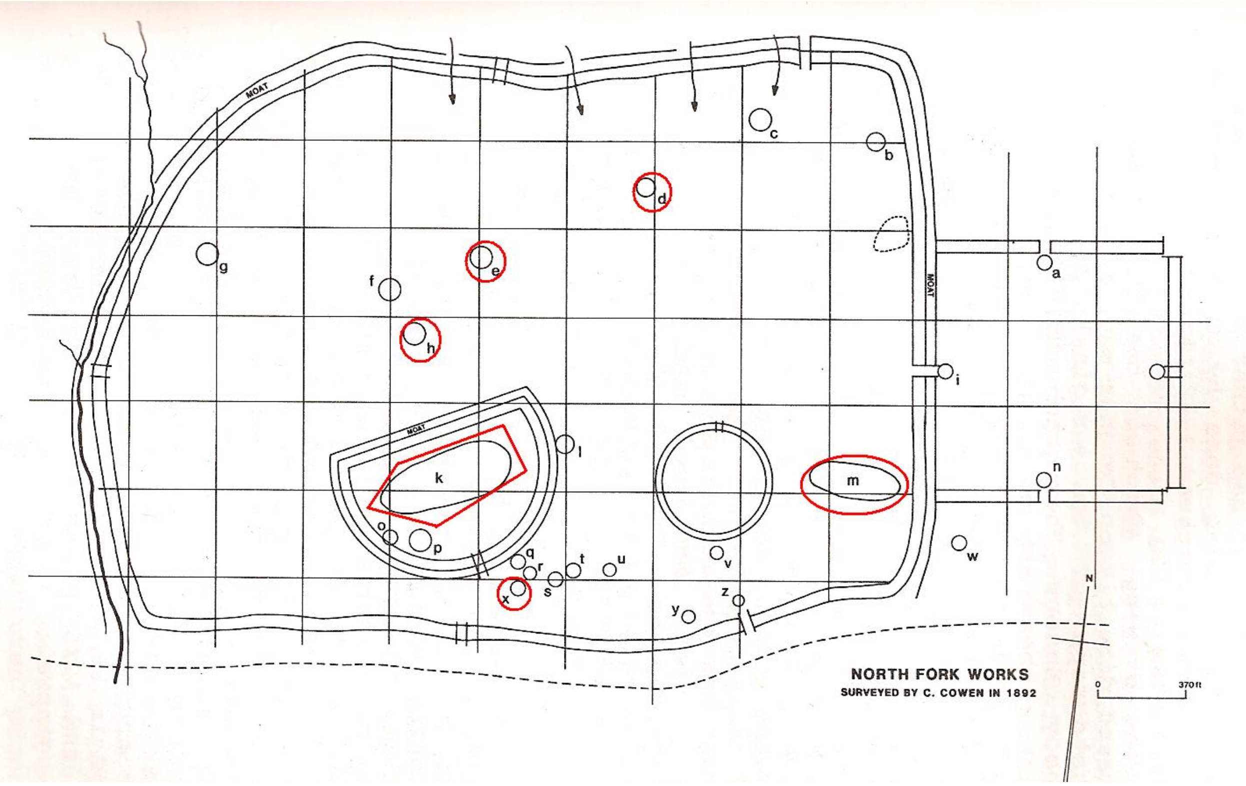

Figure 3. Hopewell Mound Group, showing Mounds 2 (e), 3 (h), 18 (d), 20 (x), 23 (m) and 25 (k) (Greber and Ruhl 1989:15). Mounds outlined in red.

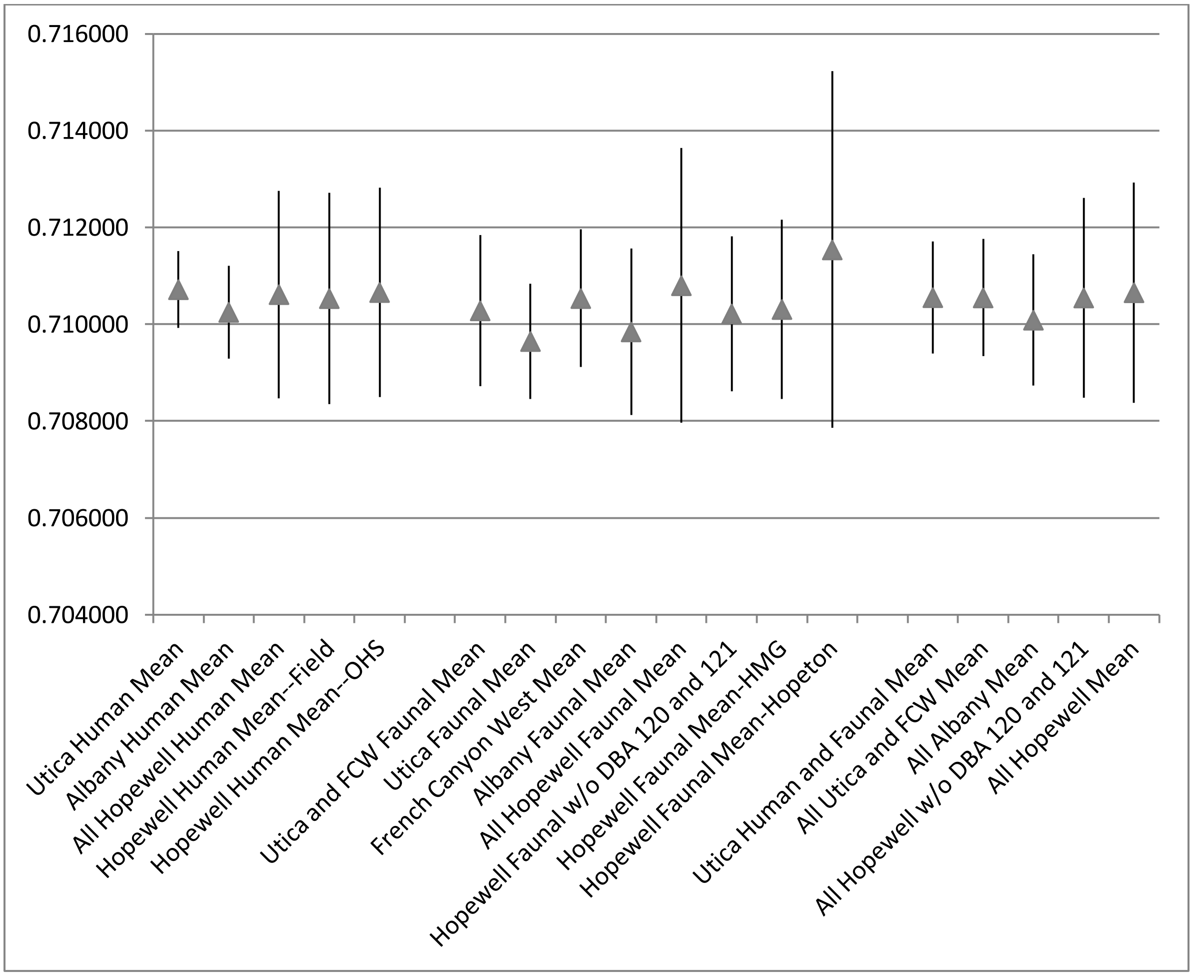

Figure 4. Means and 2*s* ranges of $^{87/86}$Sr ratios from Albany, Utica and Hopewell

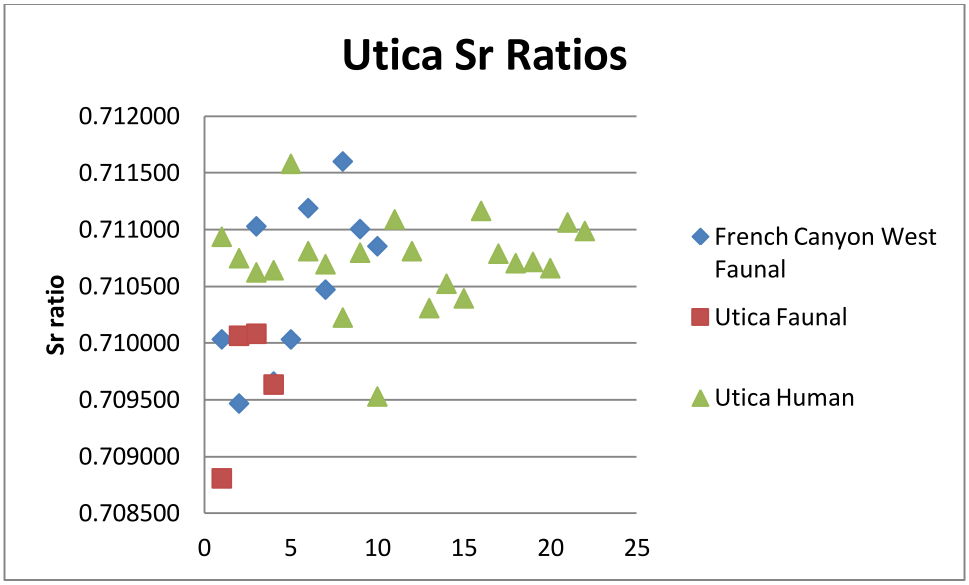

Figure 5. Utica Mounds $^{87}Sr/^{86}Sr$ ratios for Human and Faunal Material.

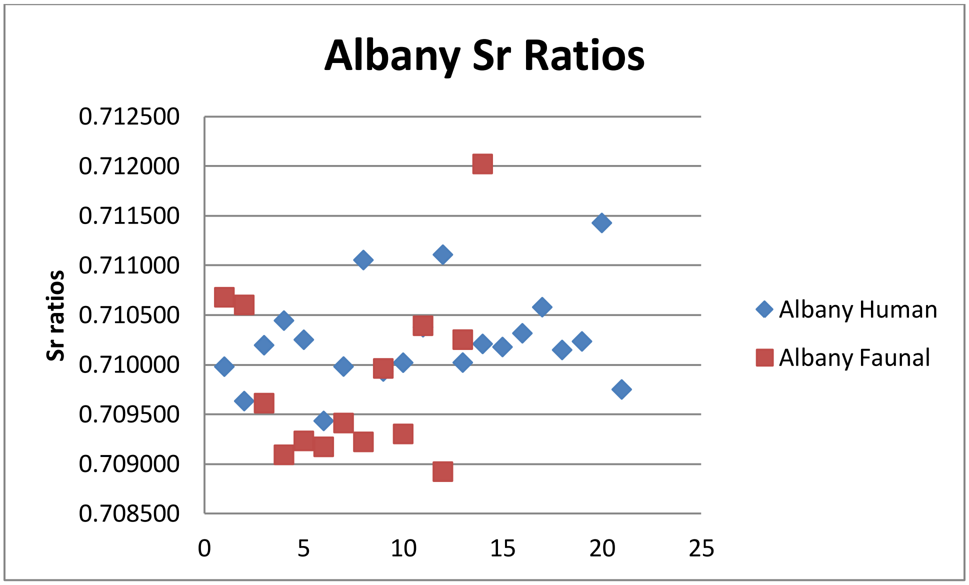

Figure 6. Albany Mounds $^{87}Sr/^{86}Sr$ Ratios for Human and Faunal Material.

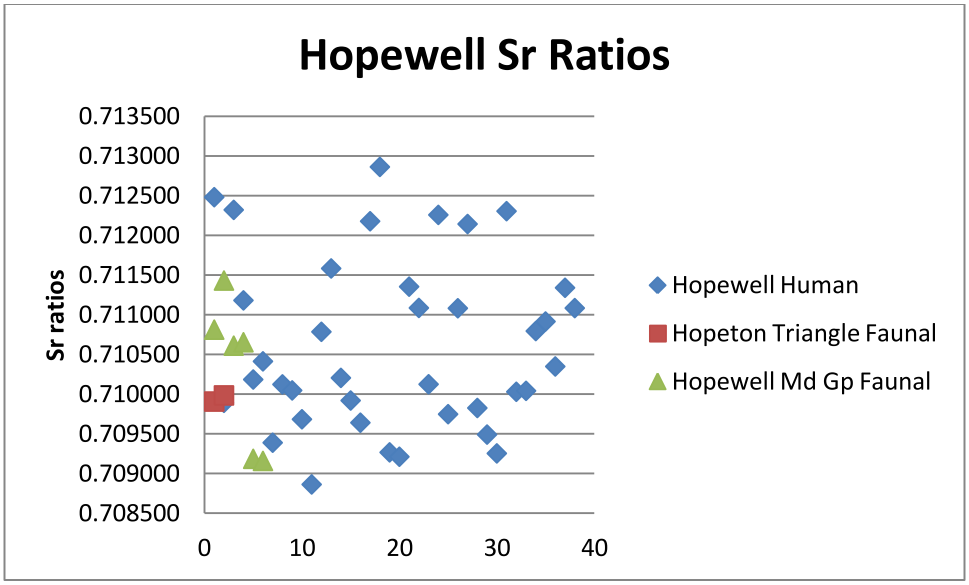

Figure 7. Hopewell $^{87}Sr/^{86}Sr$ for Human and Faunal Material

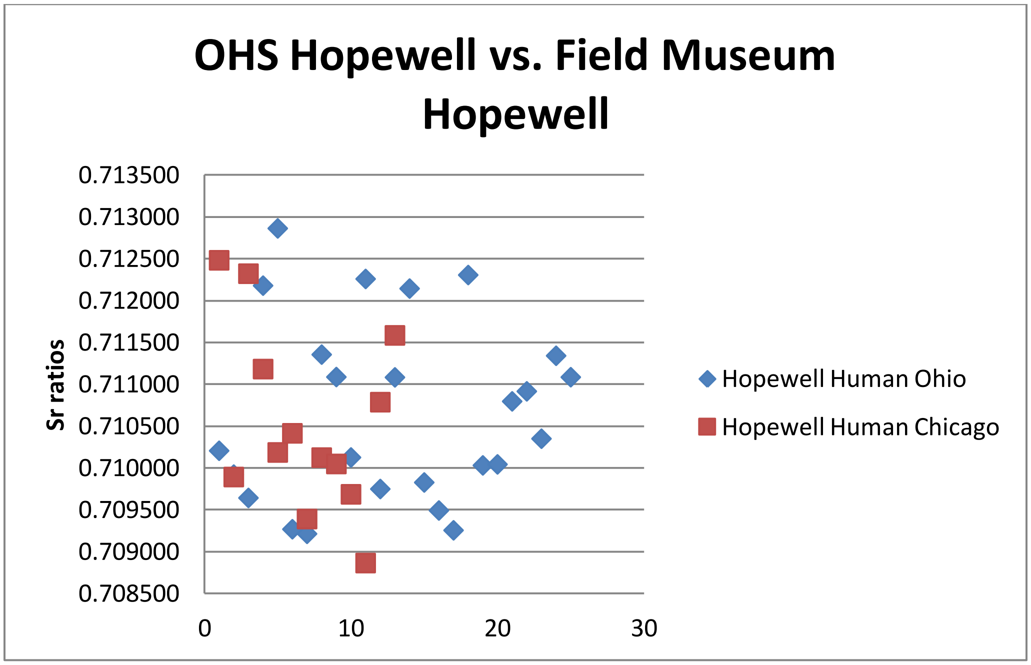

Figure 8. OHS Hopewell Human vs. Chicago Field Museum Hopewell Human

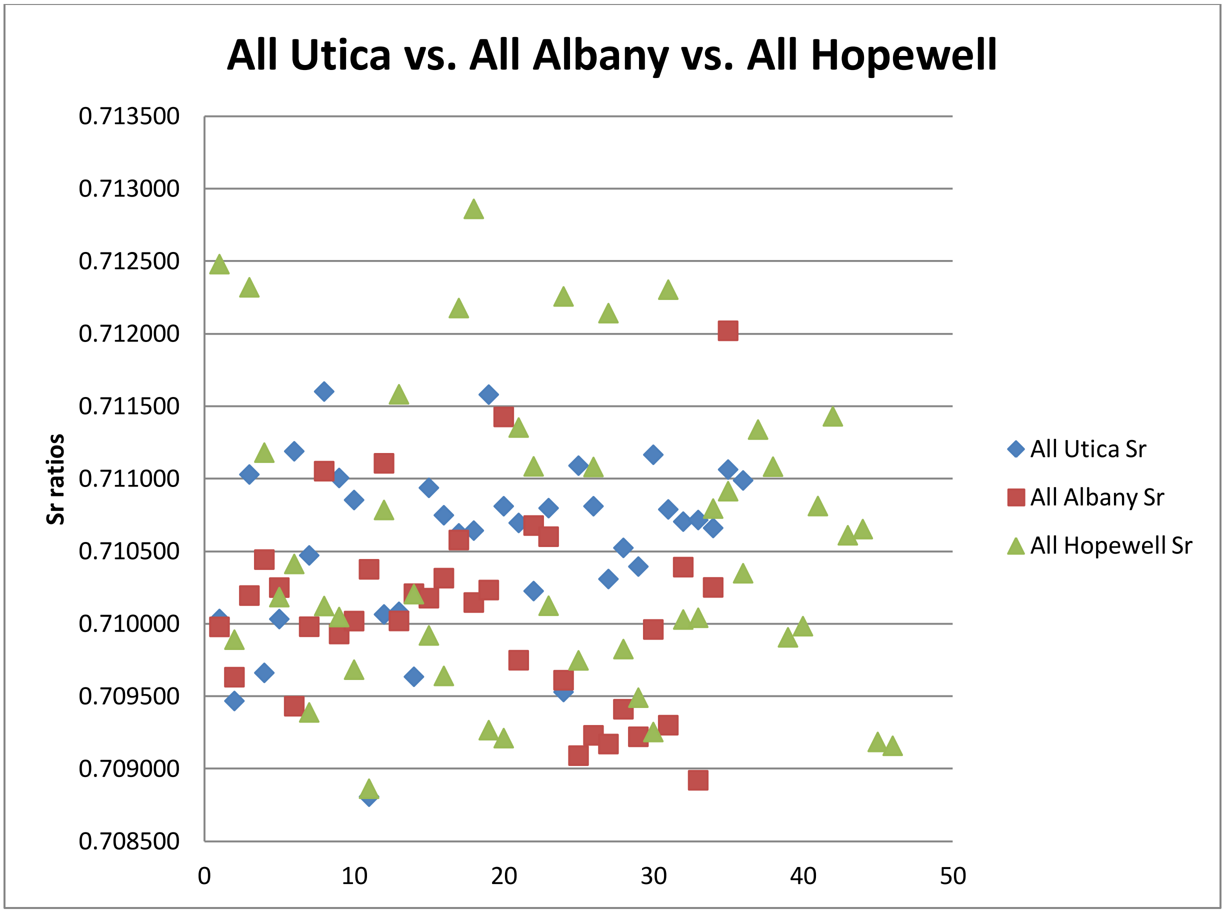

Figure 9. $^{87}Sr/^{86}Sr$ **Ratios for All Utica Material vs. All Albany Material vs. All Hopewell Material**

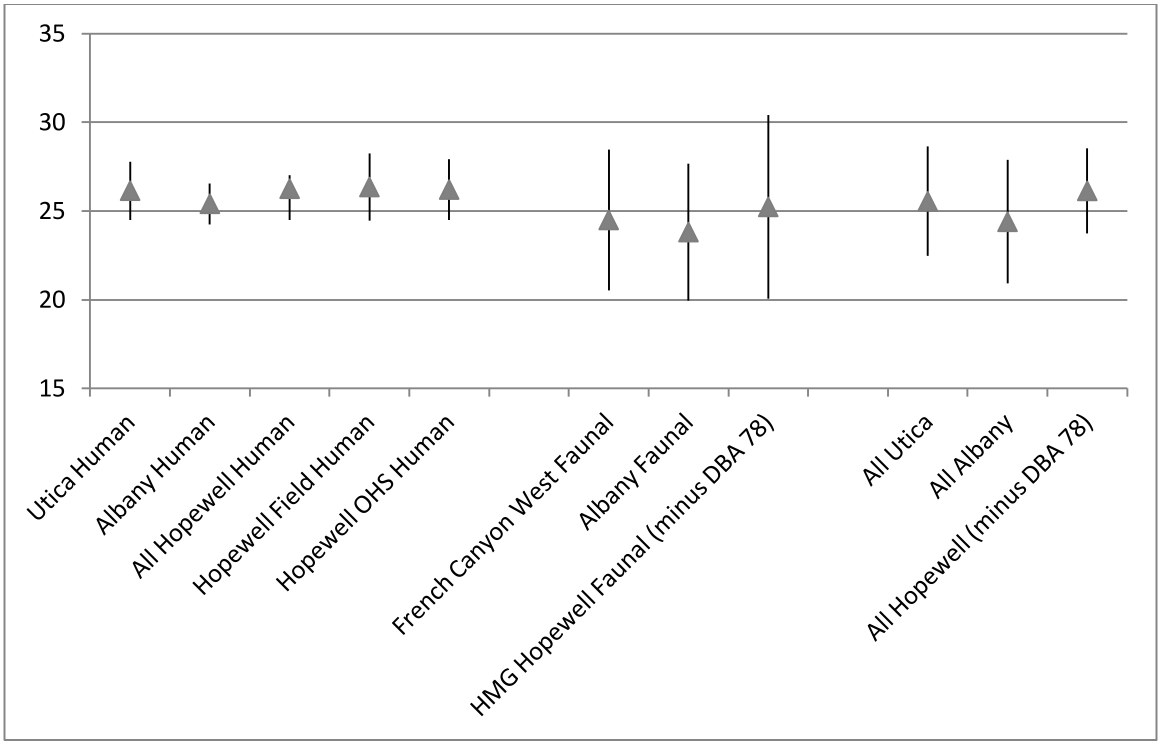

Figure 10. δ^{18}O Ranges for Utica, Albany and Hopewell Mound Group Human and Faunal Material

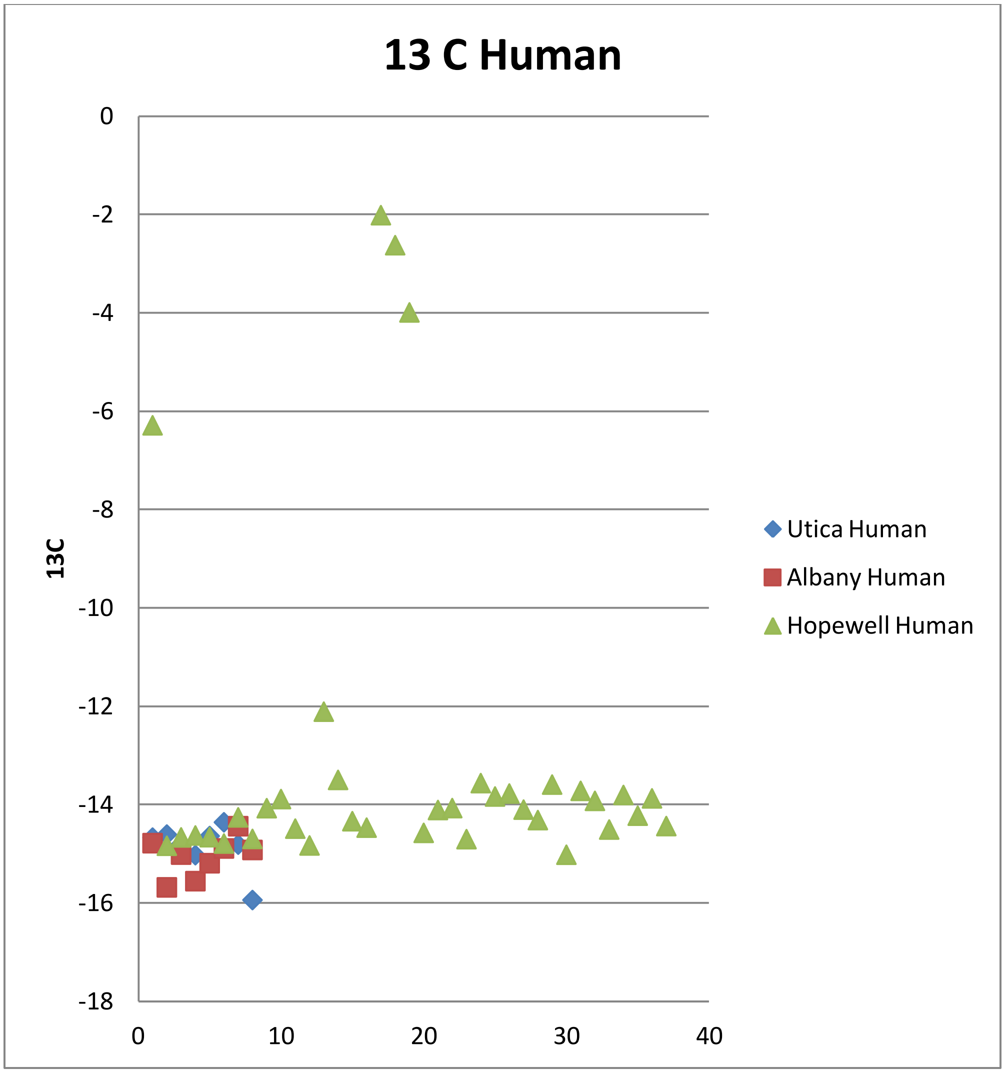

Figure 11. δ^{13}C Values for Human Material at Utica, Albany and HMG (Including Individuals of Uncertain Provenience).

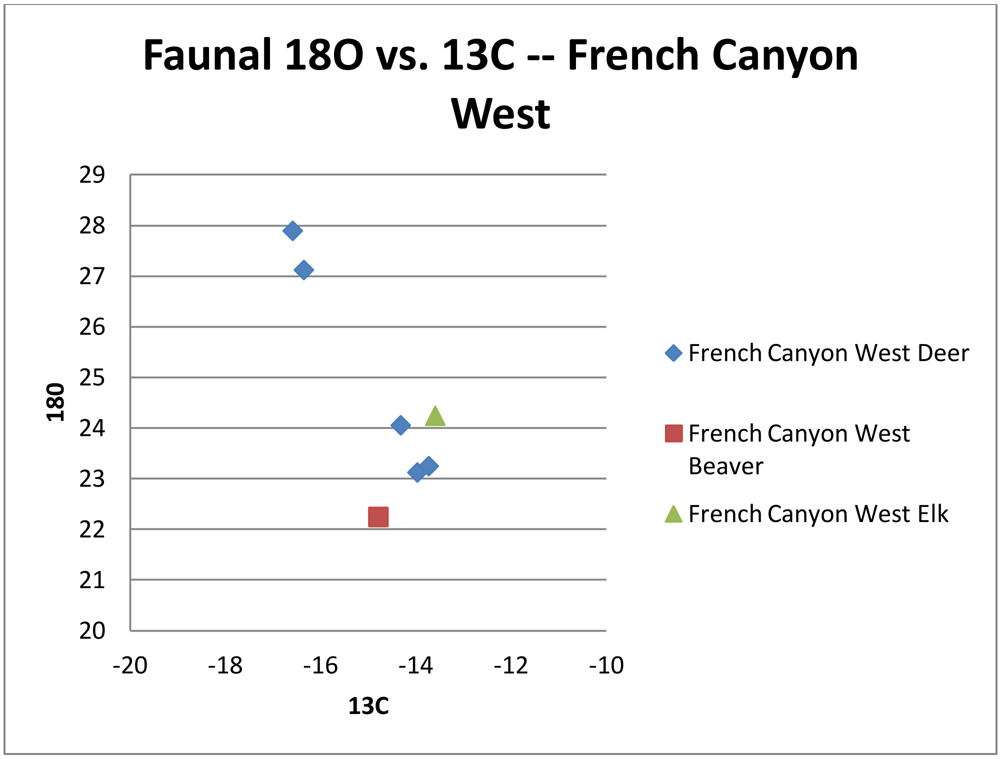

Figure 12. French Canyon West Faunal Bivariate Plot: δ^{18}O vs. δ^{13}C.

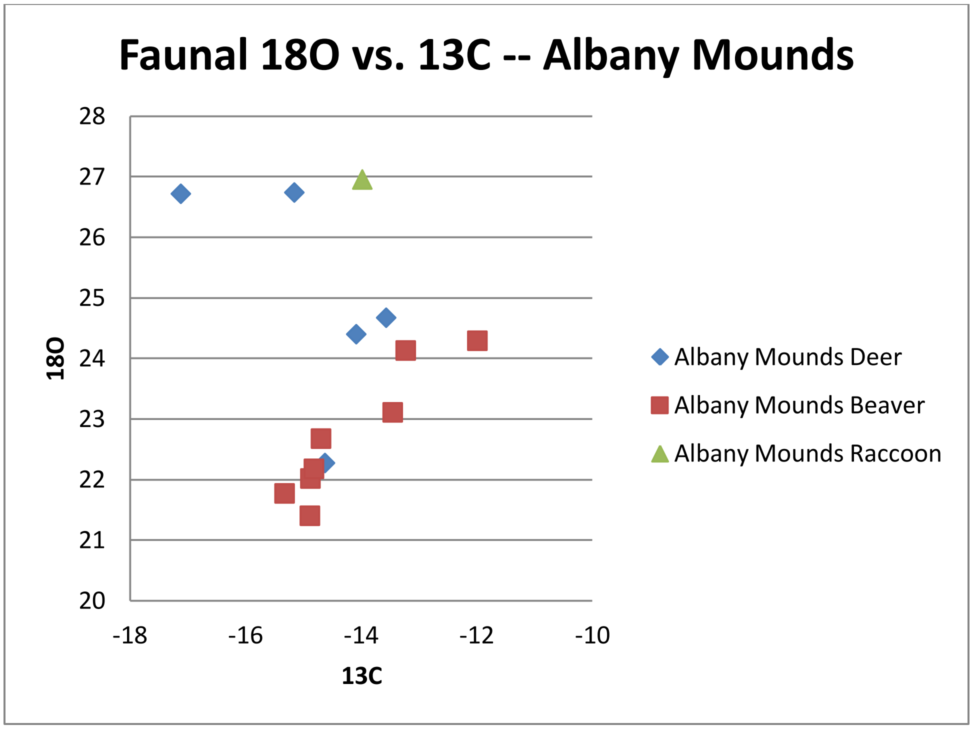

Figure 13. Albany Mounds Faunal Bivariate Scatter Plot: $\delta^{18}O$ vs. $\delta^{13}C$.

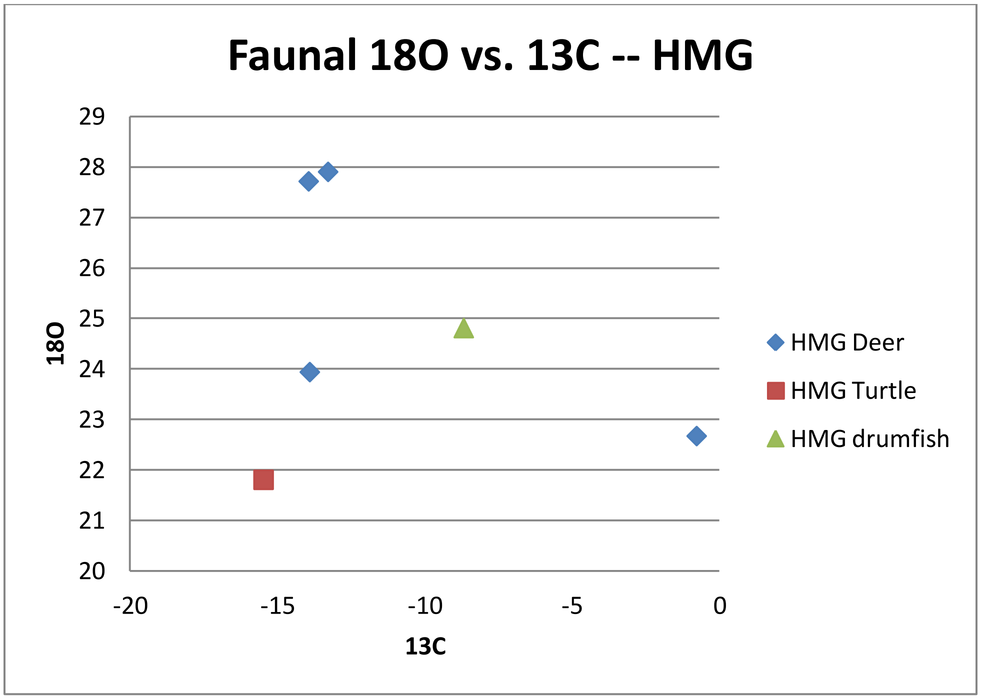

Figure 14. Hopewell Mound Group Faunal Bivariate Scatter Plot: $\delta^{18}O$ vs. $\delta^{13}C$.

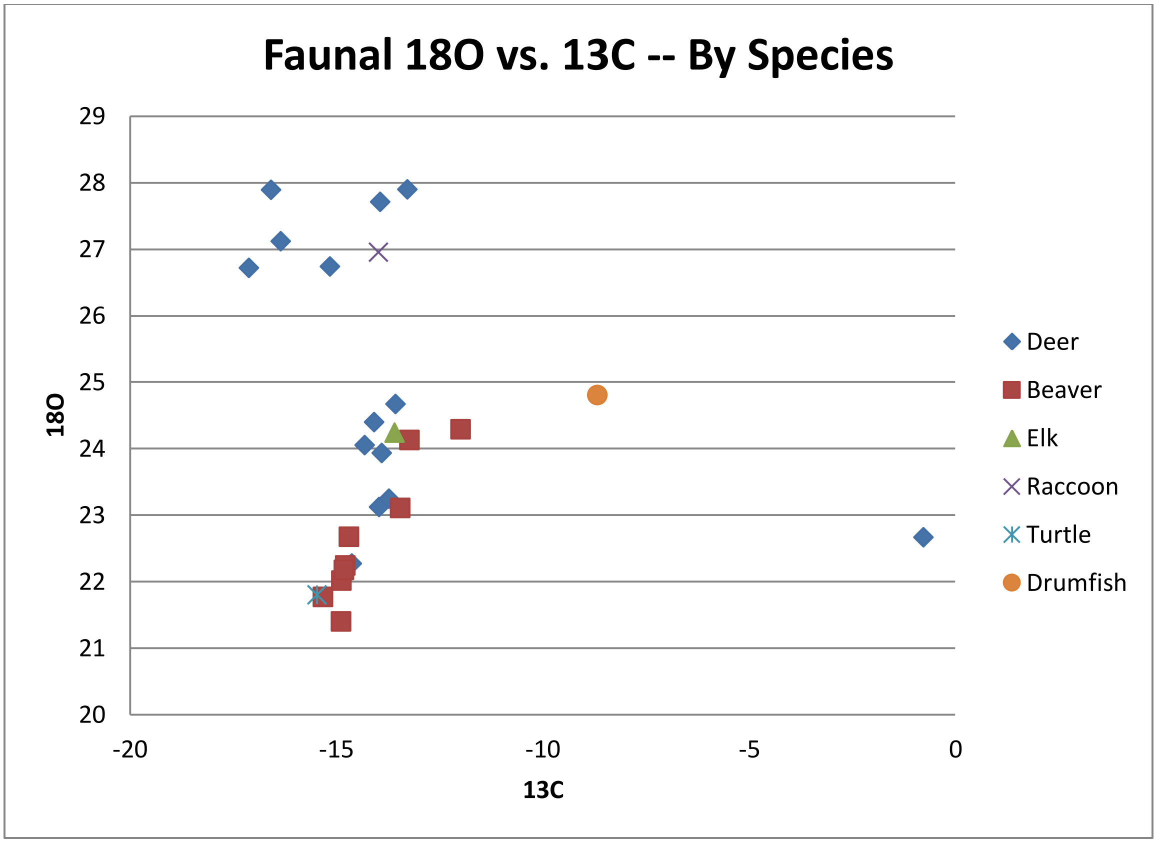

Figure 15. All Faunal Material Bivariate Scatter Plot: δ^{18}O vs. δ^{13}C.

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APPENDIX A

LENDING INSTITUTION, PROVENIENCE, SEX, AGE, AND TOOTH TYPE OF HUMAN TEETH

DBA#	Site	Coll.	Cat. #	Prov. Info.	Sex	Age	Tooth
DBA6	Utica	UIUC LoA	A3359	Skull 5, Pile 3	Unknown	Y. adol.	RPM_4
DBA7	Utica	UIUC LoA	A3327	None	Male	Adult	RPM_4
DBA8	Utica	UIUC LoA	A2695(b)	Mound III, Gp. 2	Female	Y. to M. Adult	LM_1
DBA9	Utica	UIUC LoA	A4761	Skull 2, Md. 7	Unknown	M. Adult	RPM^3
DBA10	Utica	UIUC LoA	A4412	None	Female	Adoles.	LM^1
DBA11	Utica	UIUC LoA	A3322	None	Female	M. to O. Adult	LPM^4
DBA12	Utica	UIUC LoA	A2695(c)	Mound III, Gp. 2	Male?	M. Adult	RPM_4
DBA13	Utica	UIUC LoA	A3106	Intrus. 1, Md. 13	Male	Y. to M. Adult	LPM_4
DBA14	Utica	UIUC LoA	A4772(a)	None	Female	Y. Adult	RM^1
DBA15	Utica	UIUC LoA	A3366	Kinity Mound	Unknown	Y. Adult	LM^1
DBA18	Utica	UIUC LoA	A2961	Mound 11 Skull & Skeleton	Unknown	Unknown	RPM_3
DBA19	Utica	UIUC LoA	A4410	Skull #14	Female	Y. to M. Adult	LPM_3
DBA20	Utica	UIUC LoA	A3356	None	Unknown	Unknown	LPM_3
DBA21	Utica	UIUC LoA	A3104	None	Unknown	Unknown	LPM_4
DBA22	Utica	UIUC LoA	A3326	None	Unknown	Unknown	RPM_4
DBA23	Utica	UIUC LoA	A4770	Mound 2, Gp. 2	Unknown	Unknown	LPM_4
DBA24	Utica	UIUC LoA	A2715	Mound 7, Skull 8	Unknown	Unknown	Frag. Premolar
DBA25	Utica	UIUC LoA	A4773(a)	None	Unknown	Unknown	LPM_3
DBA26	Utica	UIUC LoA	A4773(b)	None	Unknown	Unknown	RPM_3

DBA27	Utica	UIUC LoA	A3325(a)	None	Unknown	Unknown	RM$_1$
DBA28	Utica	UIUC LoA	A2705	None	Female	M. to O. Adult	RM^1
DBA29	Utica	UIUC LoA	A4777	None	Unknown	Unknown	RM^1
DBA30	Albany	ISM	AP247	Mound 9, Bur. 44	Female	Adult, 20-35 yrs	PM^3
DBA31	Albany	ISM	AP 298	Mound 20, Bur. 48	Unknown	Y. Adult	LPM$_3$
DBA32	Albany	ISM	AP 284	Mound 9, Bur. 88	Male	Adult >20 yrs	RPM$_3$
DBA33	Albany	ISM	AP280	Mound 9, Bur. 84	Male	Y. Adult (25-35)	RM^1
DBA34	Albany	ISM	AP 331	Mound 65, Bur. 2	Unknown	Unknown	RPM$_3$
DBA35	Albany	ISM	AP 193	Mound 17, Bur. 9	Female	Y. Adult (20-35)	LPM$_3$
DBA36	Albany	ISM	AP231	Mound 9, Bur. 26	Female	M. Adult	LPM^4
DBA37	Albany	ISM	AP342	Mound 20, Bur. 93	Female?	Adolesc.	RPM$_4$
DBA38	Albany	ISM	AP 194	Mound 14, Bur. 1	Female	Y. adult (20-35)	RM^1
DBA39	Albany	ISM	AP 186	Mound 17, Bur. 1	Female	Y. adult (20-35)	LPM$_3$
DBA40	Albany	ISM	AP 317	Mound 20, Bur. 85	Male?	Y. adult (20-35)	LPM^4
DBA41	Albany	ISM	AP 300	Mound 20, Bur. 51	Unknown	Y. adult (20-35)	LM^1
DBA42	Albany	ISM	AP 329	Mound 12, Bur. 4	Male	Adolesc.	RPM^3
DBA43	Albany	ISM	AP 310	Mound 20, Bur. 72	Male	Y. adult	LPM$_3$
DBA44	Albany	ISM	AP 248	Mound 9, Bur. 46	Female	Adolesc.	LPM$_3$
DBA45	Albany	ISM	AP 283	Mound 9, Bur. 87	Unknown	Adolesc.	LM$_1$
DBA46	Albany	ISM	AP 195	Mound 14, Bur. 4	Female	Y. adult	LM$_1$
DBA47	Albany	ISM	AP 286	Mound 9, Bur. 91	Male	M. adult	LM$_1$
DBA48	Albany	ISM	AP 309	Mound 20, Bur. 70	Unknown	Y. adult	LPM^3
DBA49	Albany	ISM	AP 188	Mound 17, Bur. 3	Male	Adolesc.	LPM$_4$

DBA50	Albany	ISM	AP 13	Mound 80	Unknown	Unknown	RM$_3$
DBA65	HMG	Chicago Field Museum	41593.Z	None	Female	Adult (18+)	I^1
DBA66	HMG	Chicago Field Museum	41602.B	Mound 23	Unknown	Adult	RM^3
DBA67	HMG	Chicago Field Museum	41603 (1 of 2)	Mound 25	Unknown	Unknown	LPM$_4$
DBA68	HMG	Chicago Field Museum	41603 (2 of 2)	Mound 25	Unknown	Unknown	LPM$_4$
DBA69	HMG	Chicago Field Museum	41604	None	Female	Adult (20-25)	RM^2
DBA70	HMG	Chicago Field Museum	41608	Mound 23	Unknown	Adult	RM$_3$
DBA71	HMG	Chicago Field Museum	41612	Mound 3	Unknown	Adult	LPM$_3$
DBA72	HMG	Chicago Field Museum	41613	Mound 23	Female	Adult (20+)	RPM$_3$
DBA73	HMG	Chicago Field Museum	41614	Mound 3	Female	Adult (20+)	LI^1
DBA74	HMG	Chicago Field Museum	41617	Mound 20	Unknown	Adult	RI^1
DBA75	HMG	Chicago Field Museum	41618	Mound 18	Male	Adult (25+)	LC^x
DBA76	HMG	Chicago Field Museum	41621.A	None	Female?	Adult	LPM$_4$
DBA77	HMG	Chicago Field Museum	41622	Mound 25	Unknown	Adult	LM^3
DBA94	HMG	OHS	150053	Mound 25, Bur. 41-2	Probable F	M. to O. Adult	LPM$_4$
DBA95	HMG	OHS	150056	Mound 25, Bur. 41, Ind. 63	Probable M	M. Adult	RPM$_3$
DBA96	HMG	OHS	150057	Mound 25, Bur. 41, Ind. 64	Probable F	M. Adult	RPM$_3$

DBA97	HMG	OHS	150058	Mound 25, Bur. 41, Ind. 66	Unknown	Adult	RPM$_4$
DBA98	HMG	OHS	150095	Ind. 48, Bur. C	Unknown	Adult	RPM$_3$
DBA99	HMG	OHS	150096	Ind. 49, Bur. D	Unknown	Adult	LPM$_4$
DBA100	HMG	OHS	150102	Ind. 55, Bur. H	Unknown	Adult	LPM^3
DBA101	HMG	OHS	150108	Mound 2, Bur. 1, Ind. 69	Male	M. Adult	LPM$_4$
DBA102	HMG	OHS	150109	Mound 2, Bur. 3, Lot 70	Female	Y. Adult	RPM^3
DBA103	HMG	OHS	150111	Mound 2, Bur. 3, Ind ?	Female?	Adult	RPM$_3$
DBA104	HMG	OHS	150112	Mound 2, Bur. 4, Ind. 71	Female?	Y. Adult	RM^3
DBA105	HMG	OHS	150115	Mound 25, Bur. 25, Ind. 75	Male?	M. Adult	RPM$_3$
DBA106	HMG	OHS	150116	Mound 25, Bur. 42, Ind. 76	Female?	M. Adult	RPM$_3$
DBA107	HMG	OHS	150122	Mound 25, Bur. 16, Lot 82	Female?	Adult	RPM$_3$
DBA108	HMG	OHS	150121	Mound 25, Bur. 25, Ind. 80	Male?	Adult	LPM$_4$
DBA109	HMG	OHS	150124	Mound 25, Bur. 12, Ind. 81	Unknown	Y. Adult	RPM$_3$
DBA110	HMG	OHS	150128	Mound 25, Bur. 24, Ind/Lot 91	Unknown	M. Adult	RPM$_3$
DBA111	HMG	OHS	150132	Mound 25, Bur. 15, Ind/Lot 96	Female?	Y. Adult	RPM$_3$
DBA112	HMG	OHS	150131	Mound 25, Bur. Ind. 93	Female?	Y. Adult	RPM$_4$
DBA113	HMG	OHS	150163	Mound 25, Bur ? Commingled	Unknown	Unknown	LPM^3
DBA114	HMG	OHS	150209	Mound 25, Bur. 23, Ind. 99	Male?	M. Adult	LPM^3
DBA115	HMG	OHS	150210	Mound 25, Bur. 23, Ind. 100	Unknown	M. Adult	LPM$_3$
DBA116	HMG	OHS	150212	Mound 25, Bur. 35, Ind/Lot 101	Male?	O. Adult	LM^3
DBA117	HMG	OHS	150213	Mound 25, Bur. 11, Ind. 102	Male?	Adult	RPM$_4$
DBA118	HMG	OHS	150216	Mound 25?, Bur. 9, Ind. 103	Female?	Adult	RM$_3$

APPENDIX B

SPECIES, SITE AND SKELETAL ELEMENT OF FAUNAL SPECIMENS

DBA #	Site	Collection	Cat #	Species	Element
DBA1	Utica	ISAS	A4462	*Odocoileus virginianus*	Tooth
DBA2	Utica	ISAS	A4588	*Odocoileus virginianus*	Tooth
DBA4	Utica	ISAS	A2685	Shell (*Megalonaias nervosa?)*	Shell frag.
DBA17	Plum Island	ISAS	A3731	*Odocoileus virginianus*	Tooth
DBA51	Albany	Univ. Wisc-Milwaukee	E-75-97	*Procyon lotor*	Tooth
DBA52	Albany	Univ. Wisc-Milwaukee	E-75-336	*Castor canadensis*	Tooth
DBA53	Albany	Univ. Wisc-Milwaukee	E-75-337	*Castor canadensis*	Tooth
DBA54	Albany	Univ. Wisc-Milwaukee	E-75-338	*Odocoileus virginianus*	Tooth
DBA55	Albany	Univ. Wisc-Milwaukee	E-75-338	*Castor canadensis*	Tooth
DBA56	Albany	Univ. Wisc-Milwaukee	E-75-339	*Odocoileus virginianus*	Tooth
DBA57	Albany	Univ. Wisc-Milwaukee	E-75-339	*Castor canadensis*	Tooth
DBA58	Albany	Univ. Wisc-Milwaukee	E-75-340	*Odocoileus virginianus*	Tooth
DBA59	Albany	Univ. Wisc-Milwaukee	E-75-340	*Castor canadensis*	Tooth

DBA60	Albany	Univ. Wisc-Milwaukee	E-75-341	*Odocoileus virginianus*	Tooth
DBA61	Albany	Univ. Wisc-Milwaukee	E-75-341	*Castor canadensis*	Tooth
DBA62	Albany	Univ. Wisc-Milwaukee	E-75-342	*Odocoileus virginianus*	Tooth
DBA63	Albany	Univ. Wisc-Milwaukee	E-75-342	*Castor canadensis*	Tooth
DBA64	Albany	Univ. Wisc-Milwaukee	E-75-343	*Castor canadensis*	Tooth
DBA78	HMG	Hopewell Nat'l Park Service	HOCU 10612	*Odocoileus virginianus*	Tooth
DBA79	HMG	Hopewell Nat'l Park Service	HOCU 11809	*Odocoileus virginianus*	Tooth
DBA80	HMG	Hopewell Nat'l Park Service	HOCU 22334	*Odocoileus virginianus*	Tooth
DBA81	HMG	Hopewell Nat'l Park Service	HOCU 35653	*Odocoileus virginianus*	Bone
DBA82	HMG	Hopewell Nat'l Park Service	HOCU 35650	*Apalone sp?*	Turtle shell frag
DBA83	HMG	Hopewell Nat'l Park Service	HOCU 23682	*Aplodinatus grunniens*	Tooth
DBA84	French Canyon West	ISM	1949-85, 18701	*Cervus elaphus*	Tooth
DBA85	French Canyon West	ISM	1949-85, 18073	*Odocoileus virginianus*	Tooth

DBA86	French Canyon West	ISM	1949-85, 18065	*Odocoileus virginianus*	Tooth
DBA87	French Canyon West	ISM	1949-85, 18083	*Odocoileus virginianus*	Tooth
DBA88	French Canyon West	ISM	1949-85, 18082	*Castor canadensis*	Tooth
DBA89	French Canyon West	ISM	1949-85, 18033	*Odocoileus virginianus*	Tooth
DBA90	French Canyon West	ISM	1949-85, 18081	*Odocoileus virginianus*	Tooth
DBA91	French Canyon West	ISM	1949-85, 18114	*Odocoileus virginianus*	Tooth
DBA92	French Canyon West	ISM	1949-85, 18030	*Odocoileus virginianus*	Tooth
DBA93	French Canyon West	ISM	1949-85, 18070	*Odocoileus virginianus*	Tooth
DBA119	HMG Hopeton Triangle	Hopewell Nat'l Park Service	Block B, Tooth 1	*Odocoileus virginianus*	Tooth
DBA120	HMG Hopeton Triangle	Hopewell Nat'l Park Service	Block B, Tooth 2	*Odocoileus virginianus*	Tooth
DBA121	HMG Hopeton Triangle	Hopewell Nat'l Park Service	Block B, Tooth 3	*Odocoileus virginianus*	Tooth
DBA122	HMG Hopeton Triangle	Hopewell Nat'l Park Service	Block B, Tooth 4	*Odocoileus virginianus*	Tooth.

APPENDIX C

ISOTOPIC DATA

Sample ID	Site	Species	$^{87}Sr/^{86}Sr$	$\delta^{13}C_{PDB}$‰	$\delta^{18}O_{SMOW}$‰
DBA1	Utica	*O. virginianus*	0.708807	n/a	n/a
DBA2	Utica	*O. virginianus*	0.710064	n/a	n/a
DBA3	Utica	*C. canadensis*	Not run—faulty provenience		
DBA4	Utica	*M. nervosa?*	0.710082	n/a	n/a
DBA5	Utica	*M. nervosa?*	Not run—duplicate of DBA4?		
DBA6	Utica	*H. sapiens*	0.710937	n/a	n/a
DBA7	Utica	*H. sapiens*	0.710748	n/a	n/a
DBA8	Utica	*H. sapiens*	0.710623	-15.23	27.04
DBA9	Utica	*H. sapiens*	0.710642	n/a	n/a
DBA10	Utica	*H. sapiens*	0.711580	n/a	n/a
DBA11	Utica	*H. sapiens*	0.710810	-15.04	26.91
DBA12	Utica	*H. sapiens*	0.710695	-14.93	26.22
DBA13	Utica	*H. sapiens*	0.710225	-12.48	25.93
DBA14	Utica	*H. sapiens*	0.710797	-14.37	27.82
DBA15	Utica	*H. sapiens*	0.709529	-6.11	27.02
DBA16	Utica	*O. virginianus*	Not run—duplicate of DBA1		
DBA17	Plum Island	*O. virginianus*	0.709634	n/a	n/a
DBA18	Utica	*H. sapiens*	0.711069	n/a	n/a
DBA19	Utica	*H. sapiens*	0.710812	n/a	n/a
DBA20	Utica	*H. sapiens*	0.710308	n/a	n/a

DBA21	Utica	*H. sapiens*	0.710523	-14.61	25.38
DBA22	Utica	*H. sapiens*	0.710394	n/a	n/a
DB23	Utica	*H. sapiens*	0.711165	-14.81	25.50
DBA24	Utica	*H. sapiens*	0.710788	-15.03	25.18
DBA25	Utica	*H. sapiens*	0.710704	-14.64	25.41
DBA26	Utica	*H. sapiens*	0.710715	-14.36	25.75
DBA27	Utica	*H. sapiens*	0.710660	-14.82	25.47
DBA28	Utica	*H. sapiens*	0.711063	-15.94	26.78
DBA29	Utica	*H. sapiens*	0.710998	Data lost—trap error	
DBA30	Albany	*H. sapiens*	0.709978	n/a	n/a
DBA31	Albany	*H. sapiens*	0.709631	n/a	n/a
DBA32	Albany	*H. sapiens*	0.710194	n/a	n/a
DBA33	Albany	*H. sapiens*	0.710442	-15.69	26.07
DBA34	Albany	*H. sapiens*	0.710249	Data lost—trap error	
DBA35	Albany	*H. sapiens*	0.709431	-15.02	25.12
DBA36	Albany	*H. sapiens*	0.709979	-15.56	24.47
DBA37	Albany	*H. sapiens*	0.711052	-15.19	25.49
DBA38	Albany	*H. sapiens*	0.709929	n/a	n/a
DBA39	Albany	*H. sapiens*	0.710018	n/a	n/a
DBA40	Albany	*H. sapiens*	0.710375	n/a	n/a
DBA41	Albany	*H. sapiens*	0.711106	n/a	n/a
DBA42	Albany	*H. sapiens*	0.710019	n/a	n/a
DBA43	Albany	*H. sapiens*	0.710207	-14.89	26.06
DBA44	Albany	*H. sapiens*	0.710176	n/a	n/a

DBA45	Albany	*H. sapiens*	0.710314	n/a	n/a
DBA46	Albany	*H. sapiens*	0.710577	Data lost—trap error	
DBA47	Albany	*H. sapiens*	0.710146	-14.44	25.69
DBA48	Albany	*H. sapiens*	0.710232	n/a	n/a
DBA49	Albany	*H. sapiens*	0.711426	n/a	n/a
DBA50	Albany	*H. sapiens*	0.709748	n/a	n/a
DBA51	Albany	*P. lotor*	0.7106767	n/a	n/a
DBA52	Albany	*C. canadensis*	0.710600	-14.88	22.02
DBA53	Albany	*C. canadensis*	0.709610	-13.46	23.11
DBA54	Albany	*O. virginianus*	0.709090	-15.16	26.74
DBA55	Albany	*C. canadensis*	0.709230	-11.99	24.29
DBA56	Albany	*O. virginianus*	0.709170	-13.57	24.67
DBA57	Albany	*C. canadensis*	0.709410	-14.70	22.68
DBA58	Albany	*O. virginianus*	0.709220	-14.63	22.27
DBA59	Albany	*C. canadensis*	0.709960	-13.23	24.13
DBA60	Albany	*O. virginianus*	0.709300	-14.09	24.40
DBA61	Albany	*C. canadensis*	0.710390	-14.82	22.18
DBA62	Albany	*O. virginianus*	0.708920	-17.12	26.72
DBA63	Albany	*C. canadensis*	0.710250	-14.89	21.40
DBA64	Albany	*C. canadensis*	0.712020	-15.33	21.77
DBA65	Hopewell Mound Group (HMG)	*H. sapiens*	0.712480	-6.29	27.62
DBA66	HMG	*H. sapiens*	0.709890	-14.84	27.36

DBA67	HMG	*H. sapiens*	0.712320	-14.67	25.84
DBA68	HMG	*H. sapiens*	0.711180	-14.63	25.32
DBA69	HMG	*H. sapiens*	0.710184	-14.66	25.39
DBA70	HMG	*H. sapiens*	0.710412	-14.79	25.01
DBA71	HMG	*H. sapiens*	0.709388	-14.26	27.11
DBA72	HMG	*H. sapiens*	0.710122	-14.70	26.19
DBA73	HMG	*H. sapiens*	0.710046	-14.07	26.80
DBA74	HMG	*H. sapiens*	0.709683	n/a	n/a
DBA75	HMG	*H. sapiens*	0.708862	-13.89	26.63
DBA76	HMG	*H. sapiens*	0.710785	-14.49	27.53
DBA77	HMG	*H. sapiens*	0.711582	-14.83	25.39
DBA78	HMG	*O. virginianus*	0.710812	-0.78	22.67
DBA79	HMG	*O. virginianus*	0.711430	-13.28	27.90
DBA80	HMG	*O. virginianus*	0.710610	-13.90	23.94
DBA81	HMG	*O. virginianus*	0.710652	-13.94	27.71
DBA82	HMG	*Apalone sp.?*	0.709185	-15.47	21.80
DBA83	HMG	*A. grunniens*	0.709158	-8.68	24.81
DBA84	French Canyon West (FCW)	*C. elaphus*	0.710033	-13.59	24.24
DBA85	FCW	*O. virginianus*	0.709467	-13.97	23.12
DBA86	FCW	*O. virginianus*	0.711029	Data lost—trap error	
DBA87	FCW	*O. virginianus*	0.709661	-14.32	24.05
DBA88	FCW	*C. canadensis*	0.710032	-14.79	22.24

DBA89	FCW	*O. virginianus*	0.711189	-16.59	27.89
DBA90	FCW	*O. virginianus*	0.710471	-13.73	23.25
DBA91	FCW	*O. virginianus*	0.711601	-16.35	27.12
DBA92	FCW	*O. virginianus*	0.711005	-13.64	24.02
DBA93	FCW	*O. virginianus*	0.710853	Data lost—trap error	
DBA94	HMG	*H. sapiens*	0.710204	-12.11	28.70
DBA95	HMG	*H. sapiens*	0.709919	-13.50	26.37
DBA96	HMG	*H. sapiens*	0.709640	-14.34	26.34
DBA97	HMG	*H. sapiens*	0.712177	-14.47	24.66
DBA98	HMG	*H. sapiens*	0.712861	-2.01	26.81
DBA99	HMG	*H. sapiens*	0.709266	-2.62	26.62
DBA100	HMG	*H. sapiens*	0.709211	-3.99	26.69
DBA101	HMG	*H. sapiens*	0.711353	-14.58	25.71
DBA102	HMG	*H. sapiens*	0.711085	-14.11	26.40
DBA103	HMG	*H. sapiens*	0.710124	-14.07	25.81
DBA104	HMG	*H. sapiens*	0.712257	-14.70	25.21
DBA105	HMG	*H. sapiens*	0.709747	-13.56	27.10
DBA106	HMG	*H. sapiens*	0.711081	-13.84	26.21
DBA107	HMG	*H. sapiens*	0.712142	-13.78	27.79
DBA108	HMG	*H. sapiens*	0.709825	-14.10	26.67
DBA109	HMG	*H. sapiens*	0.709490	-.14.32	26.26
DBA110	HMG	*H. sapiens*	0.709253	-13.59	25.93
DBA111	HMG	*H. sapiens*	0.712304	-15.02	24.90
DBA112	HMG	*H. sapiens*	0.710029	-13.72	25.87

DBA113	HMG	*H. sapiens*	0.710041	-13.93	26.07
DBA114	HMG	*H. sapiens*	0.710794	-14.51	26.14
DBA115	HMG	*H. sapiens*	0.710914	-13.81	25.96
DBA116	HMG	*H. sapiens*	0.710348	-14.23	25.50
DBA117	HMG	*H. sapiens*	0.711339	-13.88	25.38
DBA118	HMG	*H. sapiens*	0.711083	-14.44	26.11
DBA119	HMG	*O. virginianus*	0.709906	n/a	n/a
DBA120	HMG	*O. virginianus*	0.713070	n/a	n/a
DBA121	HMG	*O. virginianus*	0.713199	n/a	n/a
DBA122	HMG	*O. virginianus*	0.709983	n/a	n/a